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13. ABSTRACT *(Maximum 200 words)*
An assortment of instruments to support our on going research was proposed for acquisition and the proposal was approved. They consisted of a Tektronix TDS 800 Sampling Scope with one optical head (80C03) and two electrical heads for dual channel operation (SOEO1), a Keithley model 4200 DC parameter Analyzer, a Westbond wire bonder, which is capable of wedge and bond bonding with piezoelectric motion controls, and design and manufacturing of a custom deposition chamber which will utilize the gas delivery and exhaust components of our existing MOCVD system. Even though the MOCVD deposition system design was submitted, and finds committed, to McAllister Technical Services of Coeur d'Alene, Idaho well in time for the project to be completed within one year after awarding of this grant, the manufacturing has not yet been completed. This is a very reputed machine shop, one that many scientists go to for quality work. We expect thc delivery in a few months, but no set date is being provided yet. Only a portion, see the attached budget details, of the approximately $50,000 is being charged against this grant.

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DURIP 01 Final Report for

Request for Critical Equipment to Pursue Semiconductor Research at Virginia Microelectronics Center (VMC)

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Summary

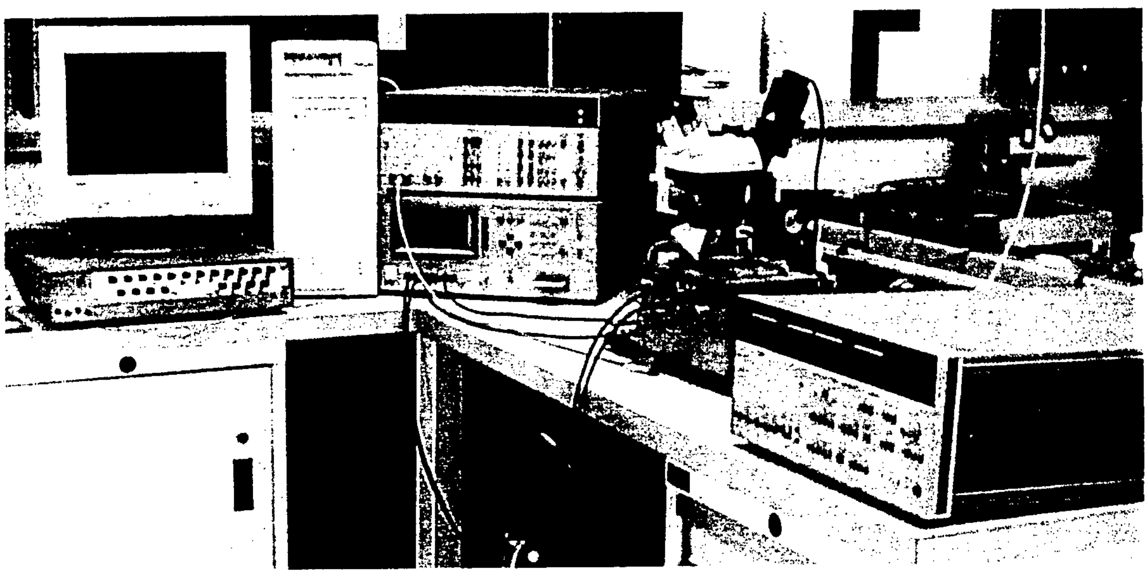
An assortment of instruments to support our on going research was proposed for acquisition and the proposal was approved. They consisted of a Tektronix TDS 800 **Sampling Scope** with one optical head (80C03) and two electrical heads for dual channel operation (80E01), a Keithley model 4200 **DC parameter Analyzer,** a Westbond **wire bonder**, which is capable of wedge and bond bonding with piezoelectric motion controls, and design and manufacturing of a **custom deposition chamber** which will utilize the gas delivery and exhaust components of our existing MOCVD system. Even though the MOCVD deposition system design was submitted, and funds committed, to McAllister Technical Services of Coeur d'Alene, Idaho well in time for the project to be completed within one year after awarding of this grant, the manufacturing has not yet been completed. This is a very reputed machine shop, one that many scientists go to for quality work. We expect the delivery in a few months, but no set date is being provided yet. Only a portion, see the attached budget details, of the approximately $50,000 is being charged against this grant.

