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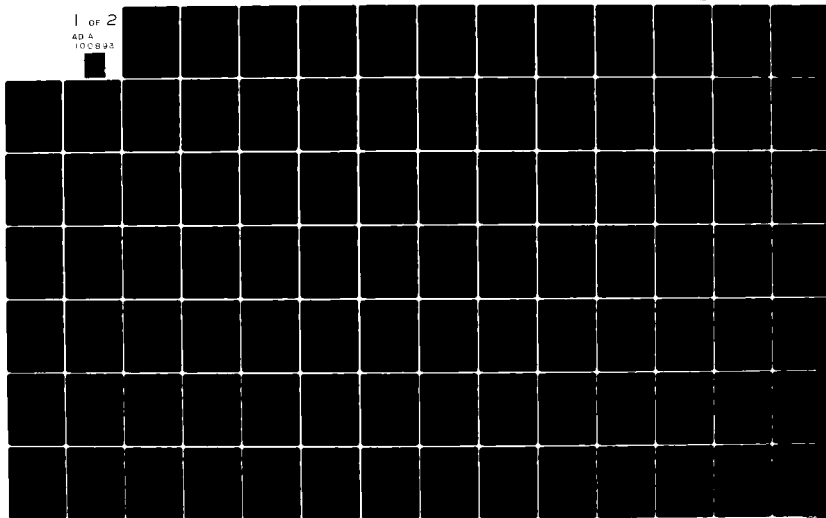
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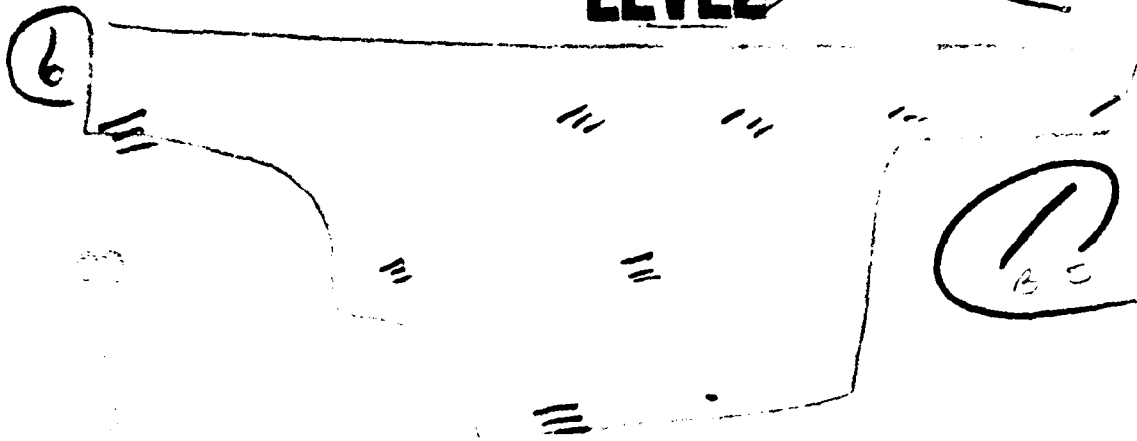
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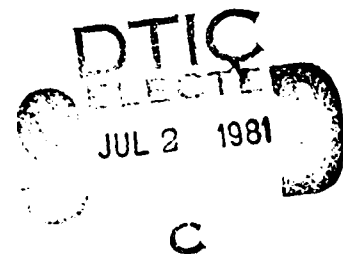
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For Further Information

This booklet represents a summary of the programs of the Electronic and Solid State Sciences Program (Code 427) for physical year 1976. Further information about these programs can be obtained, either from the Director, Dr. John O. Dimmock, at (202)692-4216, or from the scientific officers, who are:

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SOLID STATE PHYSICS

RR 011-02-01, SOLID STATE PHYSICS, (Dr. D. K. Ferry, 202 692-4217)

NR 318-002, University of Pennsylvania, "Magnetic Memory Materials and Liquid Crystals", P.I. - Dr. Herb Callen, N00014-76-C-0106

It is proposed to analyze the preferential-site-ordering mechanism which determines uniaxial anisotropy in garnets. This will provide a new method of determining the dynamics and mechanism of crystal growth in such materials. Such information is needed for improving magnetic materials useful in magnetic bubble technology. Domain hardness, wall mobility and velocity saturation are among the areas to be investigated. In addition a study will be made of modern critical phenomena theory and phase transitions in liquid crystals. Progress: It was shown that the observations of Georgy, Sturge, and Van Uitert, on the anisotropy of  $Y(3-x)Lu(x)Fe_5O_{12}$ , are in excellent agreement with the mechanism previously suggested by Callen and Akselrad. The data are consistent with a tetrahedral iron mechanism, although they do not exclude an octahedral iron mechanism. The relative contributions of the two sublattices and the relevant physical considerations have been determined. These effects are pertinent to the mechanism of preferential site ordering in these alloys. The analogy between a smectic-A liquid crystal and a superconductor is made closer by a transformation on the smectic system. Within the context of the Wilson-Fisher recursion relations, it has been shown that the critical properties of the two systems are the same, and that therefore the phase transition from smectic-A to nematic will always be at least weakly first order.

Recent Publications:

1. H. Callen, "Growth Induced Anisotropy in Garnets with Mixed Diamagnetic Rare-Earth Ions:  $Y_{3-x}Lu_xFe_5O_{12}$ ," J. Applied Physics, Vol. 45, No. 5, pp 2348-50, May 1974.
2. T. C. Lubensky and R. G. Priest, "Critical Exponents for a Symmetric Traceless Tensor Field Theory Model," Physics Letters, Vol. 48A, No. 2, pp 103-4, June 1974.
3. H. Callen, "Thermodynamics as a Science of Symmetry," Foundations of Physics, Vol. 4, No. 4, pp 423-43, December 1974.
4. E. I. Halperin and T. C. Lubensky, "On the Analogy Between Smectic-A Liquid Crystals and Superconductors," Solid State Communications, Vol. 14, pp 997-1001, 1974.

NR 318-003, Harvard University, "Superconductors, Magnetic Detectors, and Magnetic Electronics," P.I. - Dr. Michael Tinkham, N00014-76-C-0032

Far infrared spectroscopy and laser sources are used to probe and determine the energy gaps in superconducting materials. Magnetic resonance techniques are also applied to metals and to magnetic materials. The major work is on the interaction of far-infrared laser radiation with superconducting weak-link devices. Progress: Far infrared cyclotron resonance has been observed in copper. The observed lineshapes have been analyzed with various calculations of the surface impedance change at resonance, taking into account the Fermi surface anisotropy, in addition to retardation effects and propagation effects.

Recent Publications:

J. M. Peech, "Far Infrared Cyclotron Resonance in Metals," Technical Report 9, September 1974.

NR 318-004, Clarkson College of Technology, "Magnetic Control Mechanisms at Critical Temperatures," P.I. - Dr. Earl Anderson, N00014-76-C-0051

A careful study will be made of representative samples of ferromagnetic, anti-ferromagnetic and ferrimagnetic materials in the vicinity of their magnetic transitions in order to determine the critical exponents which describe their behavior. The behavior of these different types of magnetic materials will be compared to see how they differ at the transition temperature and how they are applicable as control mechanisms in magnetic circuits. The device implications of magnetic behavior at the transition point will be surveyed. Additional magnetic materials having potential magnetic control capabilities will be sought and magnetic measurements to determine their properties carried out. Progress: A study has been made of the critical magnetic properties of lutetium iron garnet. Values of the critical exponents were observed to fulfill the scaling relationship, within the limits of experimental error. The critical temperature, obtained from the kink-point plot of applied magnetic versus break-point temperature, was reaffirmed through utilization of the Kouvel-Fisher analysis.

Recent Publications:

A. A. Stelmach, E. E. Anderson, and S. Arajs, "Magnetization of Lutetium Iron Garnet Near the Critical Point," J. Phys. Chems. Solids, Vol. 34, 1343-1346, 1973.

NR 318-005, University of Pennsylvania, "Optical and Acoustical Spectroscopy of Solids," Dr. Elias Burstein, N00014-76-C-0107

Surface electromagnetic waves and surface acoustic waves and their interaction with electrons in solids and with each other are studied to give the electrical properties of solid state materials. The interaction of surface electromagnetic waves (polaritons) with anisotropic dielectric and permeable solids will be studied via techniques such as attenuated total reflection (ATR). Progress: Surface polariton dispersion curves have been obtained for an n-InSb-air interface in a magnetic field using the ATR method and are found to be in qualitative agreement with theory. In particular, the curves show the predicted non-reciprocal nature of the surface polariton propagation, and the appearance of virtual excitation type branches of the dispersion curves. On the basis of data obtained in zero magnetic field on etched surfaces, the quantitative differences between experimental and theoretical dispersion curves are attributed to surface damage.

#### Recent Publications:

1. D. L. Mills and E. Burstein, "The Electromagnetic Modes of Media," Reports on Progress in Physics 37, 817-926 (1974).
2. E. Burstein, "Phase Matched Electromagnetic Generation and Detection of Surface Elastic Waves on Non-Conducting Solids," J. Appl. Physics 45, 4360 (1974).
3. E. Burstein, W. P. Chen, Y. J. Chen and A. Hartstein, "Propagating Electromagnetic Modes at Interfaces," J. Vac. Sci. Technol. 11, 1004 (1974).
4. A. Hartstein and E. Burstein, "Observation of Magneto-plasmon-type Surface Polaritons on n-InSb," Solid State Communications 14, 1223 (1974).
5. M. L. Shand, Y. L. Ching and E. Burstein, "Raman Scattering by Optical Phonons and Polaritons in CuCl," Solid State Communications 15, 1209 (1974).
6. A. Hartstein, E. Burstein, E. D. Palik, R. Kaplan, R. W. Gammon and B. W. Henvis, "Optic Phonon-Magnetoplasmon Type Surface Polaritons on n-InSb," Int. Conf. Physics of Semicond., Stuttgart 1974 (Teubner, Stuttgart, 1974) p. 541.

NR 318-007, University of Colorado, "Band Structure Modifications in Superlattice Structures," P.I. - Dr. Herbert Kroemer, N00014-76-C-0115

The effects of screening and self-energy are studied in the Peierl's instability in periodic superlattices. Work on purely electronic modifications of such instabilities is also carried out. A study of the dynamics of the motion of a Peierl's instability through its host lattice and of its high field behavior will be undertaken. A study of two-dimensional surface superlattices created by atomic steps on an off-oriented semiconductor surface will be carried out.

Progress: In layer-type superlattices the electron motion perpendicular to the direction of periodicity is not quantized, a fact that greatly weakens the beneficial effects of the superlattice. The overlap of the energy bands in this structure essentially precludes the occurrence of negative differential mobility caused by a transfer of electrons between minibands. The effects seen so far in the Esaki-Tsu type structures are more likely due to modified Gunn effect. In order to realize more than just a fraction of the promise of the superlattice it will probably be necessary to prepare them in substances in which the electron motion is inherently one-dimensional

#### Recent Publications:

H. Kroemer, "Negative Bulk Mobility Devices - What Next?", Proceedings of the International Electron Devices Meeting, Washington, D.C., December 1974, pp 3-4.

NR 318-009, Rensselaer Polytechnic Institute, "Wave-Solid Interactions," P.I. - Dr. Harold Tiersten, N00014-76-C-0368

Theoretical investigations of the guiding of magnetoelastic and piezoelectric surface waves in deformable media and on the nonlinear interactions in acoustoelectric devices will be carried out. Progress: An analysis of the reflection of surface waves by an array of reflecting strips by means of derived approximate equations was carried out. These equations are expressed in terms of the known fundamental material constants and no measurement of model parameters is required. Agreement with experiment in Y-Z lithium niobate is good. The extremely accurate approximate solution for the fundamental nondispersive antisymmetric mode of the wedge waveguide in isotropic materials has been completed. A method of analysis has been obtained for the treatment of abrupt discontinuities in determining the influence of the radiating continuous spectrum on the propagation of elastic surface waves guided by thin films. An analysis of trapped energy resonators operating in overtones of coupled thickness-shear and thickness-twist has been completed.

## Recent Publications:

1. H. F. Tiersten, "An analysis of trapped energy resonators operating in overtones of coupled thickness-shear and thickness-twist", Tech. Rpt. No. 13, July 1975.

2. H. G. delorenzi and H. F. Tiersten, "On the introduction of the electromagnetic field with heat conducting deformable semiconductors," *Journal of Mathematical Physics* 16, 930-5" (1975).

3. H. F. Tiersten, "Analysis of intermodulation in rotated X-cut quartz thickness-shear resonators", *Proceedings of the 28th Annual Symposium on Frequency Control* (1974), pp. 1-4.

4. H. F. Tiersten, "Analysis of trapped energy resonators operating in overtones of thickness-shear", *Proceedings of the 28th Annual Symposium on Frequency Control* (1974), pp. 44-48.

5. H. F. Tiersten and J. C. Baumhauer, "Second harmonic generation and parametric excitation of surface waves in elastic and piezoelectric solids", *Journal of Applied Physics* 45, 4272-87 (1974).

6. H. F. Tiersten and D. Rubin, "On the fundamental antisymmetric mode of the wedge guide", *1974 Ultrasonics Symposium Proceedings*, pp. 117-120.

7. H. F. Tiersten, "Nonlinear electroelastic equations cubic in the small field variables," *Journal of the Acoustical Society of America* 57, 660-6 (1975).

8. H. F. Tiersten, "Analysis of intermodulation in thickness-shear and trapped energy radiators", *Journal of the Acoustical Society of America* 57, 667-81 (1975).

NR 218-010, University of California at Los Angeles, "Magnetic Alloys and Organic Conductors," P.I. - Dr. Raymond Orbach, N00014-75-C-0245

The physical properties of conducting organic solids will be investigated theoretically by developing new models of charge transfer in quasi-one dimensional narrow band solids. Electron spin resonance will be used to investigate dilute magnetic alloys that have nearly unstable moments and exhibit large negative exchange coupling. Additional work will be undertaken to investigate the effect of the large negative exchange coupling on negative thermopower in dilute magnetic alloys. Additionally, an investigation of fluctuations in normal or superconductors near the superconducting transition temperature will be carried out. Progress: The thermoelectric power of a narrow-band Hubbard chain with an arbitrary number of

electrons per site was studied. The calculations were carried out to the lowest order in the transfer integral. It was found that a characteristic electron density ( $=2/3$ ) existed below which the thermoelectric power is negative at all temperatures. In contrast, for the density larger than  $2/3$ , the thermopower is small and negative only above a characteristic temperature, below which there is a change of sign and slope. The applicability of the results to the charge-transfer salts of tetracyanoquinodimethane (TCNQ) was pointed out.

Recent Publications:

1. D. Davidov, K. Maki, R. Orbach, C. Rettori, and E. P. Chock, "Re-Entrant Critical Field Behavior in  $Gd_xTh_{1-x}Ru_2$ : Correlation with EPR," *Physics Letters* 45A, 163 (1973).
2. D. Davidov, C. Rettori, K. Baberschke, E. P. Chock, and R. Orbach, "Correlation Between Electron Spin Resonance and Superconductivity in  $Gd_xB_{1-x}Ru_2$  (B=Th, Ce, La)," *Physics Letters* 45A, 161 (1973).
3. N. L. H. Li and R. Orbach, "Superexchange," *A.I.P. Conf. Proc.* 10, 1238 (1973).
4. P. Pincus, "Charge Transfer Molecular Solids," Selected Topics in Physics, Astrophysics, and Astronomy, p. 138 (1973).
5. P. Pincus, P. Chaikin, and C. F. Coll, "Correlated Pairs in the Attractive Hubbard Model," *Solid State Communications* 12, 1265 (1973).
6. C. Rettori and D. Davidov, "Comment on the Hyperfine Constant of Rare-Earth Ions in Dilute Alloys: Th: Fr," *Physical Review B* 10, 4033 (1974).
7. C. F. Coll and G. Beni, "The Effect of Polarons on the Conductivity of the Narrow-Band Hubbard Chain," *Solid State Communications* 15, 997 (1974).
8. D. J. Scalapino, Y. Imry, and P. Pincus, "Generalized Ginzberg-Landau Theory of Pseudo-One-Dimensional Systems," *Physical Review B* 11, 2042 (1975).
9. J-P. Gallinar, "Thermodynamics of an Extended Hubbard-Model Chain. II. Strong-Coupling Limit," *Physical Review B* 11, 4421 (1975).
10. T. Tonegawa, H. Shiba, and P. Pincus, "Thermodynamics of the Impure Classical Heisenberg Chain," *Physical Review B* 11, 4683 (1975).
11. P. M. Chaikin, P. Pincus, and G. Beni, "Peierls' Transitions in Alternate Lattices," *Journal of Physics C: Solid State Physics* 8, L65 (1975).

12. P. Pincus, "Basic Principles and Concepts in the Physics of Low Dimensional Cooperative Systems," in Low-Dimensional Cooperative Phenomena. J. T. Keller, Ed., (Plenum, New York, 1974) pp. 1-21.
13. C. Rettori, D. Davidov, and H. M. Kim, "Crystalline-Field Effects in the EPR of Er in Various Cubic Metals," Physical Review B 8, 5335 (1973).
14. R. Orbach, "Electron Spin Resonance in Superconductors," Physics Letters 47A, 281 (1974).
15. R. Orbach, "Energy Transfer and Anderson Localization," Physics Letters 48A, 417 (1974).
16. R. Orbach, M. Peter, and D. Shaltiel, "The Magnetic Resonance of Dilute Magnetic Alloys," Archives des Sciences 27, 141 (1974).
17. G. Beni and P. Pincus, "Thermodynamics of an Extended Hubbard Chain. I: Atomic Limit for the Half-Filled Band," Physical Review B 2, 2963 (1974).
18. G. Beni, P. Pincus, and J. Kanomori, "Low Temperature Properties of the One-Dimensional Polaron Band. I. Extreme Band-Narrowing Regime," Physical Review B 10, 1896 (1974).
19. U. Bernstein and P. Pincus, "Thermodynamic Properties of the Dimerized Half-Filled-Band Hubbard Chain," Physical Review B 10, 3626 (1974).
20. G. B. Arnold, "Upper Critical Field and Critical Temperature for Superconducting Alloys Described by the Anderson Model," Physical Review B 10, 105 (1974).
21. S. E. Barnes, "Fine-Structure Splitting of a Localized Moment in a Metal: A Diagrammatic Analysis," Physical Review B 9, 4789 (1974).
22. G. Beni, "Peierls Transition in a Quasi-One Dimensional System," Solid State Communications 17, 269 (1974).
23. C. F. Coll, "Excitation Spectrum of the One-Dimensional Hubbard Model," Physical Review B 9, 2150 (1974).
24. O. Entin-Wohlman, G. Deutscher, and R. Orbach, "Anomalous Spin-Flip Lifetime Near the Heisenberg-Ferromagnet Critical Point," Physical Review B 11, 219 (1975).
25. G. Beni and C. F. Coll, "Thermoelectric Power in Half-Filled Bands," Physical Review B 11, 573 (1975).

