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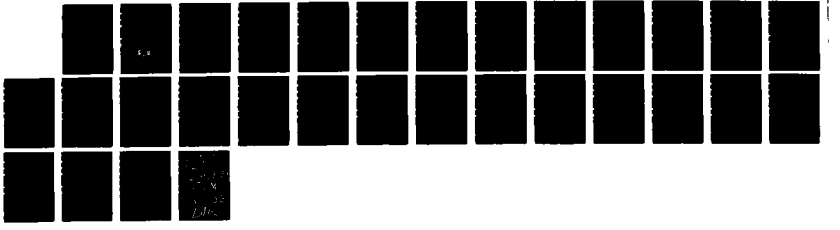

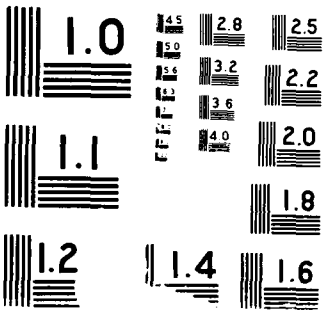
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COLUMBIA UNIVERSITY

ANNUAL LETTER REPORT

September 15, 1986 - September 14, 1987

TO THE

OFFICE OF NAVAL RESEARCH
UNIVERSITY RESEARCH INITIATIVE PROGRAM

CONTRACT N00014-86-K-0694

MICROELECTRONICS SCIENCE LABORATORY
NEW YORK, NEW YORK 10027

March, 1988

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OFFICE OF NAVAL RESEARCH
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CONTRACT
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Period
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SUBMITTED BY:

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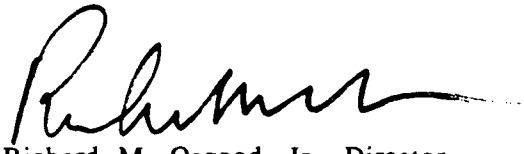

Richard M. Osgood, Jr., Director
Microelectronics Sciences Laboratories
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Professor of Physics
Co-Director, Columbia Radiation Laboratory

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I. DIRECTOR'S OVERVIEW

A. Introduction

The first year of our Navy URI program has been unusually successful in establishing a university center for research in the fundamental surface chemistry and physics of electronics materials and materials processing. The establishment of the center is the result of the combined resources from the U. S. Navy, private industry (IBM), and Columbia University.

In our first year, our plan was to use our matching IBM grant to support the salaries of most of the researchers working on the URI program, including collaborative research with NRL and to acquire some IBM instrumentation. In the meantime, our URI funds in the first year were to be used to provide a substantial increase in our research capability at Columbia through the purchase of major items of capital equipment. Finally, the first year would also be used to establish new laboratories at Columbia for research in semiconductor processing: these laboratories were renovated with Columbia University funds. As will be explained below, all of these objectives have been met or exceeded.

In brief, then, the ONR-URI program has had a major impact at Columbia by establishing a broad-based program in electronic materials science. The program has made a difference here.

B. Objective

The objective of this URI research program is "to form an interdisciplinary research center to study several prominent classes of interfacial reactions which are important in the fabrication of submicrometer circuits and devices."

The ONR/URI funding has enabled Columbia to establish this new interdisciplinary research center on campus, the Microelectronics Sciences Laboratories (MSL). This center draws from the resources of three departments--Chemistry, Electrical Engineering, and Applied Physics. It has directly enabled three well known scientists to initiate their university research careers at Columbia: Professor Wen Wang, Professor Irving Herman, and Professor Dave Auston. In addition, during the second year, two new junior professors will begin research in the surface chemistry of electronics materials. Their

research will be aided indirectly by the equipment and research orientation at Columbia established by the ONR program: Professor Robert White, polymers for packaging (Department of Electrical Engineering) and Professor Brian Bent, the surface chemistry of CVD growth (Department of Chemistry).

C. Capital Equipment

We have purchased five major items of capital equipment using the URI money. These items are listed in Table 1. Each of these instruments has given the Microelectronics Sciences Laboratories a major new thrust in the experimental capability for investigating interfacial chemistry of electronics materials. For example, prior to the formation of the ONR center, Columbia had no experimental facilities for epitaxial growth. With the newly purchased MBE machine, the MSL will be able to examine a number of problems concerning the growth and processing of heterostructure materials. The work at Columbia will draw on the intellectual resources of the two major national industrial research centers in MBE growth, Bell Labs and IBM Research, and provide a first-class opportunity for educating students in solid-state physics and surface chemistry.

In two of the cases of the equipment purchases, the MBE machine and optical diagnosis system, Columbia University made major contributions to the purchase of the equipment. In the case of the MBE machine, for example, two-thirds of the cost was covered by gifts to the University from industry and alumni.

One of the most significant aspects about this capital equipment is that as of the writing of this report (March, 1988), the equipment has all been installed and is currently being used for experiments in the Navy program.

D. Contacts with Navy Laboratories

Our most extensive contacts with Navy Laboratories have been with NRL. The contacts have been in two forms: seminars by ONR personnel at Columbia and collaborative experiments with NRL personnel at NRL.

The personnel involved in these contacts are presented in Table 2. Note that in the case of the Columbia ONR interaction on MBE materials, and that of light-induced, liquid-phase etching of semiconductors, joint publications have been produced. These publications are listed in the portion of the report dealing with research by specific principal investigators (Section III).