26. J.-M. Moret, E. Orbach, M. Peter, L. Stoll, J. L. Thoenes, W. Zingg, R. A. B. Devine, and P. H. Timmerman, "Temperature-Dependent Relaxation Narrowing of the Fine Structure of  $^{119}\text{Sn}$  in the  $\alpha$ -Phase of Pd," *Physical Review*, B 11, 2002 (1975).

27. F. Fryne, "Magnetic Field Dependence of the Spin Density in Antiferromagnets," *Physical Review* B 2, 1464 (1970).

28. C. Rettori, H. M. Kim, K. F. Chock, and R. Devlin, "Temperature-Dependent Behavior of Paramagnetic Ions and Conduction Electrons in Intermetallic Compounds:  $\text{Gd}_{1-x}\text{Lu}_x\text{Al}_2$ ," *Physical Review* B 12, 1171 (1975).

29. G. Beni, "Thermoelectric Power of the Narrow-Band Electron Chain at Arbitrary Electron Density:  $\text{Ag}_{1-x}\text{Mg}_x\text{Te}$ ," *Physical Review* B 10, 2186 (1974).

NR 318-014, Rockwell Science Center, "Raman Spectroscopy of  $\text{PbSnTe}$ ," P.I. - Dr. John Cape, 3006014-7107-015.

This program will study conventional Raman backscattering on epitaxially grown epitaxial films in vacuum, study the structure of the surface-induced scattering from oxide growth on the epi-film and correlate with ESCA data, and will study the spectra after evaporation of a thin film of Pb or other metal. Progress: Raman studies to date have indicated that Te precipitates are formed at the surface of  $\text{PbSnTe}$ . Scattering from Te and  $\text{TeO}_2$  has been observed. Raman signals from suitably etched  $\text{PbSnTe}$  surfaces appear to indicate the presence of Raman scattering from two  $\text{A}_1$  zone center phonons and from the LO zone center phonon.

NR 318-017, Naval Weapons Center, "Research in the Spectroscopy of Solids," P.I. - Dr. Victor Kohn.

This program will utilize the NWC facilities at the Stanford Synchrotron Radiation Project to study the ultraviolet band structure of 4-25eV, and the deep-lying core states to a higher energy range of excitations in the 25-300eV range. First studies will be carried out on the materials GaAs, InP, Si, C, and Al. The objectives are to experimentally determine the energy, symmetry, effective mass, and other parameters of interband critical points and from the band structure to band gap, to seek experimental evidence concerning the nature of the exciton or electron-electron interaction, the nature of the band structure, the fundamental gap, and to examine the electron-phonon interaction near their bulk and surface plasmon resonances. Progress: All the emissive total yield measurements were made on silicon and gallium

surfaces were prepared by the same technique as that previously employed. The results of the measurements of the photoconductivity, Hall effect, and magnetoresistance of these samples are shown in Figures 1 and 2.

NR 318-018, Naval Surface Weapons Center, Dahlgren, Virginia  
Study of Magnetophonon Effects in Germanium  
H. L. White

Damage to all solid-state devices is caused by the mobility and velocity with which they respond to the action of the normal forces. An understanding of the physical processes developed in the carrier motion mechanism is essential for progress was made in the measurement of the photoconductivity of VFeO<sub>3</sub> and in antiferromagnetic resonance studies. The spectrum in a constant field magnetic field of the photoconductivity of VFeO<sub>3</sub> is shown in Figure 1. The photoconductivity of a bar of VFeO<sub>3</sub> was measured as a function of the magnetic field. A simple exponential behavior was observed in the case of the c-axis bar with an activation energy of 0.1 eV. The photoconductivity of a c-axis bar is not a Poole-Frenkel effect. The photoconductivity of the extremely hard beam of VFeO<sub>3</sub> is shown in Figure 2. The a-axis bars have begun.

NR 318-020, Naval Surface Weapons Center, Dahlgren, Virginia  
Magnetophonon Effects in Germanium  
Burke

Magnetophonon resonances occur whenever the energy of the electronic states in a magnetic field equals the energy of the phonons with which the electrons interact, or when  $\hbar\omega_c = \hbar\omega_p$ , where  $\omega_c$  is the cyclotron frequency,  $\omega_p$  is the phonon frequency, and  $\hbar$  is Planck's constant. The effect is measured as an oscillatory magnetoresistance for the semiconductor and, very importantly, magnetoresistance is involved in the transport properties. This paper reports on studies on the PbTe system, and on the effect of carrier density, lattice temperature, and magnetic field on the magnetoresistance. Measurements will be extended to other semiconducting alloy systems. In the case of PbTe, oscillations have been observed between 100 and 1000 K. The effect is observed in Sn<sub>2</sub>Te and PbTe. Phonon energies were determined by calculating the magnetophonon resonance frequencies. The effect of the magnetoresistance is a function of the carrier density, and measuring the heavy carrier effective mass using the temperature dependence of the photoconductivity is possible.

NR 318-003, The American University, "High-Low Magnetostriuctive Rare Earth Transition Metal Systems," I.I. - Dr. Earl Callen, N00014-74-C-0736

An experimental and theoretical study will be made of various materials such as the rare earth alloys, intermetallic compounds, polycrystalline suspensions and sintered mixtures to determine their physical properties that influence the parameters suitable for yielding large magnetostriction while preserving good conductivity and structural properties for transducer application. The materials will be prepared and checked for their magnetic properties by Mossbauer analysis, by strain gauges, by conventional torque and direct movement measurements. Progress: In terbium-iron-yttrium (TbFeY) alloys, at small concentrations of Y, the magnetostriction drops linearly with increasing Y. At a critical concentration, the magnetostriction drops to zero. It has been shown in terbium-iron-cobalt (TbFeCo) that the rhombohedrality deviates strongly in a nonlinear fashion as the concentration of Fe or Co is varied. The underlying mechanism for this change is just the dependence of the Curie temperature on the alloy concentration. The magnetostriction comes almost exclusively from the Tb sublattice, which dominates the magnetostriction of the transition metal ions.

#### Recent Publications:

1. A. E. Clark, J. R. Cullen, and E. Callen, "Rhombohedral Magnetostrictive and Magnetic Materials, Distortion of Highly Tb Alloys", Proc. of Conf. on Magnetism and Magnetic Materials, 1975.
2. R. Abbundi, R. Segnan, J. J. Rhyne, and D. Swager, "Hyperfine Fields in the Absence of Magnetic Order in DySc Alloys", Proc. of Conf. on Magnetism and Magnetic Materials, 1975.

NR 318-024, General Electric Corporate Research and Development Center, "Improved Permanent Magnet Materials," I.I. - Dr. J. J. Becker, N00014-74-C-0271

The coercive force in high-anisotropy materials will be investigated in order to supply a basis for the development of permanent magnet materials surpassing the best in existence today, all of which are now based on CoSm. Present techniques are sensitive enough to permit the measurement of magnetization and hysteresis behavior of single microsample particles in great detail. Further information on the nature of the defects responsible for nucleation events in single particles will be obtained by analysis of magnetization behavior and its dependence on various physical parameters, especially temperature. Progress: Very tiny samples from bulk

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sintered Co5Sm magnets measured in 1974. Now many magnetization phenomena previously seen only in sintered particles prepared from cast material. These phenomena include magnetization discontinuities, a quantized dependence of nucleating fields on magnetizing fields, an angular  $1/\cos\theta$  trapped-wall dependence, and on occasion a completely rectangular hysteresis loop. Thus for the first time a strong link has been established between earlier reversal mechanism studies and the behavior of bulk Co5Sm magnets, the same defect-nucleated reversal behavior being observed in both.

Recent Publications:

1. J. J. Becker, "Properties of Microsamples of Sintered Cobalt-Samarium Magnets," presented at 20th Annual Conference on Magnetism and Magnetic Materials, San Francisco, AIP Conference Proceedings 24, 676 (1975).
2. J. J. Becker, "Origin of Coercivity in Cobalt-Rare-Earth Particles and Sintered Magnets," University of Dayton Symposium on Crystal Anisotropy and Coercivity of Rare-Earth-Transition-Metal Alloys, Dayton, Ohio, Oct. 17, 1974.

NR 318-027, Massachusetts Institute of Technology, "Magnetic Semiconductors, Detectors, and Electronic Devices," F.I. - Dr. George Pratt, N00014-75-C-0785

Use is made of new models of many electron systems in magnetic solids in order to determine their points of transition from metal to insulator and conditions of spontaneous magnetization. Calculations of energy levels associated with deep traps, defects, and impurities are calculated by means of cluster techniques of energy band theory. The magnetic after-effect will continue to be investigated as a sensitive detection scheme. Progress: The electronic energy levels associated with vacancies and interstitials in PbTe have been calculated using the Johnson-Slater cluster method with a  $Pb_4Te_4$  cluster. This is a SCF relativistic calculation and the results are similar to those reported earlier. Agreement with the previous Parada-Pratt first principles calculation using conventional band theory is also good.

Recent Publications:

G. W. Pratt, "Production of Quasistatic High Magnetic Fields by Switching Low Voltage d.c. Generators", IEEE Trans. on Magnetics, MAG-10, 201 (1974).

[illegible]

As a result of the above work it is proposed that to formulate structural models of defects in silicon, the following measurements of photo-physical processes in hydrogenated silicon-dioxide films will be carried out: (1) the photoconductivity of the films will be determined the dependence of the photoconductivity on the photon energy and the intensity of the light will be determined; (2) the joint ground-state and excited-state lifetimes of the photoconductors, the inhomogeneous broadening of the photoconductors can be extracted. Other measurements include the dependence of the energy dependence of trapped electron concentration on the annealing temperature of silicon dioxide photoconductors. The effect of the photoconductivity of electron concentration on the measured photodepopulation response has been determined. The proper procedure for determination of defect energy levels in photoconductors using the photodepopulation technique was determined. By this method, trap population kinetics in thermal oxide silicon dioxide films were examined. It is proposed that hot electrons in the silicon-dioxide by ultraviolet excitation at the silicon-silicon-dioxide interface are involved in inverse Auger recombination of electrons localizing in traps in the silicon-dioxide.

1. "A Study of the Spectroscopy in Thin  
Films of Vanadium Dioxide in Circuit Current",  
J. Appl. Phys. 41, 1970, 2321-2324.

NR 318-039, North Texas State University, "Investigation of Optical Biasing on the Quantum Transport Properties of Semiconductors," P.I. - Dr. David Seiler, N00014-76-C-0319

The investigator will study the quantum transport of electrons and holes generated by optical irradiation in the presence of high electric and magnetic fields. During this study, new tools will be developed and utilized to provide information on determination of the non-equilibrium electron temperature and the effect of laser irradiation upon this temperature, to determine the transient effects of the Shubnikov-de Haas and magnetophonon resonance effects in pulsed electric fields and the corresponding energy relaxation times, and to study the properties of the non-equilibrium carriers through spin-splitting of the Shubnikov-de Haas effect. Progress: New

NR 318-040, Stevens Institute of Technology, "Research on Chalcopyrite Semiconductors," P.I. - Dr. George Wright, N00014-76-C-0384

Theoretical calculations of the electron energy bands will concentrate on the differing influence of these effects: the change in the chemical potential of the A-B cation sublattices in perturbation from III-V or II-VI lattices, the effect of the c/a distortion, and the effect of the anion distortion. This study will utilize a blend of symmetry, pseudopotential, deformation potential, and k-P techniques. Experiments will utilize piezo-spectroscopy to ascertain deformation potentials and optical pumping luminescence measurements to ascertain g-factors. Progress: New

NR 318-041, Emory University, "Far Infrared Optical and Magneto-optical Studies of Semiconductors," P.I. - Dr. Sidney Perkowitz, N00014-76-C-0429

Far infrared optical and magneto-optical reflection and transmission measurements will be made in III-V, II-VI, and IV-VI semiconductors and their alloys with particular emphasis placed upon the III-V ternary solid solutions. These data will be utilized to investigate dielectric behavior, coupled phonon-plasmon modes, and multi-carrier properties of the materials. The role of multiple coupled oscillators on the dielectric behavior will be investigated. Polaron coupling and the role of plasma interactions in narrow-gap materials will be investigated. Progress: New

NR 318-042, IBM San Jose Research Laboratory, "Electronic Properties of Anisotropic Organic Solids," F.I. - Dr. P. L. Greene, N00014-76-C-

The contractor will investigate the following: (1) Synthesis, purification, and film and crystal growth of derivatives of polysulphur nitride involving intercalation, substitution, and attachment of side groups; (2) measurement of the conductivity, thermopower, and specific heat of these crystals as a function of temperature; and (3) interpret the above experiments using phenomena oriented models to provide insight into molecular and solid state origins of electronic structure, metal-insulator transitions, densities of states, bandwidths, electronic effective masses, anisotropies and electron-phonon interactions.

Progress: New

NR 318-044, Western Michigan University, "Magneto-transport Studies in Semiconductors," F.I. - Dr. Vijay Arora, N00014-76-C-

Calculations will be carried out on magnetotransport effects in semiconductors in the presence of electric fields and thermal gradients. A quantum mechanical approach based upon the solution of Liouville's equation for the density matrix will be utilized. Results will be extended to the cases of nonparabolic bands, inelastic acoustic scattering, many valleyed band structure, and the effects of high electric fields. Progress: New

PR 011-11-01, SUPERCONDUCTIVITY, (E. A. Edelsack, 202 692-4218)

NR 319-054, National Bureau of Standards, Gaithersburg, "Detection of Electromagnetic Radiation by Arrays of Josephson Junctions,"  
P.I. - T. F. Finnegan, NACRP-26-73.

The electrodynamic properties of small arrays of interacting Josephson tunnel junctions are being investigated. Both radiation emission and microwave induced response characteristics are being studied. Junctions are being developed using high transition temperature, large energy gap materials. Progress: The most significant new results achieved with large area Pb-Pb oxide-Pb tunnel Josephson junctions were: (1) the successful injection-locking (with an external 4 GHz microwave source) on small arrays, and (2) the first observation of coherent emission from a radiating three junction array, coupled to a microwave stripline. Radiation from this array was detected at frequencies near 4, 8 and 12 GHz.

Recent Publications:

1. T. F. Finnegan, J. Toots and J. Wilson, "Frequency-Pulling and Coherent-Locking in Thin Film Josephson Oscillators," Proceedings of LT-14, p. 184, (North-Holland Publishing Co., (1974)).

NR 319-055, University of California, Berkeley, "Microwave and Far Infrared Superconducting Detectors for Surveillance Systems,"  
P.I. - P. Richards, N00014-60-A-0000-1056.

The properties of high frequency, wide bandwidth low noise parametric amplifiers using Josephson junctions as nonlinear elements are being investigated. Progress: Experiments at 26 GHz have shown that the noise and the conversion efficiency of mixers containing Pb junctions agree with theoretically determined values. Using a 26 GHz parametric amplifier containing a Josephson junction, significant parametric gain was observed. This is the highest frequency at which gain has been observed.

## Recent Publications:

1. "Noise in Josephson Effect mm-Wave Mixers," J. Classen, T. Taur and P. Richards, Proceeding of 1974 Applied Superconductivity Conference, Oakbrook, Ill., 1974.
2. "Josephson Junctions as Heterodyne Detectors," T. Taur, J. Classen and P. Richards, IEEE Transactions on Microwave Theory and Techniques, December 1974, Part II.

NR 319-057, Massachusetts Institute of Technology, "Superconducting Electric Machines for Naval Propulsion," P.I. - Dr. J. L. Smith, N00014-67-A-0204-0068.

The contractor is investigating the characteristics of existing superconducting machines for ship propulsion and comparing them with the characteristics of newly conceived machines. Two new machines concepts under investigation are: (1) superconducting machines having a DC superconducting field winding and two normally conducting armature windings, and (2) a high efficiency variable speed ship propulsion system utilizing AC superconducting motor and superconducting generator. Progress: The steady state testing of an iron and copper prototype of a superconducting dual armature motor was completed. A starting winding was designed and installed on the inner rotor of this motor. A simplified circuit model for this new dual-rotor class of machines has been developed.

## Recent Publications:

1. "Multipole Superconducting Electric Motors for Ship Propulsion," by P. Thullen, T. A. Keim and J. V. Minervini, IEEE Trans. on Magnetics, Vol. MAG-11, No. 2, March 1975, pp. 573-5.

NR 319-062, State University of New York, Stony Brook, "Superconducting Broadband Arrays," P.I. - Professor J. E. Lukens, N00014-75-C-0769.

The radiative properties of broadband superconducting arrays in the 1-18 GHz frequency range are being studied. These series connected arrays consist of many thin film microbridges whose properties are precisely controlled by means of electron-beam and ion milling fabrication techniques. The effects of array size and coupling on microwave output power and on the intrinsic array noise are being studied. Progress: A most important result has been the observation of voltage locking between two series connected

superconducting indium microbridges which were in close proximity. Data show the existence of an internal synchronization interaction without need of a cavity or external radiation.

#### Recent Publications:

1. "Observation of the intrinsic noise of thin-film microbridge Josephson junctions," Appl. Phys. Lett. Vol. 26, 480, 15 Apr 75, S. S. Pei and J. E. Lukens.
2. "Use of Fluxoid Quantization in the Measurement of the Inductance of Single Junctions SQUIDS," with S. S. Pei, J. Appl. Phys. 46, 2257 (1975).

NR 319-072, The Aerospace Corporation, "Josephson Parametric Amplification at Microwave and Millimeter Wavelengths," P.I. - A. Silver, N00014-76-MP-60007.

Parametric amplification properties of superconducting Josephson junctions at microwave frequencies are being studied. Parametric amplification is being studied as a function of critical current, leakage resistance, junction geometry, and frequency, in order to determine the conditions for optimization of gain, bandwidth, noise figure and frequency conversion. Progress: Impedance measurements were made at 9 GHz on niobium superconducting point contact junctions in a broadband waveguide for the purpose of studying junction parameters. Results were inconclusive due to spurious reflections and lack of an absolute reference impedance. Alternate experiments are being attempted. Experiments to study parametric amplification at 90 GHz are underway.

#### Recent Publications:

1. "Parametric Amplification with Self-Pumped Josephson Junctions," H. Kanter, IEEE Trans on Magnetics, Vol. MAG-11, 789, 1975.
2. "Low Noise Parametric Amplification with a Self-Pumped Josephson Junction," H. Kanter, J. Applied Physics.

NR 319-075, Stanford University, "Superconducting-Cavity Stabilized Oscillator for Ultra High Stability Radio Frequency Source," P.I. - Professor H. A. Schwettman, N00014-67-A-0112-0087.

The electrical, cryogenic, mechanical and environmental parameters which effect the short term frequency stability and the long term drift of superconducting cavity stabilized oscillators (CSO) are

being studied. The long term frequency drift of the SCSC are being compared to a cesium beam frequency standard and as part of this study the upper limit of the secular drift rate of the fine structure constant is being measured. Progress: Recent efforts have resulted in the following substantial improvements in the SCSC performance characteristics at 8.6 GHz: (1) the spectral density of phase fluctuations have been reduced by two decades, (2) the short-term frequency stability as measured in the time domain has been reduced by a factor of 20 to  $5 \times 10^{-15}$  for sampling times between 1 ms to 10 ms and (3) the long-term fractional frequency drift has been reduced by a factor of four to values of  $\pm 5 \times 10^{-14}$  per day.

#### Recent Publications:

1. "Superconducting-Cavity Stabilized Oscillators of  $6 \times 10^{-16}$  Stability," S. R. Stein and J. P. Turneaure, IEEE Proceedings Letters, July 1975.

NR 319-080, National Bureau of Standards, Boulder, "Microwave and Far Infrared Superconducting Detectors," P.I. - D. McDonald, NAONR-34-75.

The high frequency response to millimeter and submillimeter radiation of superconducting point contact and tunnel type Josephson junctions are being studied. Frequencies of up to 100 THz are being explored. A theoretical study of picosecond pulse generation by Josephson junctions is in progress. Progress: A prototype low power Stirling-cycle refrigerator made of non-magnetic, non-conducting materials has been built and maintained at 1K for over 1000 hours with no noticeable wear. The microscopic phenomenological theory of the Josephson effect has been reformulated so as to permit calculation of the intrinsic response time of a Josephson tunnel junction when connected to an arbitrary circuit.

#### Recent Publications:

1. P. F. Harris, "Intrinsic Response Time of a Josephson Tunnel Junction."
2. P. F. Harris, E. C. Dynes and E. M. Ginsberg, "Strong-Coupling Corrections to the Jump in the Quasiparticle Current of a Superconducting Tunnel Junction."
3. E. M. Ginsberg, P. F. Harris, and E. C. Dynes, "Strong-Coupling Corrections to the Low-Frequency Electrical Conductivity of Superconducting Tunnel Junctions."

NR 319-081, California Institute of Technology, Pasadena, "Interaction of Electromagnetic Radiation by Arrays of Superconducting Junctions," P.I. - J. Mercereau, N00014-75-C-0014.

The coupling between individual elements of an array of superconducting junctions is being examined both theoretically and experimentally. Impedance, noise, emission power, frequency range and sensitivity are being studied. Progress: The oscillation of individual elements in a superconducting series array of proximity coupled Josephson junctions have been found to lock together into a single synchronous mode when the spacing between junctions is made sufficiently small (e.g. less than six microns in arrays of Nb-Ta junctions for frequencies up to 100 KHz). This phenomenon occurs spontaneously without the need of either external radiation or a resonant cavity.

#### Recent Publications:

1. "Noise Measurements in Superconducting Proximity Bridges," S. K. Decker and J. E. Mercereau, *Appl. Phys. Lett.* 27, 466 (1975).
2. "Stripline Coupling to Josephson Oscillators," T. Gang and J. E. Mercereau, *J. Appl. Phys.* 26, 4986, (1975).

NR 319-082, University of Pennsylvania, Philadelphia, "Optically Excited Superconducting Devices," P.I. - P. N. Langenberg, N00014-75-C-0925.

The dc I-V characteristics of the optically-induced weak links are being studied in several superconducting materials. The dependence of the critical current on temperature, light intensity and magnetic field are being investigated. The response of these optically induced weak links to microwave radiation is also being studied. Progress: Using optical excitation to produce an excess of quasiparticles (i.e. non-paired electrons) in thin-film superconducting microbridges has to date proved inconclusive. As an alternate technique, 1  $\mu\text{m}$  x 2  $\mu\text{m}$  tunnel junction evaporated on a long tin microbridge was used. Quasiparticles were injected through the tunnel barrier. These experiments were successful in demonstrating the feasibility of an electrically tunable superconducting Josephson weak link using the method of localized injection of excess quasiparticles.

#### Recent Publications:

1. P. N. Langenberg, "Nonequilibrium Phenomena in Superconductivity," *Low Temperature Physics - 1974* V. 1, V. (North-Holland/American Elsevier, Amsterdam and New York, 1974) p. 1-11.

319-094, Massachusetts Institute of Technology, "Synthesis of High Transition Temperature Al<sub>5</sub> Superconducting by Means of Ion Implantation," P.I. - Dr. Robert M. Rose, N00014-76-C-0297.

Substrates of Nb<sub>3</sub>Al will be prepared, characterized and implanted with Si ions at various dosages and energies. Measurements of transition temperature and other superconducting properties will be made as a function of implantation temperature and initial specimen preparation. Progress: New.

Recent Publications:

None

NP 319-095, University of Maryland, "Noise and Relaxation Phenomena in Solids at Low Temperatures," P.I. - Dr. Joseph Weber, N00014-76-C-0426

The relaxation time associated with the noise from metal and dielectric crystals at low temperatures will be investigated. The noise and  $Q$  of a niobium cylinder at low temperature will be studied. Progress: New.

Recent Publications:

None

NP 319-096, Cornell University, "Superconducting Detectors," P.I. - P. Buhrman, N00014-76-C-0526.

The electrodynamic properties and intrinsic noise of superconducting quantum magnetometers biased at rf frequencies above 100 MHz will be determined employing both computer analysis and experimentation. Using superconducting thin film indium weak links and variable thickness niobium bridges as microwave detectors, a detailed study of heating effects will be made. Progress: New.

Recent Publications:

None

NR 319-007, Westinghouse Electric Corporation, Pittsburgh, "Biasing of Microwave Emitting Josephson Junction Arrays," P.I. - M. Janacko, N00014-76-C-0600.

The effects of critical circuit parameters on interconnected Josephson junction circuits will be analytically studied. Thin film junctions to be investigated include the microbridge and proximity types. The emitted radiation from these junctions at X-band frequencies will be experimentally investigated. Signal to noise ratios, power outputs, frequency line width and frequency range of operation are among the parameters to be measured. Progress: New.

Recent Publications:

None

NR 319-098, University of California, Santa Barbara, "Transport Properties of Nonequilibrium Superconducting Materials," P.I. - D. J. Scalapino, N00014-76-C-0535.

The processes by which various nonequilibrium instabilities cause breakdown in superconductors will be studied. For small perturbations from the equilibrium state, the quasiparticle and phonon deviations will be compared for a variety of excitation mechanisms. Changes in energy gap, transition temperature and quasiparticle relaxation rates will be determined. Progress: New.

Recent Publications:

None

319-1000, University of California, Berkeley, "Detection of Electromagnetic Radiation by Semiconductor-Barrier Tunnel Junctions," P.I. - Professor T. Van Duzer, N00014-76-C-0533.

The current-voltage characteristics of superconducting sandwich-type tunnel junctions containing silicon barriers of varying thicknesses and doping profiles will be studied. An improved circuit model of the semiconductor barrier will be developed, using three series-connected shunt RC circuits to represent the quasiparticle and displacement currents. Progress: New.

Recent Publications:

None

NR 319-101, Science Applications, Inc., La Jolla, California,  
 "Properties of Nonequilibrium Superconductors," F.I. - L. Esquivel,  
 N00014-76-c-0010.

The dynamic processes by which the thermal time wave functions describing individual electron pairs are coupled to form a time-of-phase state for bulk superconductors and Josephson junctions will be examined in detail. Superconducting array systems will theoretically be studied with the intent of determining the conditions necessary for mode locking as well as the structure of the self-generated radiation field and the noise characteristics of the system. Progress: New.

Recent Publications:

None

NR 319-104, Catholic University of America, "Time Dependent Superconducting Device Characteristics," F.I. - E. A. Ivers, N00014-76-c-

The signal strength and dimensional and frequency limitations of Josephson junction arrays and SQUIDS will be studied as a function of inelastic electron-phonon collision time and quasiparticle diffusion distance. Also the extension of quasiparticle diffusion theory into the rf region will be experimentally tested. Progress: New.

Recent Publications:

None

NR 319-105, Stanford University, "Superconducting Magnetometer," F.I. - E. L. Giffard, N00014-76-c-

Flux noise sources, flux noise and voltage noise, will be experimentally measured in order to provide a complete representation of SQUID magnetometer noise. The noise in a 20-30 MHz biased SQUID system will be characterized as a function of frequency, down to input frequencies of 20 KHz. Progress: New.

Recent Publications:

None

REPTILES AND AMPHIBIANS

NR 371-31-31, ELECTROMAGNETIC RADIATION AND PROPAGATION, R. M. Whaley,  
1971-1972, 1973

NR 371-31, University of Colorado, Boulder, Colorado, "An Investigation into the Electromagnetic Diffraction of a Dielectric Wedge",  
R. L. Lewis.

This program will attempt to develop an analytic physical technique to solve the problem of diffraction and scatter of electromagnetic waves by a dielectric wedge to enable calculation of the radiation properties of dielectric antenna arrays or of antennas incorporating dielectric supports, as well as the radar reflection and EM pulse response from dielectric objects. The approach is to expand the fields as an integral of plane waves with field matching at the dielectric surface and develop a pair of coupled functional equations for the spectral density functions. A solution is obtained by matching the singularities in the functional equations, giving a family of poles and branch cuts. The integral equations will be solved using well known techniques such as steepest descent to extract the leading terms of specular reflection, diffraction fields, shadow boundary field, and lateral waves, thus giving both a numerical solution and physical interpretation of the scattering process.  
Progress: New

Recent Publications:

None

NR 371-322, Watkins-Johnson Co., Palo Alto, Cal., "Propagation in Single and Coupled Microstrip Transmission Lines on Anisotropic Substrate",  
R. L. G. Krowne.

The objective of this study is to perform a theoretical and experimental analysis of propagation on single and coupled microstrip transmission lines on an anisotropic substrate such as boron nitride, leading to the design of a 10 dB directional coupler. A theoretical analysis of propagation in single and coupled microstrip transmission lines on a substrate with anisotropic dielectric constant such as boron nitride will be performed using techniques such as the method of moments, and will include analysis of the dispersion relations, line impedances, and losses. An optimum theoretical design for a broadband 10dB directional coupler will be fabricated, and experimental measurements performed to confirm the theoretical analysis. Progress: New.

## Recent Publications:

None

NR 371-340, University of Illinois, Urbana Illinois, "Investigation of Electromagnetic Scattering from Apertures in Cylindrical Structures", E.I.-S. Mitra, N00014-75-2-0750.

This effort will carry out an accurate analysis of the aperture coupling phenomena in loss cylindrical structures whose radii are comparable to the wavelength of the incident field. It is proposed to employ accurate and efficient numerical and analytical techniques which have been expressly developed for solving the scattering problems encountered.

Progress: A spectral domain interpretation of a high frequency diffraction phenomena has been developed which introduces the concept of a spectral diffraction coefficient, resembling Keller's coefficient. The solution of two-dimensional problems of diffraction of an arbitrary field (with no caustics) by a half-plane was investigated and results obtained for any observation angle including, in particular, the determination of the field at the shadow boundary. The high frequency scalar diffraction by apertures and semi-infinite cylinders is formulated in a systematic manner and the formulation, which is valid for any observation angle was compared with that of Ufimtsev's results were also obtained for the diffracted field at the caustics.

## Recent Publications:

None

NR 371-366, Brown University, Providence, R.I., "Peripheral or Edge-Guided Mode in Planar Ferrite Loaded Waveguiding Structures", E.I.-D.M. Belle, N00014-75-2-0750.

The purpose of this program is to develop the theory of edge guided mode propagation in ferrite loaded waveguides, which will lead to optimum design of microstrip devices such as isolators, phase shifters, circulators and distributed unidirectional microwave amplifiers. Prototype devices utilizing the edge guided mode have been built and are characterized by extremely wide band performance which may be useful for high data rate or spread spectrum communications, or for frequency hopping or high resolution radars, however a basic understanding of this mode

is lacking. The propagation characteristics of the lowest order edge guided modes will be determined for canonical structures of increasing complexity using integral equation and mode matching techniques. Progress: Numerical solutions of the dispersion relations for surface modes on dielectric-ferrite interfaces have been developed. Comparison with the experimental results for the edge guided mode shows similar characteristics. Computer programs were developed for the surface mode which will become an integral part of the more complex programs required to analyze the edge guided mode.

Recent Publications:

None

NR 371-088, University of Colorado, Boulder, Colorado, "Electromagnetic Susceptibility Study of Metallic Enclosures and Electronic Circuits", P.I.-D.C. Chang, N00014-76-C-0318.

This program will investigate, theoretically, the electromagnetic penetration into apertured cylindrical enclosures of circular cross-section. Two types of plane wave penetration scheme will be considered, one with the wave incident broadside to the cylinder, and the other with the wave normally incident upon the end of the enclosure. In addition, a theoretical study will be made of the conditions for the existence of low-attenuation, substrate-attached modes in electronic circuits and transmission structures. The excitation and propagation characteristics of such modes will also be investigated. Progress: New.

Recent Publications:

None

NR 371-089, University of California, Los Angeles, Cal., "Propagation Characteristics of Arbitrarily-Shaped Dielectric Waveguides", P.I.-C.W. Yeh, N00014-76-C-0321.

Finite element techniques will be used to obtain the propagation characteristics of electromagnetic waves along dielectric guiding structures whose cores maybe of arbitrary cross-sectional shape and whose material media maybe inhomogeneous in more than one transverse direction. The proposed methodology will be applied to several important problems dealing with practical optical filter or integrated optical waveguides whose cross-sectional index of refraction distribution maybe quite arbitrary. Progress: An efficient method of computing

the Dispersion characteristics and Poynting flux distribution of radially stratified fibers using only  $4 \times 4$  matrix operations has been developed.

Recent Publications:

None

NR 371-147, Polytechnic Institute of New York, Brooklyn, N. Y., "Basic Wave Propagation through Turbulent Ionized Media", P.I.-N. Marcuvitz, N00014-76-C-0176.

Propagation through non-linear and/or turbulent media is being investigated. The general techniques being developed treat the wavepackets as quasi-particles, and treats the propagation through non-linear/turbulent media using kinetic equations.

Progress: The areas investigated include electron beam interaction with a background plasma with generation of electron-acoustic waves, coherent wave propagation in a non-linear medium whose dielectric constant is a function of the mean square electric field intensity, wave-wave interactions excited by high power EM waves, wave-matter interactions, and microwave scattering from turbulent plasma.

Recent Publications:

1. D. Attwood, "Microwave Scattering from an Overdense Turbulent Plasma," Physics of Fluids, Vol. 17, No. 6, June 1974.

2. D. Attwood, "Suppression of Ionization Waves by Hydrodynamic Turbulence," Physics of Fluids, Vol. 17, No. 6, June 1974.

3. N. Marcuvitz, "On the Theory of Plasma Turbulence," Journal of Mathematical Physics, Vol. 15, No. 6, June 1974.

NR 371-108, The Ohio State University Research Foundation, Columbus, Ohio, "Fundamental Investigation of a Hybrid Technique for General Electromagnetic Scatterers and Antennas", P.I.-G.A. Thiele, N00014-76-C-0573.

A hybrid technique of determining antenna impedance and radiation pattern will be developed by unifying the method of moments and geometric theory of diffraction. The method of moments technique for calculating the impedance matrix will be extended by separate

calculation of the contribution to the matrix elements from the regions where the method of moments and geometric theory of diffraction respectively apply. Progress: New

Recent Publications:

None

NR 371-401, Massachusetts Institute of Technology, Cambridge, Mass., "Ultra-low Frequency Radio Signals", F.I.-T.E. Madden, N00014-76-C-0087

The purpose of this program is to investigate naturally occurring ULF radiation known as micropulsations. Micropulsations near the Schumann Resonance (about 8Hz) can be used to detect large ionospheric disturbances due to polar cap absorption (PCA), sudden ionospheric disturbances (SII) events, and nuclear blast. Since the resonances are excited by lightning, they can be used to track thunderstorm activity. At lower frequency, the effective surface impedance can be measured by taking the ratio of horizontal to vertical electric field. Since the skin depth increases with decreasing frequency, the effective earth conductivity profile can be determined. Geothermal areas can be determined in this manner since the conductivity is temperature dependent. The earth conductivity profile is an important factor in ELF antenna siting since the efficiency increases with decreasing earth conductivity. Progress: A study of electrical conductivity structures in New England using 1 to 100 kHz and low frequency magneto-tellurics has been completed. A very thorough treatment of the error analysis and the special problems of combining magneto-telluric data collected from widely dispersed areas were considered. The electric field intervals were strongly affected by the continent-coast edge effects, but strong edge effects were also found at the western end of the array.

Recent Publications:

1. I.W. Sasameyer and T. E. Madden, "Low Frequency Magnetotelluric Survey of New England", Tech. Report, September 1976.

NR 371-405, Syracuse University, Syracuse, N.Y., "Synthesis of Reactively Loaded Antenna Systems", F.I.-T.E. Harrington, N00014-76-C-0089.