E. IBM Program

Since the IBM matching grant has played an integral role in our URI research program, we would like to summarize briefly the results of the program here. As in the case of the ONR program, major items of capital equipment have been purchased. These items include IBM spectrometers including NMR, FTIR, and UV/visible instruments. These have been used generally to investigate surface-adsorbed molecular layers. The specific instruments are listed in Table 3. Most important, however, the grant provided funding for several interdisciplinary postdoctoral fellows and graduate students. These researchers enabled URI-proposed research to be done in the first year of the URI program. Finally, the IBM grant provides seed money for research by two new faculty members at Columbia in the general area of research of the Navy program.

We note that this IBM funded program is only the strongest example of many industrial affiliations and collaborations in the New York area that have resulted from the establishment of MSL at Columbia.

TABLE 1: CAPITAL EQUIPMENT (PURCHASED)

1. MOLECULAR BEAM EPITAXY (TWO CHAMBERS)

2. INFRARED DIODE LASER

3. UHV SURFACE ANALYSIS AND METALLIZATION SYSTEM

4. OPTICAL DIAGNOSIS SYSTEM (AND LUMINESCENCE)

TABLE 2: CONTACTS WITH NAVY LABORATORIES
(Naval Research Laboratory)

I. NRL SEMINAR TALKS AT COLUMBIA:

1. ED PALIK: "Study of Orientation Dependent Etching of Silicon in Aqueous KOH"
2. C. T. YAO: "Hot Electron Effects on MOSFET Terminal Capacitance"
3. MARTY PACKERAR: "Microstructure Research and Development at NRL: An Overview"
4. OREST J. GLEMBOCKI: "Interband Transitions in Microstructures"

II. COLLABORATIVE RESEARCH PROJECTS:

1. DR. STEVE BISHOP IS CURRENTLY WORKING WITH PROFESSOR WEN WANG
2. DR. OREST GLEMBOCKI AND DR. ED PALIK ARE CURRENTLY WORKING WITH PROFESSOR R. M. OSGOOD, DR. DRAGAN PODLESNIK, AND DR.ALAN WILLNER
3. DR. ED PALIK IS CURRENTLY WORKING WITH PROFESSOR IRVING HERMAN

TABLE 3: IBM MATERIALS RESEARCH PROGRAM AT COLUMBIA

EQUIPMENT PURCHASES:

1. NMR SPECTROMETER (SOLID STATE CAPABILITY)
2. UV/VIS SPECTROPHOTOMETER (1)
3. FTIR SPECTROMETER (IR44) (2)
4. LIQUID CHROMATOGRAPH

II. PROGRESS REPORTS

A. ULTRAFAST OPTOELECTRONIC MEASUREMENTS OF SURFACES AND INTERFACES (Professor D. H. AUSTON)

Work is nearing completion on the establishment of an experimental facility for the measurement of the optical and electronic properties of surfaces and interfaces on time scales in the picosecond and femtosecond range. This laboratory will have a state-of-the-art laser facility for the generation and measurement of high intensity optical pulses as short as 30 fs for probing the linear and nonlinear properties of materials. A capability for electronic measurements of materials and devices with time resolutions as fast as 100 fs will also be available by the use of electro-optic and photoconducting materials and techniques.

Some of the experiments planned for the near future are: [1] The measurement of the relaxation kinetics of hot electrons at the surface of bulk semiconductors and at the interfaces of semiconductor heterostructures. These experiments are aimed at determining the relaxation mechanisms and cooling rates of hot electrons which have been heated by both optical and electric fields. The unique capabilities of our experimental facility will permit us to use both electronic and optical excitation with time resolution in the range of 100 fs. We expect this approach will provide a more complete understanding of some of the dynamical properties of hot electrons such as velocity overshoot and intervalley scattering. [2] Research on the nonlinear optical reflectivity of short pulses at the surface of semiconductor multi-quantum wells will be initiated, with the goal of investigating the high speed optical properties of new heterostructures. For example, strained-layer superlattices will be investigated for their electro-optic properties arising from optical modulation of trapped charge at the interfaces. [3] Work is also planned on the use of short optical pulses to generate and detect coherent phonons in the Teraherz frequency range at the surface of electro-optic superlattices. It is expected that this approach will permit the development of a coherent phonon spectroscopy capability in a frequency range that is now inaccessible by conventional methods. [4] New work is also planned on dynamical measurements of surface photolytic reactions using ultrashort electrical pulses to probe the transient dielectric properties of surface adsorbates.

B. QUANTUM STATE RESOLVED STUDIES OF GAS/SURFACE CHEMICAL REACTIONS (Professor G. FLYNN)

Our efforts over the past year have focused on three major issues. The first is the direct detection of Cl atoms using time resolved infrared diode laser absorption to detect the atomic transition

$$Cl(^2P_{3/2})+h\nu \rightarrow Cl(^2P_{1/2}) \qquad \text{(Absorption at 880 cm}^{-1}\text{)}$$

We have succeeded in producing a good calibration spectrum in the region of the Cl absorption, a crucial step in locating atomic lines to an accuracy of about one part in 10^7. As is often the case with lead-salt infrared diode lasers, our initial element had a "hole" in the mode profile in the wavelength region surrounding the Cl atom absorption line. We have just installed a replacement device which appears to lase in the correct frequency range, and we expect to detect Cl atoms very shortly. Following this, we will be investigating chemical reactions of these atoms with surfaces, molecules and ions of interest in plasma etching enviornments.

The second project which we have been pursuing is the study of the vibrational energy distribution of-molecules produced as the result of a chemical reaction occurring at a surface. We have used diode laser probing to determine the vibrational temperature of carbon dioxide molecules which are formed when CO and oxygen combine on platinum. A particularly interesting feature of this reaction is that the carbon dioxide asymmetric stretch mode is more excited than the bending mode indicating a highly asymmetric transition state. The question arises as to whether similar information can be obtained from reactions occurring on other surfaces, such as silicon. If so, the data obtained should provide fundamental insights into the reaction dynamics on the surface and hence lead to better control of etching processes.

The third project which we have started is to understand the chemical reactions of $O(^1D)$ atoms and their quenching to the relatively unreactive $O(^3P)$. Our interest in this system stems from recent conversations with Dr. Andrew Tam at IBM Almaden Laboratories. We plan to investigate the etching of carbon films using oxidizing agents such as $O(^1D)$ in an effort to understand the photochemistry and photophysics of these systems. Quenching by carbon dioxide, which is expected to be a major product of any carbon etching process, proceeds rapidly (nearly gas kinetic), but we have found that the energy lost from the $O(^1D)$ atom does not show up in the low vibrational levels of CO_2 for

more than 20 collisions. This means that there is a potential source of high energy species in the system which may have a dramatic effect on the etching and surface reactions in this very interesting chemical system.

C. IN SITU OPTICAL DIAGNOSTICS OF SEMICONDUCTORS PREPARED BY LASER CHEMICAL PROCESSING AND OTHER NOVEL METHODS

(Professor I. P. Herman)

The major accomplishment this year has been the establishment of the MSL/APNE Laser Diagnostics/Solid State Physics Laboratory. This facility includes a mainframe argon-ion laser and krypton-ion laser, a triple spectrometer (double-subtractive plus single-dispersive), a high resolution double spectrometer, a diode array acquisition system, two optical tables, a laser microscope, a vacuum station, and a diamond anvil cell. Virtually all this capital equipment was acquired through the ONR/URI program. This laboratory is now totally operational.

The study of Raman analysis of silicon microstructures on fused silica and sapphire is well underway. Experimental measurements of Stokes and anti-Stokes scattering in laser heated microstructures, fabricated in the MSL, have been made using one beam or two beam (4880Å, 5145Å) laser heating and microprobing. A finite difference laser heating code has been developed and linked to a Raman spectrum program to analyze these experiments. The goal of these experiments is to develop in-situ diagnostics during thin film processing. In this case, the specific aim is to monitor temperature during laser heating at interfaces.

A related theoretical study has been devoted to analyzing strains induced during thermal direct laser processing of semiconductors. The stress and strain distribution during laser heating by a Gaussian beam has been obtained in terms of a one-dimensional integral.

Nucleation effects during laser chemical vapor deposition of localized thin films were the subject of a collaboration with U. C. Davis/LLNL. Monte Carlo simulations of the initial thin film growth of silicon on various substrates was completed. Attempts to confirm the conclusions of this study experimentally, led to the unexpected observation of photon-inhibited growth during the laser-assisted deposition of silicon from silane on c-Si substrates (5145Å).

Several collaborative efforts involving Raman analysis in semiconductor thin film processing were begun this year. Raman study of grooves etched in Si by Cl_2 was conducted with V. Treyz and Professor Osgood. Laser doping of GaAs was examined

with T. Licata and Professor Osgood. Preliminary measurements were made in the Raman microprobe of Si membranes with E. Palik (NRL), and the optical analysis of excimer-laser-deposited Ge-Si alloys (G. Eden at the University of Illinois/Urbana). Note that in the two collaborative efforts with Professor Osgood's group in the MSL, only the project involvement by Professor Herman is ONR/URI supported.

D. LASER ALTERATION OF SURFACE CHEMISTRY IN ELECTRONIC PROCESSING

(C. F. Yu, D. V. Podlesnik, Professional Research Staff; R.M. Osgood, Jr., Professor and Principal Investigator)

The objective of this research is to develop an understanding of the basic surface physics which controls light-assisted chemical reactions on electronic materials. The central focus of our research is to understand the enhancement of reactions on semiconductor surfaces. In this case, visible and ultraviolet radiation can produce a well defined excitation of the surface through the formation of electron-hole pairs. The magnitude of this surface excitation can be studied by a variety of well known solid-state techniques, and as a function of a variety of materials and optical parameters. Optically induced chemistry on semiconductor surface is also being examined by several groups of AT&T and IBM Research Laboratories.

We have commenced our studies by examining the mechanism of UV-enhancement of oxidation on GaAs. This laser-enhanced oxidation can be used for low-temperature oxide growth and is potentially useful for device applications. Specifically, laser grown oxides have been used in our laboratory to allow alteration of Schottky barrier heights in metal-GaAs contacts. (See report by E. Yang, below.)

In our mechanism studies, we have investigated the oxidation of light-enhanced gallium arsenide surfaces. This includes deep-UV, near-UV and visible light using Auger electron spectroscopy and x-ray photoelectron spectroscopy for the study of submonolayer and above monolayer regimes, respectively. The onset of a strong wavelength dependence of the enhanced oxidation was observed after the oxygen coverage reached more than half a monolayer. An abrupt threshold for this wavelength dependence was also observed at a ~ 4.1-eV photon energy. We have considered two possible mechanisms to explain the UV enhanced oxidation.

Before discussing these mechanisms, however, it is important to discuss other mechanisms which we do not feel contribute to the light-induced chemistry. One effect is the direct photon excitation of O_2 molecules before they reach the surface. The dissociation limit for O_2 is known to be 5.1 eV. Except where noted, this energy is greater than the

photon energies used in our experiments. In order to check further that O_2 was not being excited by radiation in the gas phase, a cylindrical lens (1 m focal length) was used to focus a 248-nm KrF excimer-laser beam parallel to the surface of a clean-GaAs sample in the reaction chamber. The energy of these photons is 4.99 eV. For a 20 min exposure, virtually no oxide was formed.