The use of reactively loaded antenna arrays to form and steer directive beams will be investigated. The effect of the proper choice of the reactive loads in influencing the frequency bandwidth will be investigated. Characteristic modes of the antenna structure are used to synthesize a desired pattern, or to optimize a given parameter, and then to resonate the current by reactive loading of elements. Progress: Good results have been obtained on small reactively-loaded linear and circular arrays for forming directive beams and scanning them by varying the reactive loads. Such arrays have the following advantages over conventional phased-array antennas: (1) Only one element is fed by the transmitter, hence, matching the array to the transmitter is accomplished by a single one-port matching network. (2) No transmission lines are connected to the remaining elements, their excitation being obtained from the electromagnetic interaction. (3) Control of the directive beam is obtained by reactances which can be varied by electronic means. (4) All mutual interactions between elements are accounted for in the theory, and in fact are necessary for proper control of the array. Techniques for maximizing endfire gain of a linear array have been developed. Mathematical techniques for the analysis of a non-linearly loaded multiport antenna structure was developed, including the effect of imperfect ground.

#### Recent Publications:

1. R. F. Harrington and J. R. Mantz, "Reactively Loaded Directive Antennas", Technical Report 74-6, September 1974.
2. Y. Chang and R. F. Harrington, "A Surface Formulation for Characteristic Modes of Material Bodies", Technical Report 74-7, October 1974.
3. H. K. Schuman and R. F. Harrington, "A Low Frequency Expansion for Characteristic Modes of Conducting Bodies", Technical Report 75-3, August 1975.
4. R. F. Harrington, R. F. Wallenburg and A. K. Harvey, "Design of Reactively Controlled Antenna Arrays", Technical Report 75-4, September 1975.
5. J. Luzwick and R. F. Harrington, "A Comparison of Optimization Techniques as Applied to Gain Optimization of a Reactively Loaded Linear Array", Technical Report 76-1, Feb 1976.
6. T. K. Sarkar, L. L. Weiner, and R. F. Harrington, "Analysis of Nonlinearly Loaded N-Port Antenna Structures", Technical Report 76-2, Apr 1976.

RR 021-01-02, SPACE RADIATION ENVIRONMENT (Dr. H. W. Mullaney, 100-692-1014/15/16)

NR 323-001, University of Iowa, Iowa City, Iowa, "Communications: Solar radiations in Near Space, Interactions with the Magnetosphere & Ionosphere, & Effects on Naval Communications," U.S.-Professor J. A. Van Allen, 200014-76-0-0016.

Emphasis in on: corpuscular radiations trapped or transiently present in the earth's magnetic field, and solar, interplanetary and terrestrial phenomena associated with these radiation (e.g. solar flares, aurorae, geomagnetic storms, heating of the atmosphere and ionospheric effects of particle precipitation); energetic solar electrons; solar x-rays; very low frequency (VLF) radio phenomena in the magnetosphere; radio frequency emissions from the sun and flare activity; and interactions of the solar wind with the magnetosphere. Progress: HAWKEYE I was launched and all scientific instruments are operating perfectly. Data is being taken from the energetic particle, electric and magnetic field experiments and reduced to a preliminary master science data tape in real time. The entire data acquisition and reduction system is setting a new standard for the efficient and rapid handling of data from a satellite. Preliminary papers on the scientific results of these experiments in the polar cusp region of the magnetosphere have been reported.

#### Recent Publications:

1. E. T. Sarris and J. A. Van Allen, "Effects of Interplanetary Shock Waves on Energetic Charged Particles", J. Geophys. Res., 79, 4157-4173, 1974.

Chapman, Stanford University, Stanford, Cal., "Deep Disturbances in Auroral Disturbances", J. Geophys. Res., 67, 1962, 1-11.

formation of the auroral arcs is explained as a result of the interaction of the solar magnetic field and the Earth's magnetic field. The solar magnetic field is disturbed, the resulting disturbance in the solar wind and the interaction between the Earth's magnetic field and the solar magnetic field as they vary in the vicinity of the Earth. The disturbance in the solar magnetic field is observed near the center of the disturbance will be observed in an effort to correlate these disturbances with magnetic waves that give space into the corona, deeper into the solar wind and deeper into the solar wind. See also: Final alignment of the solar magnetic field. The new solar magnetic field has been observed. The analysis of the relation between the polarity of the interplanetary magnetic field and polar reconnection has introduced a new and possibly unknown polar current system and requires a new revision of the accepted theory of polar cap reconnection. A new alignment of the spiral magnetic field has been reported for the very first polarity and current system variation in that region. The polarity of the spiral magnetic field of interplanetary field is not as well understood as it is, than the predicted  $10^8$  Gauss.

#### References:

1. J. M. Wilcox, "Solar Activity and the Aurora", J. Geophys. Res., 67, 1962, 1-11.
2. H. A. Larson, J. Chapman, "The Role of the Solar Wind in Polar Cap Magnetic Variations", J. Geophys. Res., 67, 1962, 1-11.
3. J. Chapman, J. M. Wilcox, "The Role of the Interplanetary Magnetic Field in the Polar Cap Variations", J. Geophys. Res., 67, 1962, 1-11.
4. J. Chapman, J. M. Wilcox, "The Role of the Interplanetary Magnetic Field in the Polar Cap Variations", J. Geophys. Res., 67, 1962, 1-11.
5. J. Chapman, J. M. Wilcox, "The Role of the Interplanetary Magnetic Field in the Polar Cap Variations", J. Geophys. Res., 67, 1962, 1-11.

4. L. E. Eovalgaard, J. M. Wilcox and T. L. Fuvall, "A Model Linking the Polar and the Sector Structured Solar Magnetic Fields", Solar Physics **87**, 157-170, 1974.

5. R. H. Scherrer, M. El-Say, "The Relationship Between the Slowly Varying Component of Solar Radio Emission and Large Scale Heliospheric Magnetic Field Patterns", Solar Physics **85**, 361-368, 1973.

DA 343-004, University of California, Berkeley, Cal., "Communication: Vector Electric Field Measurements", P.I.-Dr. F. C. Menner, NSG 343-75-S-0094.

A vector electric field experiment has been designed and built to be flown on an Air Force satellite OS-6 expected to be launched this year. The launch into a polar orbit with an apogee of 5000 miles will enable vector electric field measurements in a previously unexplored region. This launch is part of DOD STS Flight 74-1.

Progress: Electric field data from satellite observations have revealed an isotropic electric field vector at 400 km in the mid-latitude regions which is not coincident as has been previously reported by others. The region of this turbulent electric field is in agreement with that of ionospheric plasma turbulence inferred from scintillation of radio stars and measurements of spread E. An additional mode, not electrostatic, is due to the electric component of an electromagnetic wave giving an observed emission of ELF hiss. Observations of intense low-frequency electric field fluctuation near the magnetic equator are correlated with spread E at equatorial ground stations suggest ionosphere electric field turbulence is caused by same instability responsible in the high-latitude case.

#### Recent Publications:

1. F. C. Menner, M. J. Kelley, "A Review of the Recent Results of In-situ Ionospheric Irregularity Measurements and Their Relation to Electrostatic Instabilities", Proc. of IRI, 1-5, 1975.

2. M. J. Kelley, T. W. Carlson, F. C. Menner, "Application of Electric Field and Fast Langmuir Probe for the In-situ Observation of Electrostatic Waves and Irregularities", Proc. of IRI, 6-8, 1975.

3. M. F. Bilen, M. J. Kelley, "The Temperature Gradient Instability of the Equatorial Edge of the Ionospheric Plasma Sheet", J. Geophys. Res., (submitted) 1975.

4. M. J. Kelley, R. T. Gurnett, F. C. Menner, "Properties of ELF Electromagnetic Waves in and above the Earth's Ionosphere Derived from Plasma Wave Experiments on the OS-6 and OS-7 Satellites", J. Geophys. Res., (in press) 1975.

NR 004-006, University of California, Los Angeles, Cal.,  
 "Communications: Magnetospheric Substorms", E.L.-Dr. E.L.  
 McPherron, N00014-69-A-0000-4016.

Ground and satellite magnetic field data will be used to infer parameters of models of field aligned currents during the growth phase of a substorm. Studies of substorm magnetic perturbation will continue. This work includes improvements in low latitude magnetic mapping procedures, improvements in the parameterization of substorm growth and expansion phases, and application of these improved procedures to a large set of computer identified substorm expansions. An attempt will be made to determine in what manner partial ring current development precedes major substorm expansion and how frequently a major expansion causes further ring current enhancement during the expansion phase. Progress: Studies of ground and satellite signatures of multiple onset substorms has shown that the near earth plasma sheet thins prior to onset followed by a rapid expansion in response to each onset while in the distant tail the plasma sheet thins following the first onset and expands only after the last of a sequence of onsets.

#### Recent Publications:

1. Russell, C. T., McPherron, E.L. and Burton, R.L., "On the cause of geomagnetic storms", J. Geophys. Res., 79 (7) 1105, 1974.
2. Clauer, C.R. and McPherron, E.L., "Mapping the local time-universal time development of magnetospheric substorms at mid-latitudes", J. Geophys. Res. 79 (19), 2811, 1974.
3. Clauer, C.R. and McPherron, E.L., "Variability of mid-latitude magnetic parameters used to characterized magnetospheric substorms", J. Geophys. Res. 79 (19), 2898, 1974.
4. Hurning, E.L., McPherron, E.L. and Jackson, D.D., "Application of linear inverse theory to a simple current model of the magnetospheric substorm expansion", J. Geophys. Res., 79 (34), 5000, 1974.
5. Chan, M.N., McPherron, E.L. and Russell, C.T., "Substorm and interplanetary magnetic field effects on the geomagnetic tail lobe", J. Geophys. Res., 80 (1), 191, 1975.

6. Kokubun, S., McPherron, R.L. and Russell, C.T., "Triggering of substorm expansion phase by storm sudden commencement", Ios, 56 (13), 117, 1974.

7. Iyete, T., McPherron, R.L. and Kokubun, S., "Orb and satellite measurements during westward moving substorms", Ios, 56 (13), 1176, 1974.

8. Gnan, M.M., McPherron, R.L. and Russell, C.T., "The magnetic signatures of magnetospheric substorms: Computerized statistical analysis", Ios, 56 (13), 1177, 1974.

9. West, H.L., Jr., Iyete, T., McPherron, R.L. and Back, B.M., "The response of the near-earth plasma sheet to multiple onset substorms", Ios, 56 (16), 441, 1975.

10. Iyete, T., McPherron, R.L., Hares, L.W. and West, H.L., Jr., "The distinction between substorms and convection-driven auroral-zone negative bays", Ios, 56 (16), 445, 1975.

NSF-45-039, Grant at University, Stanford, Cal., "Communications Plasma Physics", R.L.-in-Cosser R.A. Sturrock, NS0114-03-A-0110-0001.

Study relating to solar flares and their prediction will continue. Study of flare mechanisms and radiations and magnetic field changes as observed in visible and UV as indicators of preflare conditions. The solar atmosphere will be modeled to include magnetic fields with an energy loss, heat flow, and propagation of acoustic waves. Data from the H&K videometer, which views the sun in the H-alpha band will be compared with the theoretical analysis. Progress: An analytical/numerical model of whistler wave-electron beam coupling to predict triggered VLF emission in the earth's magnetosphere has been developed. A model for predicting solar UV emissions has been developed.

#### Recent publications:

1. Y. Sakarawa, East, T., "The Storage and Release of Magnetic Energy", Flare-Related Magnetic Field Dynamics Conference, VLF, High Altitude Observatory, Boulder, Colorado, p. 187, 1974.

2. L.W. Knight, R.A. Sturrock, "Two-Fluid Model of the Solar Corona", Sol. Ws, 47, 183, 1974.

1. A. M. Iressler, L. M. Firrell and E. S. White, "Angular Distribution of Cosmic Rays", Phys. Rev., **71**, 1947.

2. L. M. Firrell, "The Angular Distribution of Cosmic Rays", Phys. Rev., **71**, 1947.

3. "The Angular Distribution of Cosmic Rays", Phys. Rev., **71**, 1947.

4. "The Angular Distribution of Cosmic Rays", Phys. Rev., **71**, 1947.

5. "The Angular Distribution of Cosmic Rays", Phys. Rev., **71**, 1947.

#### References

1. A. M. Iressler, L. M. Firrell and E. S. White, "Angular Distribution and Altitude Dependence of Atmospheric Cosmic Rays", Phys. Rev., **71**, 1947.

2. L. M. Firrell, L. M. Iressler, and E. S. White, "The Angular Distribution of Cosmic Rays", Phys. Rev., **71**, 1947.

3. L. M. Firrell and E. S. White, "The Angular Distribution of Cosmic Rays", Phys. Rev., **71**, 1947.

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1. Amstutz, C. L., J. Am. Chem. Soc., 1939, 61, "Immunized, Isolated Electric Fish as Power Source", Science, 86, 1935, 401, with Miller, "Electrical 'Power' Fish", Science, 86, 1935, 401.

19. J. L. Doolittle, *Science*, **261**, 1535 (1992).  
 "They have shown: low-energy barrier to life", *Sci-*  
 ence, **261**, 1535, 1536.

Utilizing the recent technique for measuring magnetic fields in electric fields, this experiment in conjunction with a magnetic field experiment will serve to demonstrate the role of the ionospheric plasma. In order to determine and modify one of the field instrument components, we intend to modify this instrument to be used in this experiment by adding a probe while awaiting spacecraft instrumentation.

1. *Phragmites australis* (Cav.) Trin. ex Steud.

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Dr. R. H. Howard, Carnegie Institute of Washington, Washington, D.C.,  
 "Communications: Solar Flares and Communications", 1.1.-  
 Dr. R. H. Howard, N00014-76-1-1111.

The work will consist of obtaining and reducing data from the solar magnetograph at the Mount Wilson Observatory, which will provide information concerning magnetic and velocity fields on the sun. The results will be analyzed for basic processes in the development and decay of solar active regions and in the solar activity cycle. Full-disk observations as well as fine-scan observations will be made. Specific observing programs will include a study of the magnetic fluxes, lifetimes, and rotation rates of small magnetic features. These are important characteristics of the fundamental magnetic elements on the sun. Data reduction of accumulated material will continue with emphasis on circulation patterns of the solar atmosphere and the relation of these patterns with solar activity. Progress: Spherical harmonic analysis of the magnetic fields on the solar surface over recent years has been completed. By this means the large-scale structure of the corona magnetic field will be examined. It is this field that represents the base of the interplanetary magnetic field and determines initial conditions for the solar wind and transmission of particles through interstellar space to the earth.

#### Recent Publications:

1. Howard, R., "Studies of Solar Magnetic Fields: The Magnetic Fluxes", Solar Physics, 38, 59, 1974.
2. Howard, R., "Studies of Solar Magnetic Fields: The Average Field Strength", Solar Physics, 38, 283, 1974.
3. Howard, R., "Studies of Solar Magnetic Fields: The East-West Orientation of Field Lines", Solar Physics, 39, 275, 1974.
4. Altschuler, M. D., Trotter, D.H., Newkirk, Jr., G., and Howard, R., 1974, Solar Physics, 39, 3, 1974.

NR 323-028, Lockheed Palo Alto Research Lab, Palo Alto, Cal.,  
 "Navy Environment: Magneto-Ionospheric Plasma", P.I.-Dr.  
 H.G. Shelley, N00014-75-C-0099.

The experiment is an energetic ion mass spectrometer and a multi-channel electron spectrometer which measures low-energy ions and electrons in the range from a fraction of a keV to about 30 keV. The opportunity to use heavy ions as tracers to probe mass and charge-dependent magnetospheric processes will furnish a new technique to study the still unknown mechanisms responsible for the energization and transport of magnetospheric plasma. A measurement with higher sensitivity and better mass resolution will be performed and extended to energy ranges not covered in the previous experiment. The possibility also now exists of performing active experiments in coordination with chemical releases planned by DNR, NASA, and the Max-Planck Institute of Germany.  
Progress: Construction of instrument is proceeding according to schedule.

#### Recent Publications:

None

NR 323-031, Cornell University, Ithaca, New York, "Communications: Electrostatic Waves", P.I.-Dr. M.C. Kelley, N00014-75-C-0780.

A vector electric field measurement has been designed and built to be flown on an Air Force satellite S3-3 expected to be launched this year. The launch into a polar orbit with an apogee of 5000 miles will enable vector electric field measurements in a previously unexplored region. This launch is part of the DoD STF Flight 74-2. Progress: Electric field data from satellite observations has revealed an isotropic electric field vector at 400 km in the high latitude regions which is not coincident as had been previously reported by others. The region of this turbulent electric field is in good agreement with that of ionospheric plasma turbulence as deduced from scintillation of radio stars and measurements of spread F. An additional mode, not electrostatic, is due to the electric component of an electromagnetic wave giving an observed emission of ELF hiss. Observations of intense low-frequency electric field fluctuation near the magnetic equator are correlated with spread F at equatorial ground stations suggest ionosphere electric field turbulence is caused by same instability responsible in the high latitude case.

## Recent Publications:

1. M.E. Hudson, M.C. Kelley, "The Temperature Gradient Drift Instability at the Equatorward Edge of the Ionospheric Plasma Trough", J. Geophys. Res. (in press).

NR 323-032, McDonnell Douglas Astronautics Co., Huntington Beach, Cal., "Communications: Quantitative Global Model of Ionospheric Electron Density", P.I.-W.P. Olson, N00014-75-C-0821.

A quantitative model, global in extent, will be developed to predict ionospheric electron density using monitored data from ground stations and satellite systems such as SCLRAD and ISMF. Solar electromagnetic fluxes, fluxes of charged particles into the ionosphere will be used to input this model. Progress: Work is progressing on schedule.

## Recent Publications:

None

NR 323-042, Stanford Electronics Laboratory, Stanford, Cal., "Communications: VLF/ELF Propagation Effects", P.I.-Professor R.A. Helliwell, N00014-67-A-0112-0012.

To study the effects of wave-induced particle precipitation on VLF/ELF propagation in the earth-ionosphere waveguide, available experimental data on whistler-induced perturbations will be used to develop a physical model of the perturbation. From this physical model an electrical model will be derived to explain the observed perturbations (up to 6db) in VLF/ELF signal strength. A model of magnetospheric duct propagation will also be developed. This model will be used to predict the whistler-mode field intensity at a given ground observation point from a given transmitter. Progress: Artificially stimulated VLF emissions (ASE) are triggered in the magnetosphere by whistler mode signals from transmitters. These emissions may be separated into two classes, rising and falling in frequency. Several hundred ASE have been analyzed by Fast Fourier transform. Averages taken over many events indicate that both rising and falling tones show the same initial behavior. The emissions begin at the frequency of the triggering signal rather than at an offset frequency. Both tones initially rise in frequency, falling tones reversing slope at a point 1.5-2.0 Hz above the triggering signal.

## Recent Publications:

1. Stiles, W.C. and E.A. Hollwell, "Frequency-time behavior of artificially stimulated VLF emissions", J. Geophys. Res., 80, C18, 1975.
2. W.C. Stiles, "Controlled VLF Experiments", in VLF-VLF Polar Wave Propagation, J.A. Holtet, Ed., (J. Reidel Publ. Co., Dordrecht-Holland, 1976), pp. 435-49.
3. Bell, T.F., "ULF wave generation through particle precipitation induced by VLF transmitters", (to be published in J. Geophys. Res., 1975).
4. Walker, A.D.M., "The theory of whistler propagation", (submitted to Rev. of Geophys. Space Phys., Aug. 1975).

PHYSICAL ELECTRONICS

NR 001-07-01, PHYSICAL ELECTRONICS (Dr. David K. Ferry, 202-697-4217)

NR 373-002, IBM T. J. Watson Research Center, "Electronic Structure and Properties of the Oxides of Tetrahedral Semiconductors," P.I. - Dr. Socrates Pantelides, N00014-76-C-

The oxides of the tetrahedral semiconductors ( $\text{SiO}_2$ ,  $\text{GeO}_2$ ,  $\text{SnO}_2$  and the AB<sub>4</sub>-type oxides of the AB-type compound semiconductors, e.g.,  $\text{AlPO}_4$ ,  $\text{GaAsO}_4$ , etc.) are important technological materials used widely in the fabrication of electron devices. Their crystal structures are generally complicated and the overall symmetry is low so that theoretical studies of the properties of these materials have been very limited in scope. In this program, a theoretical investigation of the properties of these materials will be carried out using both conventional and newly-developed techniques, particularly suited to the situation and exploiting complementary aspects of tight-binding pseudopotential methods. This investigation will include the energy bands, x-ray photoemission spectra, optical absorption spectra, x-ray emission and absorption spectra, dielectric functions, effective charges, elastic constants, stability of structures, heats of formation, the electronic structure and dynamics of defects, and surface and interface states. Progress: New

NR 474-003, Brown University, "Experimental and Theoretical Investigation of the Transport Properties of Semiconducting Surface Inversion Layers," P.I. - Dr. Philip Stiles, N00014-76-C-

This program will investigate both experimentally and theoretically, the physics of charge transport in compound semiconducting surfaces. The first experimental approach will be to obtain good liquid re-semiconductor interfaces and explore the above phenomena. It is intended to characterize the material, physical, and technological properties. The investigators will ascertain the theoretical role of material parameters, the single particle spectrum, many-body effects, and model interfaces to ascertain what role other parameters play in this charge transport. It is their intention to arrive at a realistic theoretical description of both charge transport and recombination in the surfaces of compound semiconductors. Progress: New

NR 372-025, University of Colorado, "Heterojunction Contacts for Transferred Electron Devices," P.I. - Dr. Russell Hayes, N00014-75-C-0472

Controlled heterojunction contact barriers will be prepared by growth of quaternary lattice-matched layers of (In, Ga) (As,P) solid solutions on indium phosphide. By varying the constituency of the quaternary compound, it will be possible to vary the heterojunction barrier height continuously, and thus to determine its effect on the performance of transferred electron devices in indium phosphide. Lattice matching is important to minimize defect states at the heterojunction interface. Theoretical analysis will accompany the experiments to provide a sound scientific basis for a rational heterojunction technology. Progress: InGaAsP layers have been grown on InP with composition that are approximately lattice matched to the InP and with a band gap in the 1.35-1.37 eV range. The layers were compensated n-type with a net donor concentration of  $1 \times 10^{17}/\text{cc}$  and an electron mobility of  $2250 \text{ cm}^2/\text{V-sec}$ . Photoluminescence studies indicate a Zn or Cd acceptor is present.

NR 372-026, California Institute of Technology, "Condensation of Injected Electrons and Holes in Semiconductors," P.I. - Dr. Thomas McGill, N00014-75-C-0423

A comprehensive experimental program will study the condensation of the electron-hole gas injected in semiconductor double injection devices at low temperatures. Emphasis will be placed on studying the electrical device double injection process at low temperatures and its interaction with condensate will be developed. Progress: Electrically injected carriers at low temperatures may be found as free electrons and holes, as excitonic pairs, as bound excitons, or as an electron-hole condensed liquid. This latter phase is a high density phase containing about  $3 \times 10^{18}/\text{cm}^3$  in silicon. Impurities play an important role in determining which state the carriers are in and the time decay of the nonequilibrium distribution. Electric fields have been shown to affect the population dynamics of the various phases.

#### Recent Publications:

1. V. Marrello, T. F. Lee, R. N. Silver, T. C. McGill, and J. W. Mayer, "Condensation of Injected Electrons and Holes in Germanium," *Phys. Rev. Letters* 31, No. 9, 593-594 (1973).

2. R. E. Hammond, V. Marrello, R. N. Silver, T. C. McGill, and J. W. Mayer, "Condensation of Injected Electrons and Holes in Silicon," *Solid State Comm.* 15, 251-253 (1974).

3. V. Marrello, P. B. Hammond, R. N. Silver, T. C. McGill, and J. W. Mayer, "Electron Hole Condensate Radiation from Ge Double Injection Devices Between 1.5° and 4.2°K," Phys. Letters 47A, 3, 237-238 (1974).

NR 372-035, Stanford University, "Control of Impurities in the Epitaxial Growth of High Quality GaAs," P.I. - Dr. David Stevenson, N00014-75-C-0887

The investigators will analyze the thermal-chemical reactions in a controlled growth system to determine the source of impurities, correlate the residual impurity with gas species, and modify the reactions accordingly. Two principal activities are to be undertaken: the development of liquid phase epitaxial growth techniques to control impurities; and the design and construction of a molecular beam-mass analyzer system to sample, at growth temperatures and atmospheric pressure, the gaseous environment involved in the chemical transport reactions during crystal growth. Progress: It has been shown that a major source of impurities in the growth of GaAs epitaxial layers arises from chemical transport reactions involving the protective gas atmosphere, container and crucible materials and growth ingredients. In growth studies, dramatic changes in layer properties occur for different pre-growth annealing conditions. The shallow and deep levels appear to be dependent on impurities that arise from chemical reactions between the growth system components. A model on the attachment at the liquid-solid interface has been developed that predicts that impurities are segregated at the boundaries of clusters of GaAs. Both n- and p-type layers were produced, depending upon the anneal. The design and construction of a molecular beam-mass analyzer is described that is capable of analyzing a gaseous system at high temperature and at atmospheric pressure.

#### Recent Publications:

B. L. Mattes, Yu-M. Hwang, and G. L. Pearson, "Growth and Properties of Semi-Insulating Epitaxial GaAs", J. Vac. Sci. and Technology 12, 869 (1975).

NR 372-055, Princeton University, "Compound Semiconductor Surfaces," P.I. - Dr. Peter Mark, N00014-75-C-0394

This program will carry out research on the microscopic surface and bulk properties of semiconductors that influence the formation of thin film overlayers and surface reaction kinetics. The effects of bulk doping and of surface crystallographic index and structure, surface composition and surface topography will be investigated. Analytical

tools will include low energy electron diffraction, Auger electron spectroscopy, scanning electron microscopy, conductivity modulation, and ellipsometric analysis. Progress: The systematic examination of the surface structure of various compound semiconductors was continued by a LEED examination of GaN surfaces. From a complete LEED symmetry analysis, it has been concluded that the non-polar surfaces terminated with an ideal surface unit mesh and that the final lattice plane spacing is within 1% of the ideal termination. This is in agreement with earlier similar work on  $\text{InP}$ , reported in this contract. The polar surfaces, in contrast, always terminate in a non-ideal fashion. They are either reconstructed, facet-covered or terminated with the incorrect rotational symmetry as if certain patches of the surface were wurtzite-connected and other patches were zincblende-connected. A systematic study of the effect of bonding ionicity on the kinetics of gas-solid interactions at ordered non-polar compound semiconductor surfaces has been begun and the initial results have been published. This work was stimulated by the earlier research which showed that oxygen uptake at ordered surfaces of  $\text{InP}$  and  $\text{InSb}$  was much slower than that reported in the literature for ordered surfaces of  $\text{Si}$ . It was also stimulated by the early work of Mead and collaborators which showed that bonding ionicity played a dominant role in Schottky barrier formation.

#### Recent Publications:

1. J. J. Chang and E. Mark, "Leed Analysis of the Ordered Non-Polar Surfaces of  $\text{InP}$ ", *J. Vac. Sci. Technol.* 11, 1061 (1974).
2. J. J. Chang and E. Mark, "Leed Analysis of the Polar Surfaces of  $\text{InP}$ ", *J. Vac. Sci. Technol.* 11, 1067 (1974).
3. E. H. Hefner Jr. and E. Mark, "High Temperature Growth of the  $\text{InP}$  and Metal-Insulator-Metal Structures," *J. Appl. Phys.* 45, 1177 (1974).
4. E. Hefner, J. J. Walmark and E. Mark, "Temperature and Time-Dependent Conductivity Effects in  $\text{InP}$  Surface Schottky Diodes," *J. Vac. Sci. Technol.* 11, 1070 (1974).
5. E. Mark and W. L. Schottky, "Chemical Control of Surface Properties at the Ordered Surfaces of  $\text{InP}$  and  $\text{InSb}$ ," *Proc. 1974 IEEE Conf. on Solid State Surface Sci.*, 1, 107 (1974).
6. E. Mark, J. J. Chang, and J. Walmark, *IEEE Trans. on Electron Devices*, "A Schottky Diode Structure for the Control of Surface Properties," *IEEE Trans. on Electron Devices*, 21, 1077 (1974).

NR 473-058, Brown University, "Transport Properties of InGaAs Solid Solutions at High Electric Fields," P.I. - Dr. Maurice Glicksman, N00014-75-C-0565

The investigator will measure the velocity-electric field characteristics of n-type samples of high quality solid solutions of InGaAs. Measurements will be made on material epitaxially grown on GaAs substrates, and having values of composition corresponding to x between 0 and 0.25. Initial studies will focus on the measurement of the characteristics using short pulse and microwave techniques. In later stages, the focus will be on the theoretical analysis of the data to determine the scattering parameters of the material. Progress: Preliminary measurements of InGaAs alloy samples indicate that the threshold field for Gunn effect increases with increasing InAs composition. Apparatus has been assembled for studying the microwave properties of the alloys.

NR 474-76, University of Texas, "The Synthesis of Useful Electronic Structures Using Solid-Solid Phase Reactions Near Surfaces," P.I. - Dr. Roger Kaiser, N00014-75-C-0916

Solid-solid surface reactions (solid phase epitaxy) may offer an important new method for realizing reasonably complex layered device structures with a minimum of processing complexity. The interfaces in these structures formed by this technique may be quite different than those formed by serial deposition from the gas phase or growth from a gas-solid interface. The difference in terms of impurities and lattice mismatches at the boundaries may have significant effects on device performance, reliability, life and repeatability of fabrication. The main objective of this study is to develop a specific set of thermodynamic and kinetic requirements for each useful type of electronic structure. This may involve an overall set of rules in terms of heats of formation, kinetic constants, etc., for thin film growth between two elements or compounds. In addition, the constraints implied by considering specific combinations of materials with radically different transport properties in a definite order may well allow us to be more specific in these rules or allow us to re-specify them in terms of substituting more readily available static thermodynamic constants in place of some kinetic parameters. Specific systems upon which this effort will concentrate are binary and ternary systems with layered structures of the form  $M_1p_1q_1$ ,  $M_2p_2q_2/M_1$ ,  $M_1M_2$ ,  $M_1p_1M_2$  and  $CM_1M_2$ , etc., where M refers to a metal and C to a semiconductor. The latter is of interest because it corresponds to the Si-metal binary systems for which experimental data currently exists and is being expanded by other groups. Progress: During the past year, a model for the first phase nucleated in a planar binary reaction couple has been

level paper submitted for publication. All experimental indications are that the state of lowest eutectic composition is of first order importance as an initial condition preceding the nucleation of the first crystalline phase. This eutectic region may be either a supercooled metastable state produced by the initial formation process or else it may indeed be the equilibrium phase for a narrow interfacial region. These have led to the conclusion that the first compound nucleated in planar binary reaction couples is the most stable congruently melting compound adjacent to the lowest temperature eutectic on the bulk equilibrium phase diagram. Preliminary analysis of the initial formation in binary reaction couples suggests that the stability of properly prepared interfaces, and subsequent nucleation phases, is dependent on the as-deposited concentration profile. The investigators propose that the lowest energy state of the interface system is possibly an amorphous binary solid with the lowest eutectic concentration. It is speculated that the stability of this interface is related to its width and new phases are nucleated at temperatures where large concentration fluctuations are generated by the onset of chemical reactions at the interface.

NR 372-077, California Institute of Technology, "Solid Phase Epitaxial Growth," P.I. - Dr. Marc Nicolet, N00014-75-C-0011

The broad objective of the program is to investigate the basic processes which control this form of epitaxial growth. It is proposed to study: (1) growth kinetics, (2) the role of the metal layer, (3) incorporation of dopant atoms, and (4) correlation with regrowth of implanted amorphous layers and consideration of other substrates such as Ge or GaAs. A second task will further investigate the metal-silicon interface and dissolution and growth reactions which take place at this interface. Measurements will be made on the velocities of dissolution and/or growth proceeding simultaneously in several crystal directions. A third, new task will investigate the effects of high dose rate and high dose effects on ion implantation on the growth of the epitaxial layers. Progress: During the last year, backscattering spectrometry and scanning electron microscopy (SEM) have been used to study the transport of Si from an amorphous Si layer ( $< 1 \mu\text{m}$ ) through a Pd-silicide layer onto  $\langle 100 \rangle$  oriented Si. For a given annealing temperature, two distinct stages of this process have been observed. The initial transient stage starts with island growth of Si and ends with a uniform layer of Si on the substrate. The thickness of the initial transient stage is found to be equal to the thickness of the Pd-silicide layer. The second stage of growth is characterized by a linear time dependence which is 3-10x slower than the transient stage. Auger electron spectroscopy has established that carbon is present in the Pd/Si and the amorphous Si layers, probably arising from the carbon crucible of the evaporation system. These carbon impurities may be related to the variations in growth rate observed between different runs. Nickel silicide gives rise to growth that is qualitatively similar to Pd/Si, with an inter-

transient stage is less distinct. Investigations of intentional doping of the grown layers has begun.

#### Recent Publications:

1. J. C. McCaldin, "Atom movements occurring at solid metal-semiconductor interfaces," *Journal Vacuum Science and Technology* 11, 990 (1974).
2. H. Muller, W. K. Chu, J. Gyulai, J. W. Mayer, T. W. Sigmon, and T. R. Cass, "Crystal orientation dependence of residual disorder in As-implanted Si," *Applied Physics Letters* 26, 292 (1975).
3. C. Canali, S. U. Campisan, S. S. Lau, Z. L. Liaw, and J. W. Mayer, "Solid-phase epitaxial growth of Si through palladium-silicide layers," *Journal of Applied Physics* 46, 2831 (1975).
4. J. E. Best and J. C. McCaldin, "Si-Al Interface Shapes Developed during heating of integrated circuits," *Journal of Applied Physics* 46, 4071 (1975).

NR 372-087, Naval Surface Weapons Center, "High Field Transport in Ternary Alloy Semiconductors," P.I. - Dr. Gary Carver

This program will study the transport properties of the semiconducting alloy system (Pb, Sn) Te in strong electric fields. This material is finding extensive application in 8-14 micrometer wavelength range imaging devices, but little is known about the transport properties. The thrust of the effort will be to determine the saturated drift velocity and investigate whether dynamic instabilities, related to bulk negative differential conductivity, may be initiated in this alloy system. Phenomenologically, the  $Pb_{1-x}Sn_xTe$  alloys are a rich system. The multi-valley band structure, the evidence for subsidiary minima in both the conduction and valence bands, and the possibility of strong nonlinear properties due to electric field dependent phonon scattering interactions all point toward fertile ground for new physics or improved devices. Progress: The electron velocity as a function of electric field has been measured in several samples of n-PbTe and the saturated value was found to be somewhere between  $1$  and  $3 \times 10^7$  cm/sec at 77°K. The effects of contacts are non-negligible and are being studied to reduce the uncertainty. Preliminary observations of high-field domain formation has occurred in samples of PbTe and BiTe. The domains propagate with a velocity near to  $2 \times 10^7$  cm/sec. The domains appear to be several hundred micrometers in length, form near the cathode, and decay as they travel toward the anode.

NR 372-095, Colorado State University, "Compound Semiconductor Surfaces and Interfaces," P.I. - Dr. Carl Wilmsen, N00014-76-C-0387

Insulators on InP, InSb, and InAs will be investigated for their electrical and mechanical properties and for low surface state densities. Several analytical techniques, such as Auger electron spectroscopy, ESCA, capacitance-voltage, and capacitance-conductance measurements will be utilized to study the interface properties to obtain a correlation between surface state properties and chemical composition. Theoretical calculations of surface oxidation energies as a function of position and coverage will also be carried out. Initial studies will focus on a double layer insulator with an anodic oxide overlaid with a sputtered oxide, such as silicon dioxide.