The effect of a laser-induced temperature rise can also be eliminated as a cause of oxidation. We confirmed experimentally that the temperature required for our typical oxide growth rate was 450^{o} C. Calculations of the temperature rise of our GaAs surfaces due to the very low intensity radiation, typically 1 mJ/cm2, give a maximum transient temperature rise of 3^{0}C. Furthermore, due to similar absorption depths of 351 and 248-nm-laser radiation in GaAs, equivalent intensities of illumination would produce a nearly identical surface temperature rise in each case. However, we have seen that for equivalent exposures, the 248-nm light enhances the oxidation much more than the 351-nm light. Therefore, thermal effects can be ruled out as the cause of the wavelength dependence of the photoenhanced oxidation of GaAs.

Both of the mechanisms that we are now evaluating involve as a starting point the transfer of charge to the adsorbing oxygen molecules or atoms. This charge transfer has actually been observed by STM studies of the O_2-covered GaAs surface. Light would assist the process by production of a charge at the semiconductor surface. While this portion of the mechanism explains the enhancement seen when the photon energy is just above the band gap, it does not explain the very strong enhancement at deep UV wavelengths. Instead we feel that another mechanism peculiar to UV photons must be operable.

In particular, in the first of the proposed mechanisms, we hypothesize that O_2 would form in the oxide by the attachment of ejected photogenerated electrons to the oxygen molecules. Photodissociation of this species which occurs only in the medium UV, will cause a much stronger enhancement of oxidation than is seen with visible photons. While a direct experimental proof of the presence of O_2 and its photodissociation is yet to be made, this mechanism offers a simple explanation for the strong wavelength dependence of the oxidation enhancement; it is also in agreement with the strong coverage dependence of the UV enhancement that we have observed.

In the second possible mechanism for UV enhancement, photon absorption in different parts of the Brillouin zone results, it is known, in the generation of electrons and holes with kinetic different energies. For example, holes generated by the 5-eV UV photons will possess ~2.5eV of excess energy through an X-edge transition, while excess energy from visible-photon absorption is transferred mainly to the electrons. A

consequence of the generation of these nonthermal carriers is that the interface chemistry is altered under ultraviolet illumination. More energetic carriers produced by deep UV photons will induce much faster oxidation on the GaAs surface.

Finally, we note in closing that two other projects concerning the laser-induced chemistry of chemisorbed organometallic molecules using UV and IR spectroscopic techniques are also supported in part by the IBM matching program. The results of the research in these experiments, shown in the following abstracts, have been submitted to Chemical Physics Letters.

1. A UV SPECTROSCOPIC STUDY OF DMZnAND DMCd CHEMISORBED ON QUARTZ - Ping Shaw, Zhen Wu and Richard M. Osgood, Jr.

The ultraviolet (UV) transmission spectra of dimethylzinc (DMZn) and dimethylcadmium (DMCd) hemisorbed on quartz surface between 190-290 nm have been measured. From the spectra corresponding to different baking histories prior to chemisorption, it is shown that at room temperature the surface hydroxyl groups play an extremely important role in the chemisorption of DMZn and DMCd molecules. Spectra changes due to thermal effects and low-power 248-nm excimer-laser irradiation were compared. The difference between pyrolytic and photolytic desorption is discussed.

2. INFRARED TOTAL INTERNAL REFLECTION SPECTROSCOPY OF DIMETHYLCADMIUM ON SILICON - Esaul Sanchez, Ping Shaw, James A. O'Neill and Richard M. Osgood, Jr.

The surface chemistry of dimethylcadmium (DMCd) on silicon surfaces is monitored through changes in the infrared spectra of both chemically and physically adsorbed molecules. A technique involving total internal reflection of the IR probe beam was employed to isolate the surface-molecule signal from that due to ambient gas-phase molecules. Fourier-transformed infrared spectra of DMCd on silicon were recorded in the region from 2.0-5.0 mm where the CH vibrational modes of the molecule occur. Excimer laser irradiation of the molecules at 248 nm under conditions appropriate for Cd film deposition resulted in changes in the observed spectra due to dissociation of both surface and gas-phase molecules.

E. PHOTOCHEMICAL AND PHOTOPHYSICAL PROBES OF INTERFACES
(Professor N. J. Turro)

During the grant period we have employed electron spin labels to examine the solid liquid interface. Given below is a brief review of these and related studies.

We have employed stable spin labeling techniques with our current EPR spectrometer to investigate various aspects of the solid/liquid interface. For example,[1] we have used three nitroxide spin probes to investigate the structure of sodium dodecyl sulfate (SDS) hemimicelles that are formed by adsorption of SDS on alumina particles. An EPR analysis showed that the rotational correlation times of the probes in the SDS hemimicelles vary according to the distance from the alumina surface. We concluded that the nitroxide sees a more ordered environment as it is positioned closer to the alumina surface. These results represented the first examples of variations in the flexibility or microviscosity within a hemimicelle. We have also used[2] a nitroxide spin probe to study the structure of the adsorbed layer of SDS as a function of coverage of alumina by SDS. It was found that at low concentration of SDS the probe aggregated itself on the surface, but as SDS is added and hemimicelles begin to form, the probe aggregates break up and the nitroxide probe becomes adsorbed into the SDS hemimicelles. In other studies,[3] we have investigated the EPR of nitroxide probes adsorbed on clay surfaces and showed that the sites of photochemically generated free radicals adsorbed on the clay lead to enormously different reactivity toward the stable free radical traps.