Progress: New

NR 372-096, Naval Research Laboratory, "Solid Phase Epitaxial Studies Using Molecular Beam Deposition Techniques," P.I. - Dr. John Davey

Solid-solid surface reactions (solid phase epitaxy) may offer an important new method for realizing reasonably complex layered device structures with a minimum of processing complexity. ONR has recently begun a coordinated program to investigate the physical properties of these interactions in several universities and industry. While striking recrystallization effects have been seen, evaporation of the amorphous silicon has disadvantages. Similarly, growth of single crystal silicon by molecular beam epitaxy (vacuum evaporation) at low temperatures has been singularly unsuccessful. Preliminary studies at NRL indicate that by placing a metal layer on the silicon substrate and heating to 600 C during evaporation, thus combining solid-phase-epitaxy with molecular beam epitaxy, single crystal silicon can be grown, a result that could be an important stride forward in semiconductor technology. This program will continue these investigations. Progress: New

NR 372-097, Yeshiva University, "Piezo-Optical Determination of Deformation Potentials in Multi-Valleyed Semiconductors," P.I. - Dr. Fred Pollak, N00014-76-C-0481

An investigation of the stress-dependence of the optical absorption will be carried out in several III-V semiconductors. Wavelength modulated transmission and reflection will be utilized to measure both indirect and direct transitions from valence to conduction band. From the transition rates and the scattering processes, the absolute values for the electron-phonon and hole-phonon deformation potentials for intervalley processes can be determined. In progress: New

NR 44-187, Yale University, "Investigation of Electron-Phonon Interactions by Resonance Raman Scattering," F.I. - Dr. Richard Zhang, N00014-76-D-0643

A number of intervalley scattering mechanisms are important in the transport properties of multi-valley semiconductors. A knowledge of these parameters would assist in the evaluation of various semiconductor materials for applications in new semiconductor devices. Unfortunately, the only information on these parameters, is often inferred from the transport calculations themselves. This program will attempt to determine these parameters through a resonant Raman technique. Resonant one-phonon and multiphonon interactions will be used to provide data on the electron-phonon coupling strengths for interband transitions between non-equivalent conduction band minima, for intervalley transitions between conduction band minima, for electron one-phonon interactions at the conduction and valence band maxima, and for electron two-phonon interactions at these maxima. Progress: New

NR 44-243, California Institute of Technology, "Solid State Electronic Devices," F.I. - Dr. Carver A. Mead, N00014-76-D-0467

This research investigates the optimization, capable from large scale integrated circuit technology, of new architectures for microprocessor - programmable microprocessors. An integrated circuit programmable microprocessor of unique architecture and unusual capability is being fabricated. This system is based upon a distributed mode of function for the various activities of computation and control. Progress: The arithmetic-logic module has been completed and operated perfectly in the first mask set. This device gives the machine all of the normal logical, arithmetical, and general purpose operations. The data memory control chip has also been made operational.

NR 44-266, University of Pennsylvania, "Crystal Mismatch in Hetero-luminescent Materials," F.I. - Dr. Campbell Laird, N00014-76-D-0467

Epitaxial films of GaAs, InGa, and InAlP will be grown on substrates of GaAs, GaP, and InP, respectively, both in step and graded heterojunction geometries. Observation slices will be prepared for study by electron microscopy of the quality and crystalline characteristics of the films. Of particular interest is dislocations due to strain arising from a change of the substrate-epitaxial layer interface with the studies of the formation and behavior of the dislocations to be carried out with the aim of controlling their density. Progress: The mismatch dislocation structures in conventionally oriented (001) GaAs and InGaAs heterojunctions were studied by TEM, X-ray diffraction, stress-induced birefringence and dislocation etching. It is concluded that elimination of the desirable defect structures in current devices

devices by modification of fabrication procedures is going to be difficult. Instead, orientations of  $(11\bar{2})$  and  $(11\bar{2})$  are suggested. In the former, two slip systems on the same plane are most highly stressed, consequently little work-hardening should be experienced by the dislocations gliding in to compensate the misfit and the compensation should be rather complete. The second orientation makes use of two highly work-hardening systems, where the Burgers vectors compensate very inefficiently, so that they interact to give dislocations with efficient compensation and potentially benign effects on electrical properties.

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6. C. C. Tseng, W. T. Tsang, and S. Wang, "A Thin-Film Prism as a Beam Separator for Multimode Guided Waves in Integrated Circuits," Optics Commun., Vol. 14, pp. 441-444, March (1975).

7. W. T. Tsang, C. C. Tseng, and S. Wang, "Optical Waveguides Fabricated by Preferential Etching," Appl. Optics, Vol. 14, pp. 1400-1404, May (1975).

8. W. T. Tsang and S. Wang, "Preferentially Etched Diffraction Gratings in Silicon," J. Appl. Phys., Vol. 46, pp. 2107-2110, May (1975).

9. C. C. Tseng and S. Wang, "Integrated Grating-Type Semiconductor Barrier Photoresistor with Optical Channel Waveguide," Appl. Phys. Lett., Vol. 26, pp. 632-634, June 1 (1975).

10. C. C. Tseng, D. Botz, and S. Wang, "Optical Lens and Mirror Fabricated by Preferential Etching," Appl. Phys. Lett., Vol. 26, pp. 699-701, June 15 (1975).

11. W. T. Tsang and S. Wang, "Experimental Studies of Photoresist Gratings," Wave Electronics, Vol. 1, pp. 74-94, July (1975).

NS 009-007, Polytechnic Institute of New York, "Light Beam Coupler for Integrated Optical Circuits," P.I. - Dr. Theo Tamir, N00014-75-C-0401

Optical waveguides which leak energy (but do not dissipate it by absorption or scattering) are adapted as couplers between integrated circuit elements or as beam formers. Changes in guide thickness or modulated grating structures are studied as the mechanism to produce the desired beam behavior. Progress: The perturbation approach has been highly successful in providing highly accurate results for the analysis of wave phenomena on dielectric gratings. The work and results obtained during the past half-year period include the formulation of solutions for treating TM-mode problems, which are more complicated than those of TE modes discussed in the past, the development of equivalent networks, which greatly facilitate the understanding of the physical mechanism involved in the guiding and scattering of waves by dielectric gratings, the derivation of leaky-wave dispersion curves for use in beam-coupler applications, and the development of systematic criteria for the design of dielectric gratings having desirable physical characteristics.

#### Recent Publications:

1. S. T. Peng and T. Tamir, "Directional Flaring of Waves Guided by Asymmetric Dielectric Gratings," Optics Commun., Vol. 11, pp. 401-409, August 1974.

2. A. Saad, H. L. Bertoni and T. Tamir, "Beam Scattering by Nonuniform Leaky-Wave Structures," Proc. IEEE, Vol. 62, (Special Issue on Rays and Beams), pp. 1552-1561; November 1974.
3. S. T. Peng and T. Tamir, "Effect of Groove Profile on the Performance of Dielectric Grating Couplers," Proc. Symp. Optical and Acoustical Micro-Electronics, Polytechnic Press, pp. 377-392, 1975.
4. S. T. Peng, T. Tamir and H. L. Bertoni, "Theory of Periodic Dielectric Waveguides", IEEE Trans. Microwave Theory and Techniques (Special Issue on Integrated Optics and Optical Waveguides), Vol. MTT-23, pp. 123-133; January 1975.
5. K. Handa, S. T. Peng and T. Tamir, "Improved Perturbation Analysis of Dielectric Gratings", Appl. Physics, Vol. 5, pp. 325-328; January 1975.
6. S. T. Peng and T. Tamir, "TM-Mode Perturbation Analysis of Dielectric Gratings", App. Phys., Vol. 6, pp. 35-38, May 1975.
7. T. Tamir (Editor), "Integrated Optics", Springer-Verlag, New York, Heidelberg, Berlin; 1975.

NR 009-017, Rensselaer Polytechnic Institute, "Optical Real Time Signal Processors Using Surface Rayleigh Waves," P.I. - Dr. Pankaj Das, N00014-75-C-0772

The interaction of acoustic surface waves and integrated optical waves will be studied for signal processor applications. Two acoustic surface waves can be correlated through the acousto-optic interaction with the correlation signal appearing in the diffracted optical signal. The application of this to correlators, modulators, and filters will be investigated. The use of acoustic surface waves for determining the surface properties of semiconductors will be investigated. Progress: Signal processing functions such as convolution correlation, and Fourier transform have been obtained in real-time using the efficient diffraction of laser light from acoustic surface waves propagating on lithium niobate. Different device configurations and detection schemes have been considered. Results were found for the usual delay-line transducer configuration, as well as for an improved scheme which eliminates the problem of the reflection signal. A discussion was given indicating the extension of the acoustooptical convolver to the generation of ambiguity functions and the correlation of a light amplitude distribution with an acoustic signal.

## Recent Publications:

1. P. Das, M. E. Motamedi, and R. T. Webster, "Determination of Semiconductor Surface Properties Using Surface Acoustic Waves", Applied Physics Letters 27, 120 (1975).
2. H. Bilboa, M. E. Motamedi, and P. Das, "Study of GaAs Epitaxial Layer Using the Separated Medium Acoustoelectric Effect", in Proc. 1975 Ultrasonics Symposium.
3. M. E. Motamedi, R. T. Webster, and P. Das, "Application of SAW Delay Line Attenuation and Transverse Acoustoelectric Voltage for Determination of Semiconductor Surface Properties", in Proceedings 1975 Ultrasonics Symposium.
4. H. Gilboa, M. E. Motamedi, and P. Das, "Determination of Energy Band and Surface State Locations in GaAs Using the Separated Medium Surface Acoustoelectric Effect", Applied Physics Letters 27, 641 (1975).

NR 009-018, University of Texas, "Multiple and/or Inhomogeneous Layers for Integrated Optical Coupling and Modulation," P.I. - Dr. Bruce Buckman, N00014-75-C-0753

Large, permanent refractive index changes are obtainable in  $\text{PbI}_2$  films in the red and infrared portions of the spectrum when these films are subjected to 488 nm Ar laser radiation at film temperature around 165 celsius. Several novel coupling and modulation devices, which are feasible only when a refractive index grating formation mechanism such as this is possible, will be investigated analytically and evaluated experimentally. Progress: A matrix method for calculating the effective refractive index of guided modes on multilayer dielectric waveguides was developed and employed to calculate the effective electrooptic coefficient of such waveguide structures when one of the media composing them is electrooptic. In properly specified three-layer waveguides, enhancement of the effective electrooptic coefficient above the bulk value by as much as a factor equal to the square of the highest refractive index in the structure is possible. The maximum modulation enhancement is attainable with loosely, as well as tightly, confined waveguide modes.

## Recent Publications:

1. A. B. Buckman and N. H. Hong, "Large Refractive-Index Change in  $\text{PbI}_2$  Films by Photolysis at 150-1800", Journal of the Optical Society of America 65, 914 (1979).

BB 0.1-2-03, "Electronic International", (M. W. Yeager, Ed) 69-1.

BB 0.1-2-04, University of Northern California, "Gallium Nitride  
Review", I.I. - Professor Murray Gershenzon, N° 0.1-2-04-1.

This work is directed toward the growth and characterization of  
microwave grade gallium nitride substrates and epitaxial films for  
eventual application to solid state high power amplifiers. Progress:  
Gallium nitride material has been grown to thicknesses of 1 cm.  
Intrinsic donor conductivity of approximately  $1 \text{ ohm}^{-1} \text{ cm}^{-1}$   
results from native nitrogen vacancies.

Recent Publications:

1. Progress Report - March 1969 - "Evaluation of Gallium Nitride  
for Active Microwave Devices", M. Gershenzon.

2. Progress Report - April 1969 - "Evaluation of Gallium Nitride  
for Active Microwave Devices", M. Gershenzon.

BB 0.1-2-05, North Carolina State University, "Monte Carlo Simulation  
for Superconductivity Semiconductors", I.I. - Assoc. Prof. W. A. Little, III,  
DD0001276-0-00000.

This work seeks to bypass the expensive and time consuming method of  
synthesizing new semiconductor materials to determine their properties  
and applicability to electronic devices. Instead, predictions of the  
charge transport characteristics are predicted (by Monte Carlo computer  
simulation) from known material properties and band structure. When  
fundamental properties are not precisely known, estimates are derived  
from materials of similar structure and confidence bands are attached  
to the results. Progress: Monte Carlo methods and computer programs  
have been derived to simulate not only the high field, low mobility  
transport conditions, but the low field, higher mobility conditions as  
well. The programs have been calibrated (tested against experimental  
results for such materials as Ge, Si, GaAs and InSb). Simulations have  
been made for various mole fraction ratios of solid solutions.

Recent Publications:

1. Annual Progress Report dated September 1975 -- "Theoretical Search for Super-Velocity Semiconductors", M. A. Littlejohn and J. R. Hauser.
2. M. A. Littlejohn, J. R. Hauser, T. H. Glisson, "Monte Carlo Calculation of the Velocity-Field Relationship for Gallium Nitride", Applied Phys. Letters.
3. J. E. Andrews and M. A. Littlejohn, "Growth of GaN Thin Films from Triethylgallium Monamine", Journal of Electrochemical Society.
4. J. E. Andrews and M. A. Littlejohn, "Mass Spectroscopic Analysis of GaN Films", (A write-up).

SOLID STATE ELECTRONICS

NA 001-04-01, JOHN STATE ELECTRONICS, (L. E. Cooper, POP 00-4-14)

NA 001-000, North Carolina State University, "Electrical Properties of Ion Implanted Gallium Arsenide", I.I. - M. Littlejohn, H00010-00-1-000

The phenomena associated with the process of ion implanting gallium arsenide (GaAs) with impurities are not understood. The effects of implantation induced structural formations have not been assessed. The investigator will use techniques such as transmission electron microscopy (TEM), Auger electron spectroscopy (AES), photoluminescence, and various electrical measurement techniques to characterize the properties of implanted layers in GaAs. Sulfur, beryllium, magnesium, boron, and zinc will be implanted under various conditions of temperature and fluence. Several protecting encapsulating layers will be applied and annealing cycles carried out. Resulting structural information from TEM will be correlated with chemical data (AES) and with the electrical measurement data. Progress: Measurements have shown that a second phase metallurgical structure is formed in the Zn implanted gallium arsenide after annealing. One of these structures is a layer, which has a crystal structure (body centered tetragonal) after anneal that differs from the gallium arsenide matrix. Adjacent to this structure and extending throughout the implanted region is a precipitate of the same anomalous structure. Results show the problem of second phase growth to be further complicated by effects attributed to the type of oxide passivation for annealing. Thus spin-on and pyrolytic silicon dioxides result in different phase formations. In addition, different annealing temperatures, whether 600°C or 800°C result in a variety of results. The zinc implants were at a fairly high dose, such that solubility limits were exceeded in some cases. This would lead to different phase growths. Also, it complicated the interpretation of electrical measurements, since the Hall coefficient measurements can only be correlated with the average defect population, including buried sites as well as precipitate formation.

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beryllium, magnesium, and tellurium ions have been implanted and studied with transmission electron microscopy (TEM). The defect structures which remain after annealing are different in every case, both in size and density. Further, electrical measurements give rise to different mobility versus temperature curves for each sample. A preliminary observation has been made that the higher the defect density the higher the electrical activity. A "first try" model for the electron transport suggests that both ionized impurity and non-homogeneous defect space charge scattering mechanisms are contributing. Other mechanisms will be added to try to model the transport characteristics. The defects vary in size and seem to be dislocation loops, vacancy clusters, or interstitial clusters. Techniques are being developed to provide better identification of these.

#### Report Bibliography:

1. Benson, Littlejohn, Rao, and Jarin, "Some Recent Phase Structures in Gallium Arsenide Annealed After Implantation with Zinc", *Applied Physics Letters*, 27, 69 (1975).

NA 44-004, United Technologies Laboratories, "Effects of Contacts and Inhibit on Semiconductor Microwave Devices", R.F. - H. Bradin, NA 44-004-00337

A theoretical modeling program has been developed to simulate phenomena in transferred electron devices such as Gunn effect devices and Field Effect Transistors (FET). It has been shown previously that static field models of such devices are inadequate to explain many of the phenomenological results. The investigator, with others, has developed a "dynamic Cathode Boundary Field" model which simulates changing field conditions at the cathode. This model has been successful in explaining many device features. The model will be applied to three terminal (FET) devices to determine effects of time varying cathode conditions, of regions of negative differential mobility under the gate contact, of various contact properties (barrier heights, etc.) and of external circuit parameters. Parameters will be explored which are pertinent to device experiments at the Naval Research Laboratory. Transferred electron microwave devices are finding increased usage in electronic microwave systems both as amplifiers and for sources. Primarily gallium arsenide is used, but indium phosphide is finding wider application due to its predicted higher efficiency. However, the device parameters which yield higher efficiency in gallium arsenide are not the same as those which yield higher efficiency in indium phosphide. In addition, contact conditions which give high efficiency in indium phosphide devices apparently give poor performance in gallium arsenide devices. In general, the investigator has shown that the carrier field dependence which leads to high or low efficiency is different for GaAs and InP transferred electron devices, and is not the same.

1. N. I. Grubin, "Transferrel-Electronic Devices with Impure Semiconductor in the Contacts", a review, report # 80-01491-1, "Applied Science".

in wave action, which may also cause the generation of  
 differential amplification (DMA), are very sensitive to effect  
 of the input signal interaction. These effects have been  
 studied in the laboratory for many years experimentally and the  
 results have been used in the design of equivalent circuits, and  
 in the design of a transfer function for an advanced transfer function  
 of the material. Disturbances can be generated by the material  
 and the material but the effect is very sensitive to the input  
 signal. The effect of the growth and propagation of the signal  
 is a function of the input signal and the response will be a function  
 of the input signal as well as the ultimate output frequency limit of the  
 material. A variety of techniques will be applied to determine the  
 parameters which affect the input signal and the output  
 performance. The input and output signal will be  
 measured for a variety of conditions including applied magnetic  
 and pressure fields. This program is an excellent candidate for  
 research in higher frequency ranges.

Program: New

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system grown on GaAs substrates. Materials to be considered include InGaAs, InGaIn, and InAlAs, all grown by liquid phase epitaxy (LPE). Electron transport properties in the FET geometry as well as the heterojunction diode mode will be investigated. It is well known that the physical and electronic properties of heterojunctions are not well understood. In view of the complexity of the interface, as indicated by the previous research, it is apparent that much needs to be done in these systems. The ternary alloy semiconductors are of interest for several reasons: they have variable bandgap energies, and lattice constants (varying with alloy content); it has been suggested that they may have high saturated drift velocities needed for high frequency devices. The variable lattice constants allow for easier lattice match problems in heterojunctions as with

Recent publications:

1. R. J. Lawrence and L. P. Barman, "Electric-Current-Controlled Liquid Phase Epitaxial Growth of GaAs", presented at IEEE Workshop on Compound Semiconductor Microwave Devices Held at Philadelphia.

DA-AR-693, Naval Research Laboratory, "Study of Oxide Charge in Thermal Silicon Dioxide", R.I. - V. Baker, DA-AR-69-693.