We have demonstrated a novel use of stable nitroxide traps for unstable radical produced by photoexcitation of molecules adsorbed on clay surfaces.[5] The combination of EPR spectroscopy of the stable radicals and the corresponding reactivity of these species toward photochemically generated unstable radicals provided a facile method for probing the structure and dynamics of the microenvironment surrounding clay mineral suspensions. Furthermore, the methodology allowed the monitoring of effects of different environments within a single, heterogeneous mixture. The reactivity of the radicals produced in different sites in the clay was enormous, boding well for the use of clays as energy storage media. Having demonstrated that nitroxide spin traps for unstable radicals can serve as an indirect probe of the probing of the interfaces of microheterogeneous systems, we now propose to employ the time resolved capabilities of the requested instrument to examine the unstable radicals directly. This will be done by employing laser flash excitation of ketones adsorbed on the clay platlettes. The structures of the ketones will be varied to cause the initial site of the ketone in the heterogeneous clay to be different. The EPR spectrum will be taken in the

time resolved mode and the decay of the radicals will be monitored in real time. Careful attention will be given to line widths of the observed spectra in order to obtain information on the mobility of the radicals adsorbed on the clay surface.

As an example of experiments that would take advantage of the unique time resolution of the EPR spectrometer, we would investigate the photolysis of ketones adsorbed at the solid/gas interface of zeolites and porous silica. We have completed product analyses of this system and have found strong control of the product distributions by the detailed chemical composition and the size of the microscopic pore space available for diffusion of the radicals adsorbed at the interface of the zeolite or silica internal solid/gas surface.[6] The information obtained in these experiments is of relevance to energy research in the areas of photochemical energy conversion because we have initial evidence that the lifetimes of the radicals adsorbed in porous solids might be extended by orders of magnitude from the value of their lifetimes in homogeneous solvents or in the gas phase. In addition, information and knowledge concerning the dynamics of diffusion of highly reactive species is of great import for an understanding of the mechanism of catalytic action at the solid/gas interface and such catalysis is at the heart of current methods that convert carbon compounds to fuels, i.e., heavy oils to excellent gasolines.

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6. N. J. Turro, C. C. Cheng, P. W. Wan, C. J. Chung, and W. Mahler, "Magnetic Isotope Effects in the Photolysis of Dibenzyl Ketone on Porous Silica. 13-C and 17-0 Enrichments," J. Phys. Chem., *89*, 1567 (1985); N. J. Turro, C. C. Cheng, P. W. Wan, C. J. Chung, and W. Mahler, "Magnetic Isotope Effects in the Photolysis of Dibenzyl Ketone on Porous Silica. 13-C and 17-0 Enrichments," J. Phys. Chem., *89*, 1567 (1985).

F. MOLECULAR BEAM EPITAXY MACHINE (Professor W. Wang)

The two chamber molecular beam epitaxy machine has been received from Varian and has been partially installed.

In the meantime, a laboratory apparatus has been set-up to examine the luminescence and Raman characterization of the materials which will be grown on the MBE machine. Test samples were obtained from nearby industrial laboratories (including IBM and Siemens), to calibrate the industry.

A collaboration with Dr. Schanabrook at NRL on quantum-well structures has resulted in several publications.

G. MODIFICATION OF SCHOTTKY BARRIER HEIGHTS ON GAAS USING THIN UV GROWN OXIDES (Professor E. Yang)

Metal contacts have been deposited on very thin oxide layers (3-10 A) formed on GaAs (100) surfaces under UV illumination.[1] The Schottky barrier for the contacts on oxidized surfaces is found to vary much more strongly with the work function of the metal than is observed for contacts to clean GaAs. We have used ultraviolet (248 nm) light incident on GaAs (100) surfaces to enhance the room temperature oxidation of GaAs in dry oxygen. Well controlled, stoichiometric oxides have been formed in a UHV system prior to in situ metal deposition. XPS has been used to determine oxide thicknesses and to characterize the oxides and the reactivity of metals with the oxide layer. Both metals reactive with the oxide layer and metals nonreactive with the oxide layer have been used. I-V and infrared photoemission measurements have been used to characterize the resulting metal-GaAs contacts. A study of Schottky barrier height for metals with a wide range of work functions (e.g., Ag, Ti, Cr, Cu, Pd, Ni, Pt) on n-GaAs shows that the Schottky barrier height changes toward a value predicted by the ideal Schottky limit in the absence of

interface states, that is, high work function metals on oxidized n-GaAs have an increased barrier height, while low work function metals on oxidized surfaces have reduced barrier heights. Both stoichiometric oxides and Ga-rich oxides produce the same trend in barrier variation, but the Ga-rich oxide produces larger changes and better contact ideality factors. Barrier height changes for a metal are as large as 190 mV, or over 10% of the GaAs band gap. The increased Schottky barrier height variation has been interpreted as the result of a decrease in interface states at the metal-GaAs contact, allowing the metal work function to more strongly determine the Schottky barrier. This reduction of interface states at metal-GaAs contacts would result in a Schottky barrier variation on p-GaAs contacts which is opposite to that on n-GaAs. The barrier height variation did not depend on whether a metal reacted with the oxide, suggesting that the oxygen was affecting the GaAs surface. The results of a wide range of metal work functions on oxidized n-GaAs which show a change in Schottky barrier height toward the ideal Schottky limit will be compared to a complimentary study of contacts on oxidized p-GaAs.[2]

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M. T. Schmidt, D. V. Podlesnik, H. L. Evans, C. F. Yu, E. S. Yang, and R. M. Osgood, Jr., "The Effect of UV-Grown Oxide on Metal-GaAs Contacts," Submitted to J. Vac. Sci. Tech. September, 1987.