Silicon electronic device technology requires many stages of chemical processing and material growth. Central to this is the formation of silicon dioxide insulator layers for such things as VLSI transistors, and for passivation to isolate components and interconnections in multielement chips. Serious problems are associated with the presence of fixed electric charge in the oxide layers. Reliability, lifetime, yield and cost, and radiation vulnerability are affected by the properties of the oxide. Reliability, for instance, is tested-in and built-in. In the present cycle, thus escalating a spirally large factors. The intent of this task is to provide knowledge which should lead to solutions to these problems. Current manufacturing approaches are very empirical. Using electrical, physical, and chemical, and measurements combined with theoretical modeling, various aspects of the origin or cause of the charge which appears in the oxide films will be studied. Questions such as the following will be attacked: what parameters associated with device fabrication and processing techniques affect the oxide charge? What factors affect the lateral (along the surface) homogeneity of charge or oxide properties? What impurities in the oxide are related to the charge problem? What mechanism, if any, permits chlorine or any other impurity to exacerbate the problem? What is the role of mobile sodium ions in affecting the charge and why does sodium cluster near the silicon-silicon dioxide interface? Progress: New

Recent publications: None

<sup>a</sup> The number of subjects who were included in each group was determined by the number of subjects who completed the study.

1. *Chlorophyll a* and *Chlorophyll b* were determined by the method of Lichtenthaler and Whistler (1973). The total chlorophyll content was determined by the method of Arar and Cook (1980). The carotenoid content was determined by the method of Lichtenthaler and Whistler (1973).

new techniques and devices for generating and controlling optical radiation with simple, reproducible, inexpensive materials and technology. The term integrated optics (I.O.) for optical circuitry technology is analogous to the way that integrated circuitry is used to identify the electronic processes in semiconductor electronics. The investigator is pushing the I.O. frontier by studying quantum electronic phenomena in thin film reviews of GaAs and GaAlAs which would be compatible with integrated optics technology of the future. In particular, he is continuing to develop a device called a distributed feedback laser which makes use of a periodic spatial modulation of the interface between two materials to produce the radiation necessary for stimulating laser action. The materials are GaAs and GaAlAs used in several structures, where the GaAs acts as a waveguide and the GaAlAs provides a boundary with a variable coefficient of refraction (depending on the relative amounts of gallium and aluminum). The advantages are the following, - laser action without close tolerance mirrors in the laser cavity, possibility for mode control (enhance the optimum mode) of both longitudinal and transverse types, large reductions in threshold current density, better temperature response, materials are compatible with advanced GaAs technology, and laser operates in a wavelength region of small absorption. Progress: The investigator has studied theoretically and experimentally various injection laser structures in gallium arsenide and gallium aluminum arsenide. He will investigate the properties of distributed feedback lasers by preparing devices with surface corrugations having 0.1 micron spatial separation. A new technique of embedded heterostructure epitaxy will be developed to evaluate its usefulness in fabricating channel lasers. The distributed feedback lasers will be studied with emphasis on mode control wavelength stability. Reduction of threshold current density will be investigated in these structures.

#### Recent Publications:

1. Gover, A., Burrell, K., and Yariv, A., "Solid-State Travelling-Wave Amplification in the Collisionless Regime," *Journal of Applied Physics*, 48, 4347, (1974).
2. Yariv, A. and Gover, A., "Equivalence of the Coupled-Mode and Floquet-Bloch Formalisms in Periodic Optical Waveguides", *Applied Physics Letters*, 26, 537 (1975).

DB 44-24, University of California at Berkeley, "Millimeter Wave Maser Amplifiers", P.I. - C. Townes, N00014-74-C-0070

This study is directed toward the evolution of travelling wave type of masers, with particular emphasis given to characteristics of travelling dispersive structure elements in the maser cavity. Noise figures, tunability and sensitivity of masers operating in the 1.3 to 3 millimeter wavelength region are determined. Improvements to increase performance and to decrease size and complexity are being investigated. Development of a superconducting slow-wave structure will be accomplished to attain lower losses and hence high gain, lower pump power, and shorter wavelength. Progress: The reduction in system noise to very low figures has permitted measurements on interstellar and galactic sources not possible previously; i.e., more sensitivity and shorter observing times. They have increased the tunability around the 25 GHz central frequency to about 10%. They are developing a superconducting slow wave structure with reduced circuit losses. The slow wave structure permits greater amplification and thus smaller systems. There has now been long term operation of maser amplifiers operated in conjunction with the 36 foot antenna at the Hat Creek Observatory of the University of California and with the 85 foot antenna of the Naval Research Laboratory. There have been continuing improvements in these maser systems to increase tunability and bandwidth to reduce system noise, and some simplifications and reduction in size. Some design work is being done to produce two high stability masers for use in a spatial interferometer system for twin antennas at Hat Creek Observatory. A technique for using a slow wave superconducting structure has been demonstrated and is being incorporated into a maser amplifier. There have been many observations, using the extremely low noise amplifiers, of interstellar and galactic sources showing the abundances of a variety of molecular systems.

#### Recent Publications:

1. J. A. Mango, E. J. Johnston, M. F. Chui, A. C. Cheung, and P. Matsakis, "Molecule Searches in Comet Kohoutek (1973F) at Microwave Frequencies", *Icarus* 23, 590-594, 1974.
2. M. Bertolo, M. F. Chui, and C. H. Townes, "Isotopic Abundances and Their Variations within the Galaxy", *SCIENCE*, Vol. 184, 619-621, 1974.

W. L. - 12, "Irradiation Defects", *Phys. Rev.*, **171**, 1000-1001 (1968).

W. L. - 14, State University of New York - Albany, "Defects in Semiconductors", *Phys. Rev.* - **171**, 1000-1001 (1968).

The study of defects in semiconductors considers the defects produced by ionizing radiation and by implantation of impurity ions. There are three correlated aspects to this study: (1) the measurement of silicon and diamond which have been irradiated by electrons and neutrons or have been implanted with a variety of impurity ions; (2) Correlated EPR-pulse response and EPR-transient experiments; techniques are used to identify defects and determine energy levels and carrier capture cross sections; (3) Use of radioactive tracer techniques to survey a variety of impurities (including various sites to test predictions for ionization enhance, diffusion mechanisms in silicon, germanium, and gallium arsenide. This program will identify the radiation and impurity induced defects in semiconductors which are identified by EPR, optical and electrical measurements in silicon, diamond, and gallium arsenide. Progress: Diffusion equations have been developed for a variety of enhanced diffusion mechanisms for the Hamoni-type lattice. Experimental results indicate no enhanced diffusion of gold in silicon. No spectrum of ion implanted diamonds are not found in electron and neutron irradiated diamonds. Free and bound holes have been identified with the EPR spectra of laser doped diamonds. Theoretical calculations have shown that the self-interstitial in silicon is likely to be in a split interstitial configuration. Recent calculations which allow for Jahn-Teller distortions show that relaxation of various bands does not affect the split interstitial configuration.

#### Recent Publications:

1. "An orientation-dependent defect in ion-implanted silicon", by F. Lee, R. Grosjean and J. Corbett, *Physica Letters*, Vol. 404, **1**, 1-2, 31 Oct. 1973.

2. "Study of the Principal  $\alpha$  Values of Deep Impurity and Ionization Induced Defects in Silicon and Diamond", by F. V. Corbett and J. W. Corbett, *Physica Letters*, State University of New York, 1973--Crystal Lattice Defects, Vol. 3, pp 101-107.





from metal films deposited on crystalline semiconductor. A major part is concerned with the regrowth process which occurs in silicon and germanium single crystals which follows the damage produced in ion implantation. The regrowth kinetics, rates, repeat effects, etc., will be studied for electrically active impurities, and for isoelectronic elements. The investigator has demonstrated the solid phase epitaxial growth process using palladium silicide as a transport media to deposit silicon atoms onto a single crystal silicon substrate. Temperature were below 1000°C. He demonstrated the very strong crystal orientation dependence of the annealing of residual damage after ion implantation of silicon. The crystal orientation does not result in complete annealing and the test results require complex temperature treatment. It is proposed that the reason for lower residual damage in <110> and <112> oriented substrates is a result of faster regrowth rates in these directions which overcomes the competing mechanism of polycrystallite formation.

#### Recent Publications:

1. "Backscattering Spectrometry," J. W. Mayer, M. A. Nicolet, and W. E. Chu, *J. Vac. Sci. Technol.* 1, 89 (1977).
2. "Crystal Orientation Dependence of Residual Damage in Si Deposited Si," B. Muller, W. E. Chu, J. Gyulai, J. W. Mayer, J. W. Nigam and T. K. Pong, *Appl. Phys. Lett.* 26, 19 (1975).
3. "Solid Phase Epitaxial Growth of Si Through Palladium Silicide Layers," B. Jurek, J. M. Chantrel, J. J. Lee, L. L. Hsieh and J. W. Mayer, presented at the Electrochemical Society Meeting, Denver, May 21-25, 1976, *J. Appl. Phys.* 47, 2001 (1976).
4. "Materials Analysis by Nuclear Backscattering: Applications," J. W. Mayer and L. M. Filbrich, in *New Uses of Low Energy Accelerators*, Ed. J. V. Stiegler (Plenum Press, New York, 1976), Chapter 23, p. 1-17.
5. "Energy Straggling of  $^4\text{He}$  Ions below 1 MeV in Al, Si and Ge," J. M. Harris and M. A. Nicolet, *Phys. Rev.* B11, 1415 (1975).
6. "Energy Straggling of  $^4\text{He}$  Ions below 1 MeV in Al, Si, Ge and Ga," J. M. Harris and M. A. Nicolet, presented at the 1976 National Vacuum Symposium, Anaheim, October 9-11, 1976, *J. Vac. Sci. Technol.* 1, 214 (1976).
7. "Magnetoelectric Properties of Magnetically Thin Films," J. J. Lee, T. K. Pong, B. J. Jurek and M. A. Nicolet, *J. Phys. Chem.* 80, 1000 (1976).

1. "Energy Loss of  $10^4 - 10^5$  MeV Electrons in Solids," R. W. Fink, *J. Appl. Phys.*, 41, 444 (1970).

2. "Surface Analysis Using Nuclear Instruments," J. H. W. Lee, in New Uses of Low Energy Accelerators, R. W. Fink, Editor (Plenum Press, New York, 1971), Chapter 1, p. 1.

3. R. W. Fink, Stanford University, "Study of Low Energy Electrons on Surfaces Using Photoemission Spectroscopy", *Rev. Sci. Instrum.*, 42, 151-152 (1971).

This task will study the fundamental electronic structure of the surfaces of III-V semiconductors, using ultraviolet photoemission spectroscopy, which investigates the filled electronic states of a near surface. The electronic properties of clean surfaces, covered with adsorbates, or surfaces covered with metals, will be determined. These results will be correlated with measurements of chemical shifts from photoemitted electrons and from x-ray induced photoemitted electrons. These measurements provide data on the fundamental chemical and physical interactions occurring at the surface. Comparing this data with the current models and study is an important surface problem. This approach is more rational and effective than the empirical approaches currently used in technology areas. Progress connected with this proposal is the availability of the synchrotron radiation facility at Stanford. Only the high intensity, high resolution, continuous frequency spectrum, ultra high vacuum capability make these experiments feasible. Progress: x-ray studies of gallium arsenide (110) surfaces indicated two phases of chemical reactions: 1) a bonding of oxygen to surface arsenic at an initial "one-half" monolayer of coverage; 2) A second or different chemical bonding of arsenic coincident with beginning of a gallium - oxygen reaction. Definite evidence for different oxidation rates on p and n type gallium arsenide surfaces has been found. It has been shown how useful the synchrotron radiation source can be for these studies, by varying the photon energy, the regions of the surface or subsurface can be probed, since the escape depth (sampling depth) varied with energy. Further, a strong dependence of the oxidation of gallium arsenide on photon energy indicated on other useful properties of synchrotron studies.

Recent Publications:

1. "Surface and Interface Electronic Properties of Gallium Arsenide III-V Semiconductors", R. W. Fink and J. H. W. Lee, *Rev. Sci. Instrum.*, 42, 151-152 (1971).

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Hall measurements, C-V, I-V measurements, and others. Additional studies will be made on structures formed after an amorphous silicon layer is deposited over the metal prior to the annealing. Different forms of amorphous silicon will be studied. Polysilicon will also be considered. Progress: Epitaxial silicon layers have been grown on silicon substrates by the solid phase epitaxial growth process. All steps in the preparation, deposition, and growth processes have been accomplished in an ultra high vacuum system to avoid contaminant interactions. The crystal silicon-palladium film-amorphous silicon system was used. Measurements show that palladium is incorporated in the epitaxial layer after growth, the amount depending on the substrate orientation. Further, in the silicide formation stage the  $\text{Pd}_3\text{Si}$  layer on Si(111) is more strongly oriented to the substrate than  $\text{Pd}_3\text{Si}$  on the Si(100) face. Low temperature, slow growth rate, solid phase epitaxy offers great promise for making ultra thin electrically active layers with sharp interfaces. The impact on device technology could be very great. There is expectation that these studies will also contribute to understanding of other related problems in device technology, such as, metallization processes, silicide formation, and aging effects or both.

Recent Publications: None

NA 332-059, University of Illinois, "Ion Implantation of Gallium Arsenide", P. I. - E. Streetman, N00014-76-C-

The properties of gallium arsenide (GaAs) implanted with various dopant impurities will be studied. Many unknowns will be investigated such as, the effects of radiation damage induced by the ion bombardment, the processes by which the dopant atoms become electrically active in the semiconductor, the effects of various surface encapsulating films which prevent GaAs surface degradation during heat treatment, the determination of the spatial location of impurities before and after annealing (with special attention to enhanced diffusion effects), the correlation of resultant optical and electrical properties with implantation conditions, and the study of impurity and defect centers generated by the processing. Beryllium and sulfur impurity spatial profiles will be determined by use of mass analysis, electron spectroscopy (Auger), and the Glow Discharge Optical Spectroscopy techniques. Various electrical measurements will be made on samples fabricated into device configurations. Photoluminescence measurements will be used to investigate defect and impurity centers. This task is closely coordinated with other Navy lateral cry programs and provides a unique complement to these efforts.

Progress: New

Recent Publications: None

DA-21-61, University of Massachusetts, "Defects in Semiconductors".  
 DA-21-61, University of Massachusetts, "Defects in Semiconductors".

Extensive efforts are underway at several laboratories supported by DA-21-61, to develop semi-insulating GaAs substrates for electronic devices. The conditions which result in this material are not understood. Sometimes such materials are obtained, but mostly they are not. The main concept involves the use of chromium and/or oxygen impurities to generate the background donor contribution to provide high resistivity. How this compensation occurs, whether or not oxygen alone is responsible, whether oxygen forms complexes with chromium, whether or not lattice vacancies are involved, and what are the energy levels for these impurities, are all questions which have no answers. Other impurity and defect problems are found in the formulation and efficiency of GaAs lasers, where non-radiative recombination processes are associated with defects and dislocations. An associated problem is that of producing or understanding low defect GaAs by ion implantation.

At the University of Massachusetts experimental and theoretical studies will be made on the effects of impurities on the electrical and optical properties of gallium arsenide (GaAs). True ionization energies, carrier cross sections, and photoionization cross-sections of chromium and oxygen impurities will be determined as a function of temperature. The capture cross sections will be determined as a function of electric field because of the importance to device configurations where high electric fields are prevalent. Theoretical calculations will be made using a pseudopotential potential as a modification to a multiband effective mass approximation for chromium and oxygen impurities in GaAs. Temperature dependence and lattice relaxation effects will be taken into account. The same techniques will be applied to the study of radiation in damage produced by light ion bombardment of GaAs. Annealing studies will be undertaken.

Progress: New

Recent Publications: None

DA-21-61, National Bureau of Standards, "Structural Determination of Solid Surfaces", F.I. - D. Pierce, NBSG-76-7-

A spin polarized electron source will be incorporated into a low energy electron diffraction (LEED) system for use in the study of the surface structure (crystallography) of metals and semiconductors. It has been suggested that polarization effects in LEED experiments could reduce the ambiguity in the resulting surface structure analysis and provide clarification to understanding the factors involved in



level is usually found to be in the range of  $10^{15}$  to  $10^{16}$  cm<sup>-3</sup>. Similar sensitivity for oxygen in GaAs and iron in InP is expected. Already, EPR signals have been identified for  $\text{Fe}^{2+}$  in GaAs samples by the principal investigator. By stress and temperature studies coupled to the EPR, the symmetrical relationships of the impurity to its immediate surroundings can be achieved which is important for explaining how compensation occurs. The photoluminescence results will complement the EPR work by helping identify the energy position of the electrical state introduced by the impurity. Variations of the emission spectrum with changes in temperature, stress, and doping concentration helps in the identification of the compensation mechanisms. The main obstacle to the use of GaAs in electronic devices is in obtaining high quality material. Growth and characterization processes must be analyzed together to solve the problems. This task will play a significant role in the materials development and use of GaAs and InP for electron devices. Progress: New

Recent Publications: None

RF-54-581-001, MICROWAVE MATERIALS AND DEVICE TECHNOLOGY (M. R. H. Ser,  
202-697-1110)

RF-51-012, Westinghouse Research Laboratories, "Vertical Channel MOS  
Transistor," P.I.-Dr. T.M.S. Heng, NC0014-74-C-0012

This work exploits a vertical channel geometry to create a linear  
class A silicon MOS power FET operating in E and F bands. By virtue  
of the geometry, submicron gates can be deposited from mask sets  
whose photolithographic resolution is several micrometers. The  
geometry also greatly reduces the ratio of gate periphery to device  
area, thus reducing parasitic loading. Progress: Class A power  
output at E band has exceeded the best available bipolar class A  
power. Intermodulation distortion is about 10 dB better than that of  
bipolar power devices.

Recent Publications:

1. "A Linear Silicon Microwave MOS Transistor", P.I. Cohen, P.I.  
Wickstrom, P.A. Tremere and T.M.S. Heng, (published in Microwave Theory  
and Technique Issue on Microwave FETs, July 1976 (Special Issue)).

2. "Vertical MOS Transistor Geometry for Lower Amplifications at  
Gigahertz Frequencies", T. Heng and H. Nathanson, Electronics Letters,  
Vol. 10, No. 13, Nov 14, 1974.

RF-51-017, Varian Associates, "GaInAs FET," P.I.-Dr. Ronald Solt  
NC0014-79-C-0125

This work seeks to synthesize GaInAs material at several E<sub>0</sub>L<sub>0</sub> transition  
ratios, construct FETs of same, and compare the ternary FET properties  
to those of a similar GaAs FET. Progress: An FET constructed of 15%  
InAs/85% GaAs has exhibited an effective carrier velocity twice that  
of a 100% GaAs FET of similar geometry.