M. T. Schmidt, D. V. Podlesnik, C. F. Yu, H. L. Evans, E. S. Yang, and R. M. Osgood, Jr., " The Effect of a Thin Ultra-Violet Grown Oxide on Metal-GaAs Contacts," to be published in J. Vac. Sci. and Technol. A 6.

M. T. Schmidt, D. V. Podlesnik, C. F. Yu, X. Wu, R. M. Osgood, Jr., and E. S. Yang, "Increased Dependence of Schottky Barrier Height on Metal Work Function Due to a Thin Oxide Layer," to be published in J. Vac. Sci. Technol. B; presented at PCSI-15, Asilomar, CA, Feb. 1-4, 1988.

C. F. Yu, M. T. Schmidt, D. V. Podlesnik, E. S. Yang, and R. M. Osgood, Jr. "Ultraviolet-Light-Enhanced Reaction of Oxygen with Gallium Arsenide Surfaces," Submitted to J. Vac. Sci. Tech., 1987 AVS National Symposium Proceedings.

C. F. Yu, S. S. Todorov, and E. R. Fossum, "Characterization of Ultra-Thin SiO_2 Films Formed by Direct Low-Energy Ion Beam Oxidation," J. Vac. Sci. Technol. A5 1569 (1987).

M. T. Schmidt, D. V. Podlesnik, C. F. Yu, X. Wu, R. M. Osgood, Jr., and E. S. Yang, "Increased Dependence of GaAs Schottky Barrier Height on Metal Work Function Due to Thin Oxide Layer," submitted, J.V.S.T., Fall 1987.

M. T. Schmidt, D. V. Podlesnik, C. F. Yu, R. M. Osgood, Jr., and E. S. Yang, "Schottky Contact Characterization of Thin, Excimer-Laser Grown GaAs Oxides," in Laser and Particle-Beam Processing, edited by D. J. Ehrlich, G. S. Higashi, and M. M. Oprysko (Materials Research Society, Pittsburgh, 1988).

E. Sanchez, P. Shaw, J. A. O'Neill, "Infrared Total Internal Reflection Spectroscopy of Dimethylcadmium on Silicon," to appear, J. Vac. Sci. Technol. A, May 1988.

J. F. Hershberger, S. A. Hewitt, G. W. Flynn and R. E. Weston, Jr., "Observation of and Odd/Even Delta-J Propensity in the Collisional Excitation of CO_2 by Hot Deuterium Atoms," to be published in J. Chem. Phys., 1988.

J. G. Hershberger, J. Z. Chou, G. W. Flynn, and R. E. Weston, Jr., "Rotational State Dependence of Transient Line Widths in the CO_2 00^01 Vibrational Level Due to Translational Energy Recoil from Hot H and D Atom Collisions," submitted to Chem. Phys. Let. 1988.

G.D. Pazionis, H. Tang, L Ge and I.P. Herman, "Stokes/Anti-Stokes Raman Microprobe Analysis of Laser-Heated Silicon Microstructures on Silicon Dioxide," to be published, Mat. Res. Soc. Sym. Proc. Vol. 101 (1988).

D.E. Kotecki and I.P. Herman, "Initial Stages of Silicon Growth on the (100) Surface of Silicon By Localized Laser CVD," to be published, Mat. Res. Soc. Sym. Proc. Vol. 101 (1988).

IV. RESUMES OF PRINCIPAL INVESTIGATORS

A. DAVID H. AUSTON

Professor of Electrical Engineering
Columbia University
1336 Mudd
New York, NY 10027
(212) 280-0545

Professional Experience

1987 - present: Professor of Electrical Engineering, Applied Physics and Nuclear Engineering, Columbia University.
1969 - 1987: Member of Technical Staff; Head of the High Speed Materials and Phenomena Research Dept. in the Physics Division, AT&T Bell Labs, Murray Hill, NJ.
1979: Visiting professor in the Groupe de Physique des Solides de l'Ecole Normale Superieure, Paris, France.
1969: Acting assistant professor at University of California, Berkeley.
1963 - 1966: Research Physicist, General Motors Defense Research Laboratory, Santa Barbara, CA.

Education

PhD: 1969, University of California, Berkeley
MS: 1963, University of Toronto
BS: 1962, University of Toronto, Engineering Physics, Graduated with honors

Professional Activities

1986-present: Editor of the Springer-Verlag series of texts on Electronics and Photonics.
1986-present: Associate editor, Optics Letters.
1985-present: Advisor of the Rutgers University Center for Science Education.
1985-87: Member of the Optical Society of America; Chairman, Optoelectronics Group.
1985-87: Conference on Lasers and Electro-optics; Co-chairman, Steering Committee.
1985-86: Lasers and Electro-optics Society of the IEEE; Elected member, Administrative Committee; chairman, publications committee.
1985: Advisor to the Smithsonian Institution on the 25th anniversary of the laser.
1984: Co-chairman, 1984 Conference on Ultrafast Phenomena, Monterey, CA.

Awards

1986: First Walter Schottky Lecturer of the University of Aachen, FRG.
1985: R.W. Wood Prize of the Optical Society of America in recognition for oritinal contributions to picosecond optoelectronics.

Patents: 7
Publications: 85

Ultra-fast electronics and electro-optics
Solid-state physics
Electro-optical devices and techniques

B. GEORGE WILLIAM FLYNN

Thoma Alva Edison Professor of Chemistry
Columbia University
315 Havemeyer
New York, NY 10027
(212) 280-4162

Education

Ph.D., Harvard University, 1965
M.A., Harvard University, 1962
B.S., Yale University, 1960

Professional History

1976 - present:	Thoma Alva Edison Professor, Columbia University
1975 (Spring):	Visiting Scientist, Massachusetts Institute of Technology
1972 - 1976:	Associate Professor, Columbia University
1967 - 1972:	Assistant Professor, Columbia University

Special Grants, Awards, and Appointments

1984:	Fellow, American Physical Society, A. Cressy Morrison Award in Natural Sciences for 1983, N.Y. Academy of Sciences
1983:	Reilly Lecturer, University of Notre Dame, April
1982:	William Pyle Phillips Lecturer, Haverford College, October
1982:	Harold C. Urey Award
1974 - 1975:	John Simon Guggenheim Memorial Fellow
1973:	12th Mark Van Doren Award
1968 - 1970:	Alfred P. Sloan Research Fellow
1964 - 1965:	NSF Postdoctoral Fellowship
1960 - 1964:	NSF Predoctoral Fellowship,
1960:	B.S. degree Summa Cum Laude with exceptional distinction in Chemistry

Research Appointments

1982 :	Visiting Scientist, Rowland Institute for Science, Inc., July-August
1984 - present:	Co-Director, Columbia Radiation Laboratory
1979 - 1984:	Director, Columbia Radiation Laboratory
1975 - present:	Member, Columbia Radiation Laboratory
1978 - present:	Consultant, Brookhaven National Laboratories
1968 - 1969:	Research Collaborator, Brookhaven National Laboratories

Total Publications - 124

Chemical dynamics
Gas phase spectroscopy

C. ERIC R. FOSSUM

Assistant Professor
Department of Electrical Engineering
1334 S. W. Mudd
New York, NY 10027
(212) 280-3104

Education

Ph.D., Yale University, 1984
M.S., Yale University, 1980
B.S., Trinity College, 1979

Professional History

July 1984 to present, Assistant Professor of Electrical Engineering, Columbia University
1983, Acting Instructor, Yale University
Summers 1981 to 1983, Member of the Technical Staff, Hughes Aircraft Company Missile Systems Group
Summers 1979 to 1981, Research Assistant, Yale University

Special Grants, Awards and Appointments

Henry Prentiss Becton Prize for Excellence in Engineering and Applied Science, 1984
Howard Hughes Graduate Fellowship, 1981-1984
IBM Graduate Fellowship, 1980-1981
Yale University Fellowship, 1979-1980
Graduated with Honors in Physics; President's Fellow in Physics; Senior Physics Prize, 1979

Total Publications - 10

Device fabrication
Device physics

D. IRVING P. HERMAN

Associate Professor
Department of Applied Physics
Columbia University
202 S.W. Mudd
New York, NY 10027
(212) 280-4456

Education

Ph.D., Physics, Massachusetts Institute of Technology, 1977
B.S., Physics, Massachusetts Institute of Technology, 1972

Professional History

1986 - present:	Associate Professor, Columbia University
1986:	Co-organizer and Chairman of the Symposium on Photon, Beam, and Plasma Stimulated Chemical Processes on Surfaces held at the Materials Research Society National meeting
1985:	Advisory Committee, International Laser Science Conference
1983:	Symposium Organizer and Chairman, International Conference on Lasers, Laser Isotope Separation Symposium
1977-1986:	Professional staff member, University of California, Lawrence Livermore National Laboratory
1983 - 1988:	Thesis Advisor, Ph.D. Candidates from the Department of Applied Science, University of California at Davis, Livermore Campus
1981 - 1986:	Section Leader, Special Studies Group, Physics Department
1977:	Postdoctoral Scientist, M.I.T., Physics Department
1972 - 1977:	Fannie and John Hertz Predoctoral Research Fellow, M.I.T., Physics Department

Special Grants, Awards and Appointments

1977:	National Research Council Postdoctoral Fellow (declined)
1972-1977:	Fannie and John Hertz Predoctoral Fellow
1977:	Phi Beta Kappa
1972:	National Science Foundation Fellowship (declined)

Professional Memberships

American Physical Society
Materials Research Society
American Chemical Society
Institute of Electrical Engineers

Publications - 42

Optical diagnostics
Optical physics of solid state

E. RICHARD M. OSGOOD, JR.

Higgins Professor of Electrical Engineering
Professor of Applied Physics
Department of Electrical Engineering
1330 S. W. Mudd Building
New York, NY 10027
(212) 280-4462

Education

Ph.D., Massachusetts Institute of Technology, 1973
M.S., Ohio State University, 1968
B.S., U.S. Military Academy, 1965

Professional History

1988-present:	Higgins Professor of Electrical Engineering, Columbia University
1982-present:	Professor, Departments of Electrical Engineering and Applied Physics, Columbia University
1986-present:	Director, Columbia Microelectronics Science Laboratories
1984-present:	Co-Director, Columbia Radiation Laboratory
1983 - 1986:	Acting Director, Columbia Microelectronics Sciences Laboratories
1981 - 1982:	Associate Professor, Department of Electrical Engineering, Columbia University
1980 - 1981:	Project Leader, Direct-Write Processing Program, Lincoln Laboratory, MIT
1973 - 1980:	Staff Member, Lincoln Laboratory, Massachusetts Institute of Technology
1976(August):	Visiting Scientist, Los Alamos Scientific Laboratory
1966 - 1969:	Research Officer (Capt.), U.S.A.F. Avionics Laboratory
1965 - 1966:	Research Officer, U.S.A.F., Materials Laboratory