## Recent Publications:

1. "Microwave InGaP-xAs Schottky-Barrier-Gate Field-Effect Transistors - Preliminary Results", L.B. Locker, R. L. Fairman and J. Kinsht -- to be submitted to the 1966 Conference on "Active Semiconductor Devices for Microwaves and Integrated Circuits," Anaheim, CA, 1966.

2. "Thin Film Epitaxial Growth of InGaP-xAs on GaAs," J.L. Hyatt, to be published in the Journal of the Electrochemical Society.

DA 351-018, Varian Associates, "Monoplanar, Buried Channel FET," P.L.-Dr. Ronald Bell, N00014-75-1-0303

This work seeks to construct a GaAs FET in a geometry such that the gate is on the opposite side of the channel from the source and drain. In this manner, the gate breakdown voltage is increased and charge carrier transport occurs only in a buried channel away from substrate and oxide interfaces. Progress: Anisotropic etch procedures and through refill by chemical vapor deposition have been successfully accomplished so as to reduce parasitic capacitance. First devices are expected in June 76.

## Recent Publications:

## Title

DA 351-019, Westinghouse Research Labs, "Vertical Channel GaAs FET," P.L.-Dr. T.M.S. Benz, N00014-75-3-0418

This work exploits a vertical channel geometry to create a linear channel enhancement mode accumulation type gallium arsenide FET operating in H and I bands. The unique geometry permits the achievement of submicron gates using multimicron photolithography. Progress: An anodic oxide technique has been developed which provides surface state densities low enough ( $<1.0 \times 10^{12}$ ) for MDE operation.

## Recent Publications:

## Title

DA 351-020, Texas Instruments, "Semi-Insulating Gate FET," P.L.-Dr. John Slack, N00014-75-3-1134

This work exploits ion implantation to enhance the performance of an otherwise conventional Schottky barrier gate GaAs FET. A shallow implantation of arsenic ions along the top surface of the pre-gate channel creates a semi-insulating layer. This layer improves gate breakdown and channel stability. It eliminates the Schottky barrier

• • •

NR 50-582-001, (Exploratory Development), "Transferred Electron Logic Devices & Materials", (C. T. Yoder, PI) (50-582-001)

NR 583-001, Naval Research Laboratory, "III-V MBE Materials", I.I. - Howard Lessoff, N00014-79-WB-50117

This work seeks methods and techniques of reproducibly growing GaAs and InP substrates and GaAs epitaxial films of high quality suitable for use in the fabrication of transferred electron logic devices and/or FETs. Progress: Boron nitride boats and crucibles have been used to eliminate silicon and carbon impurities. Scales of InP and GaAs have been pulled using a rotating crucible instead of a rotating seed. Dislocation densities (as measured by etch pit densities) have dropped to nearly zero. Interface state density between GaAs substrates and GaAs L.I.E. films has been reduced by an in situ cleaning of the substrate immediately prior to epitaxial growth.

#### Recent Publications:

1. Quarterly Progress Report for 15 Feb - 15 May 1977
2. Annual Report "Research on Gunn Effect Materials", (Howard Lessoff, PI) FY 75, H. Lessoff
3. Quarterly Progress Report for 15 Aug - 15 Nov 1975 "Research on Gunn Effect Materials", Howard Lessoff.
4. "Liquid Phase Epitaxial Growth of Gallium Arsenide on an InP Substrate", I.F.K. Nordquist, Jr., H. Lessoff, L. M. Switzer, Submitted to Material Research Bulletin.

NR 584-002, Naval Research Laboratory, "III-V Materials Characterization", I. I. - Dr. Bruce McCombe, N00014-79-WB-50117

This work seeks to develop non-destructive techniques for characterizing III-V compound semiconductor substrate and epitaxial film materials for use in FETs and FET mixer wave devices. A set of characterization techniques which are both necessary and sufficient to ensure quality microwave devices will be developed for identification purposes. Progress: A

non-destructive determination of the magnitude and ratio of  $\rho_p^{++}$  and  $\rho_p^{+++}$  ions has been shown to be a good indication of the quality of insulating GaAs. A non-destructive technique has been developed whereby the perpendicular resistivity is determined by the equation  $\rho_{\perp} = 1$ . Another non-destructive microwave cavity technique measures sheet resistance. From these measurements, carrier concentration can be determined.

#### Recent Publications:

1. Quarterly Progress Report for 15 Nov 74 - 15 Feb 75.
2. Quarterly Progress Report for 15 Feb - 15 May 1975.
3. Annual Technical Report for 1 July 1974 - 30 June 75, "Development of Bulk & Epitaxial Single Crystals of III-V Compounds".
4. Annual Technical Report, 1 July 74 - 30 June 75 "Characterization of Bulk & Epitaxial Single Crystals of III-V Compounds".
5. Quarterly Progress Report for 15 May - 15 August 1975.
6. Quarterly Progress Report for 15 August - 15 November 1975.
7. "Characterization of Ferri-Insulating GaAs", I. I. Title "TSM" dated 16 June 1975.

Dr. Roy-889, Naval Electronics Laboratory Center, "InAs Related Heteroepitaxy", I. I. - Dr. Arthur Clawson, NOLC-75-WP-00000

This work seeks to grow & characterize InAs and InAs<sub>1-x</sub>As<sub>x</sub> III-V epitaxial films for TSM and FET devices. heteroepitaxial and homoepitaxial means are used. Both liquid and vapor approaches are taken.

Progress: InAs and InAs<sub>1-x</sub>As<sub>x</sub> (in various mole fraction ratios) have been grown both heteroepitaxially on GaAs and homoepitaxially on InAs. State-of-the-art InAs<sub>1-x</sub>As<sub>x</sub> has been grown. An insulating oxide with surface state density under  $1 \times 10^{14}$  has been developed to preclude the need for the traditionally employed sticky barrier gates on indium phosphide materials.

#### Recent Publications:

1. R. E. Weider, "Transport coefficients of InAs Epitaxial", Applied Physics Letters, Vol. 26, No. 4, 17 Jan 1974.

NR 383-084, RCA Princeton Labs., "TELD Shift Register Project",  
 P. I. - Dr. Y. Narayan, N00014-75-C-0100

This work seeks to develop a domestic expertise in multiterminal, transferred electron logic devices (TELDs) operating at millimeter frequencies. This particular effort further seeks to demonstrate that a shift register can be built which will operate at clock speeds exceeding 50GHz and that the TELDs therein may be configured for use as a signal correlator. Progress: A TELD shift register has been demonstrated to operate with pulse widths as narrow as 80 ps.

#### Recent Publications:

1. Bi-Monthly Progress Report #1 for Jan 1975.
2. Bi-Monthly Progress Report #2 for March 1975, dated 1 Apr 1975.
3. Bi-Monthly Progress Report #3 for May 1975, dated 15 May 1975.
4. Letter Progress Report #4 for July 1975, dated 20 July 1975.
5. Letter Progress Report #5 dated 30 Sept 1975, "Microwave Shift Register".
6. Letter Progress Report #6 dated October 1975, "Microwave Shift Register".
7. Letter Progress Report #7 dated December 1975, "Microwave Shift Register".
8. Annual Technical Report - Draft copy for the period 1 Oct 1975 to 14 Dec 1975, "Microwave Shift Register".
9. Annual Report, "Microwave Shift Register", L. N. Bhattacharyya, R. E. Smith, J. E. Wilhelm, R.I. /D. /75 for period 1 Oct 75 - 14 Dec 75.
10. Progress Report, "Microwave Shift Register", R.I. March 1976, L. N. Bhattacharyya, R. E. Smith, J. E. Wilhelm.

NR 383-029, RCA Princeton Labs., "Transverse Domain TELD", I. I. -  
Dr. Y. S. Narayan, N00014-76-C-0465

This work seeks to develop optimum TELD structures wherein adjacent "channels" are excited by a transverse spreading of the dipole domain. In this manner inter element delay and parasitic loading may be eliminated such that complex logic computations requiring many clock cycles by conventional approaches may be reduced to one or two clock cycles. Progress: New

Recent Publications:

1. Progress Report #1, February 1976, W. B. Durlice.
2. Bi-Monthly Progress Report #2, dtd. Apr 1976, W. B. Durlice.

NR 383-030, RCA Princeton Labs., "Enhancement Mode TELD", I. I. -  
Dr. Y. S. Narayan, N00014-76-C-0465

This work seeks to understand, exploit, and determine the limitations of a new normally quasi-off mode of TELD operation wherein power consumption is but 25% of that required of a conventional depletion mode TELD. Progress: New

Recent Publications:

1. Letter Progress Report #1, Feb. 1976, "Enhancement Mode TELD Logic Devices", by L. C. Upadhyayula, R. F. Smith.
2. Progress Report #2, dtd March 1976, "Enhancement Mode TELD Logic Devices", L. C. Upadhyayula, R. F. Smith.

NR 383-031, TRW Systems, Inc., "FPOK TELD", I. I. - Dale Claxton,  
N00014-76-C-0570

This work has two objectives. First, a new approach to bi-phase shift keying using active TELD greatly simplifies the circuitry required to do the job. In this respect, it eliminates bulky and expensive components such as circulators. By simplification, greater reliability is expected and size reduction up to 100% may be realized. Second, the modulation rate may be increased up to the channel limit. Progress: New

Recent Publications:

1. Status Report, "TEL Integrated Circuit Development", 1 Feb. 1976  
by Y. S. Narayan, et al.

NR 383-032, TRW Systems, Inc., "TELD A/D Converter", I. T. -  
D. Claxton, N00014-76-C-

This work seeks to demonstrate that an A/D converter can be made to operate at clock rates in excess of 5 GHz. It uses GaAs FETs and FETs on a common chip. A successive approximation approach is taken and active component count is about 10% of that of conventional architecture. Initially, 4 bits are to be developed.  
Progress: New

Recent Publications: None

SYSTEM THEORY

NR 021-05-01, SYSTEM THEORY, (Dr. David K. Ferry, PI. - 44-111)

NR 375-002, University of California, Los Angeles, "New Error Bounding Techniques for the Evaluation of Communication System Performance," P.I. - Dr. K. Yao, N00014-76-C-

Two new bounding techniques and their applications to the evaluation of performances for large classes of communication systems will be investigated. The theory of moment space bounds and its application to the evaluation of error probability for digital communications will be investigated for the cases characterized by the presence of interference distortion. The use of a new optimal receiver technique, developed in the minimum probability of estimation error sense, will be studied for performance in bandwidth extension and systems. Progress: New

NR 375-007, Texas Tech University, "Cumulants in Linear Time Domain Filtering and Control," P.I. - Dr. Stanley Liberty, N00014-76-C-

The research will utilize cumulants to develop a complete set of statistics on integral quadratic forms in Gauss-Markoff processes to obtain bounds on higher order statistics of the error energy in the estimate  $\hat{x}$ . The cumulant formulation, developed by the principal investigator, allows a matrix difference equation formulation to be set up for a quadratic performance measure. Progress: An in-depth look has been taken at a complete statistical description of linear-quadratic-Gaussian (LQG) performance measures. The development led to computationally tractable formulas that form the basis for system performance analysis. The complete statistical description of performance developed exhibits the essential quadratic nature of the LQG class of systems.

Report Publications:

1. S. Liberty and S. C. Hartwig, "On the Integral Quadratic Nature of LQG Control-Performance Measure Arguments," Technical Report, August 1976.

[illegible]

The present project will concentrate on the synthesis of thin films of distributed and integrated circuit components and on the design of the latter techniques. Emphasis will be placed on ways of increasing the speed of the process. Work accomplished in the past theoretic aspects of this project have resulted in the generalization of indirect algorithms for finding characteristic polynomials of matrices to the potential relationship to fault analysis. The key idea is that one can go from the graph model to a rectangular array, which with Gaussian cells have been used to solve a class of interplant problems. The use of clustering procedures is being investigated to relate this to utilization of fuzzy matrices and fuzzy graphs.

10. J. H. Conway, University of Pennsylvania, "Incommensurable Lengths  
in the Hyperbolic Triangle Function Transforms," *Adv. Math.*, vol.  
16, pp. 178-191, 1974.

Research will be aimed toward achieving analytical techniques leading to correlating large-signal transient and small-signal steady-state performance of a broad variety of state-of-the-art integrated circuits with certain of the key characteristics of the integrated functional process. In particular, the geometrical dimensions of the emitter, base, epitaxial collector, and buried collector, the various doping concentrations, and the diffusion profiles in the base are to be chosen as independent variables for the transient and steady-state circuit analyses to be considered. Progress: A closed-form solution of Einstein's equation applied to the base-collector region of an integrated bipolar device was developed. The solution encompasses an extension to simplified analyses published elsewhere, and it leads to a properly oriented definition of base pushout phenomena. Moreover, the analytical results evolve into practical suggestions for optimizing solid-state simulation of gain and gain-bandwidth in next-generation silicon.

1. *Introduction*

11. J. Wang, "A Integrated-oriented Model for the Simulation of Power System of an Integrated Bipolar Inverter," *IEEE Trans. Power Electron.*, **11**, 117-127, 1996.

[illegible]

will investigate. First only the current understanding of the various physical operating mechanisms, but also the latest advances from nonlinear circuit theory. Devices such as the semiconductor controlled rectifier, the TRIAC, and the Josephson Junction will be the focal point of initial investigations. Progress: New

NSF-141, Yale University, "Adaptive Techniques in Nonlinear and Control Theory," P.I. - Dr. E. S. Sorenson, NSG04-W-1-0-10

The work to be performed is concerned with theoretical questions of stability, effects of time-varying environments and the development of rapidly converging algorithms of control by adaptive techniques applicable for non-linear processes. Practical applications of adaptive array processors and adaptive control of aircraft systems will be investigated. Progress: General schemes for the adaptive control and identification of multivariable systems where entire state vectors are accessible for measurement were developed. If a model reference approach is used, and Lyapunov's direct method is employed to ensure the convergence of these schemes. An other feature is the simplicity of the stable adaptive laws, which depend explicitly on the state variables of the system and its model and on the system input. An extension has been developed for the case where only the system outputs are accessible, rather than all of the state variables. A unified approach to the synthesis of an adaptive observer is presented whereby the system state and parameters are simultaneously estimated.

#### Recent Publications:

1. Sorenson, E. S. and Ebra, I., "Stable Adaptive Schemes for System Identification and Control - Parts I and II," 1973 Trans. on Systems, Man, and Cybernetics, Vol. 3-4, No. 6, November 1973.

2. Ebra, I. and Sorenson, E. S., "Stable Adaptive Schemes for State Estimation and Identification of Linear Systems," 1973 Transactions on Automatic Control, Vol. AC-18, No. 6, December 1973.

3. Ebra, I. and Sorenson, E. S., "An Identification Scheme for Nonlinear Multivariable Systems," 1973 Trans. on Automatic Control, Vol. AC-18, No. 4, October 1973.

4. Ebra, I. and Sorenson, E. S., "A New Approach to the Design of Adaptive Observer," 1973 Trans. on Automatic Control, Vol. AC-18, No. 2, April 1973.

5. Sorenson, E. S. and Ebra, I., "Fast Adaptive Control Algorithms," 1973 Trans. on Automatic Control, Vol. AC-18, No. 2, April 1973.

NR 376-971, Rensselaer Polytechnic Institute, "Detection, Estimation, and Filtering of Signals in Impulse Noise," I.I. - Dr. James W. Modestino, N00014-75-C-0281

Efforts will be directed toward refining and extending previous impulsive noise modeling work in refining the WLF model and in modeling of impulse noise on communications networks and on FM threshold detection. Major effort will be expended in the determination of analytical performance bounds for both detection and estimating structures for these noise models. Progress: An analysis has been completed allowing exact calculation of the error probability performance of selected linear receivers operating in MLF impulsive noise environments. A study of the performance and properties of a number of coincidence detector structures has been completed. A coincidence detector is a suboptimum structure of the limiting variety which bases its decisions only on the polarity of the received data. A number of new numerical techniques have been developed for the evaluation of first and second order probability distributions of impulsive noise processes described as the linear combination of a low density shot process and background white Gaussian noise. A number of new results relating to adaptive detection in impulsive noise environments have been obtained.

#### Recent Publications:

1. J. W. Modestino, "Coincidence Procedures for the Detection of Known Signals in Statistically Undefined Background Noise," Technical Report No. 1, March 1978.
2. J. W. Modestino, "An Adaptive Detection Structure for Reception in Impulsive Noise Environments," Proc. 1978 Conference on Decision and Control, November 1978.
3. J. W. Modestino, "Adaptive Nonparametric Detection," in Nonparametric Detection, Ed. by D. Barak and T. Porat, ed-Barak, Marcel Dekker, Inc., N.Y., 1978.

NR 376-971, Texas Tech University, "Fault Detection in Electronic Systems," I.I. - Dr. Richard Cook, N00014-75-C-0281

With the increasing complexity of electronic systems, there has arisen the need for sophisticated procedures for fault detection and diagnosis in the electronic equipment that makes up these systems. While much has been accomplished to date, the problem of fault detection is not yet being solved in a satisfactory manner. The need for more sophisticated procedures is a result of the fact that as systems are extended in size and complexity, the number of faults that can occur in the system increases. The need for more sophisticated procedures is a result of the fact that as systems are extended in size and complexity, the number of faults that can occur in the system increases.

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In short, there is no theoretical foundation upon which general techniques can be developed. The object of this research is an attempt to develop such theoretical foundations. Present approaches are either local wherein the derivatives of the various external system parameters with respect to the component parameters are used to achieve the estimate or global wherein simulations of all possible faulty conditions are made prior to the test and compared with the measured external system parameters to achieve the desired estimates. This approach is based on the observation that the connections in a circuit or system define a system valued function of a system valued variable, i.e., a mapping of the internal component parameters to the externally measured system parameters. Interpretation. Progress has been made in a number of areas. It has been shown that techniques for fault analysis in the analog area can be generalized to include the digital faults. To date it only includes the "stuck-at-faults." Nevertheless, this generalization is significant. In fault prediction, an ad-hoc algorithm has been proposed that seems well. An optimum algorithm will be constructed and compared with the experimental one.

References:

1. H. J. ... "The ... Question ..."
2. H. J. ... "Circuit Theory and Application ..."

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