Special Grants, Awards, and Appointments

Fellow, Institute of Electrical and Electronic Engineers (IEEE)
Editorial Board, Laser Focus Magazine, 1970 - present
Co-Editor, Applied Physics, 1983 - present
Consultant, industrial and national laboratories
Advisory Board, MIT Spectroscopy Lab
Organizer, First and Third Materials Research Society Symposium on Laser Photochemical Diagnostics and Processing, 1982, 1984
Member, Materials Research Council, Defense Advanced Research Projects Agency
Visiting Board, Los Alamos Scientific Laboratory (Chemistry and Laser Division)
Associate Editor, IEEE Journal of Quantum Electronics, 1981 - 1988
Councilor, Materials Research Society, 1983 - 1987
Member, DOE Energy Research Advisory Panel, 1980
Hertz Foundation Predoctoral Fellow at M.I.T., 1970 - 1973
Samuel Burka Award (with Dr. W. Eppers) for the best technical paper at the Air Force Avionics Laboratory, 1968

Patents - 5
Publications - 147
Advanced device fabrication techniques
Surface physics
Physical chemistry

F. NICHOLAS J. TURRO
William P. Schweitzer Professor of Chemistry
Department of Chemistry
Columbia University
New York, NY 10027
(212) 280-2175

Education

Ph.D., California Institute of Technology, 1963 (George S. Hammond, Advisor)
NSF Postdoctoral Fellow, Harvard University, 1963-64
(Paul D. Bartlett, Advisor)
B.A., Wesleyan University (Connecticut)

Professional Experience

1981 - present, Wm. P. Schweitzer Professor of Chemistry, Columbia University
1981-84, Chairman, Department of Chemistry, Columbia University
1969-81, Professor of Chemistry, Columbia University
1967-69, Associate Professor of Chemistry, Columbia University
1965-67, Assistant Professor of Chemistry, Columbia University
1964-65, Instructor of Chemistry, Columbia University

Awards

1984, Phi Lambda Upsilon's Urey Award at Columbia University
1984, Sherman Fairchild Distinguished Scholarship at Caltech
1984, John Simon Guggenheim Memorial Foundation Fellowship (Oxford, England)
1983, U.S. Department of Energy's Ernest Orlando Lawrence Memorial Award
1981, Elected Member, American Academy of Arts and Sciences
1981, Elected Member, National Academy of Sciences
1977, N.Y. Academy of Science Halpern Award in Photochemistry
1974, ACS National Award in Pure Chemistry
1973, Phi Lambda Upsilon's National Fresenius Award in Chemistry
1972, Fellow of the N.Y. Academy of Science
1966-70, Alfred P. Sloan Fellowship

Total Publications - 360

Surface chemistry
Organic Photochemistry

G. WEN I. WANG

Professor of Electrical Engineering
Columbia University
1312 S.W. Mudd
New York, NY 10027
(212) 280-3103

Education

Ph.D., Electrical Engineering, Cornell University, Ithaca, NY, 1981
M.E.E.. Cornell University, 1979
B.Sc., Physics, National Taiwan University, 1975

Professional History

1986 - present:	Professor, Columbia University
1983 - present:	Research Staff Member, IBM Research Center, Yorktown Heights
1981 - 1982:	Member of the Technical Staff, Microelectronics Research and Development Center, Rockwell International, Thousand Oaks, California 91360
1975 - 1977:	Taiwan Military Service (compulsary)

Special Grants, Awards and Appointments

IBM Patent Award: L.L. Chang, L.Esaki, W.I. Wang, "Light Hole Semiconductor Devices," Docket No. Y0984-034, filed April 24, 1985.

Professional Memberships

Institute of Electrical and Electronics Engineers
American Physical Society

Publications - 40

Molecular beam epitaxy
Ultrafast devices
Solid state physics

H. EDWARD S. YANG

Professor and Chairman
Department of Electrical Engineering
1307 S.W. Mudd
New York, NY 10027
(212) 280-3120

Education

Ph.D., Yale University, 1965
M.S.E.E., Oklahoma State University, 1961
B.S.E.E., Taiwan Cheng-Kung University, 1957

Professional History

1987 - present:	Chairman, Department of Electrical Engineering, Columbia University
1975 - present:	Professor, Department of Electrical Engineering and Computer Science, Columbia University
1985 - 1986:	Visiting Professor, University of California - Irvine
1978 - 1979:	Research Staff Member, IBM T.J. Watson Research Center (on sabbatical leave from Columbia)
1970 - 1975:	Associate Professor, Department of Electrical Engineering and Computer Science, Columbia University
1970 and 1973:	Summer Faculty Member, IBM T.J. Watson Research Center
1965 - 1970:	Assistant Professor, Department of Electrical Engineering and Computer Science, Columbia University
1963 - 1965:	Laboratory Assistant, Yale University
1961 - 1963:	Junior and Associate Engineer, IBM Corporation, Poughkeepsie

Professional Memberships

IEEE
Sigma Xi
American Physical Society
Materials Research Society

Total Publications - 92

Metal Semiconductor Interfaces
Novel Device Structures
Surface Physics

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