All of this equipment listed above, with the exception of the MOCVD deposition chamber, has been acquired and installed, are now an integral part of our ongoing research. Some brought about new capabilities such as the sampling scope, wire bonder, and some enhanced our capabilities such as the parameter analyzer, and some simply replaced aging pumps such as the mechanical backing pump.

DC parameter analyzer for IV measurements:

High power (1 A and 100 V) and low current (down to 0.1 fA range) two and three-terminal, up to 5, I-V measurements are made using a recently introduced **Keithley 4200-SCS Semiconductor Characterization System** in conjunction with Cascade Microtech and Suss

Micro Tec probe stations. Key features of the system are point-and-click Windows-based environment, unique remote PreAmps aided current resolution down to 0.1fA, self-contained PC for faster test setup, power data analysis, graphing and printing, and on-board mass storage of test results. See the photo in location below.



Unique browser-style Project Navigator organizes tests by device type, allows access to multiple tests, and provides test sequencing and looping control. Hardware controlled by the Keithley Interactive Test Environment (KITE). User Test Module function extends KITE for external instrument control and test station integration. See a photo of the rack mount version of a Keithley 4200 parameter analyzer below.

The easy-to-use Model 4200-SCS performs lab grade DC device characterization, real-time plotting, and analysis with high precision and sub-femtoamp resolution. The 4200 SC offers the most advanced capabilities available in a fully integrated characterization system, including a complete embedded PC with Windows NT operating system and mass storage. Its self-documenting, point-and-click interface speeds and simplifies the process of taking data, so users can begin analyzing their results sooner.

Metrics software driven, through a Keithley 708 A electronic switch box, I-V and C-V measurement set-up is also available. The system utilizes HP (now Agilent Technologies) 4284A and 4275A for C-V and 4140B and 4145A for I-V units in a convenient manner. The selection of measurement type is made through the software, and the electronic switch box makes the required connection from the device under test (under a probe station) to the appropriate instrument, and the PC acquires the data

Westbond versatile wire bonder

The West Bond Model 545657Econvertible semi-automatic wedge-wedge or ball-wedge bonder is instrumental in device research. This bonder provides the ability to electrically connect the device to external terminals. With the device protected, the device can then be used in a much more general manner and allows special measurements with greater accuracy to be performed. The bonding head use ultrasonic vibrations in addition to thermal heating to make the electrical connection both mechanically stable and electrically conductive. The bonder uses 0.0007" to 0.002" diameter gold wire to attach the devices to the external leads.

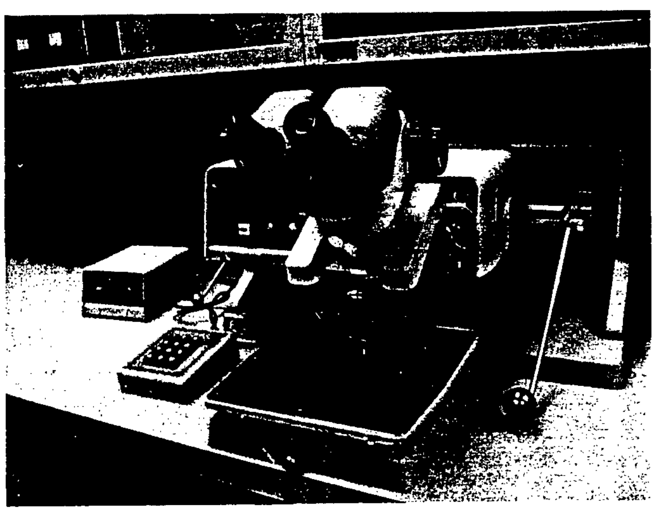
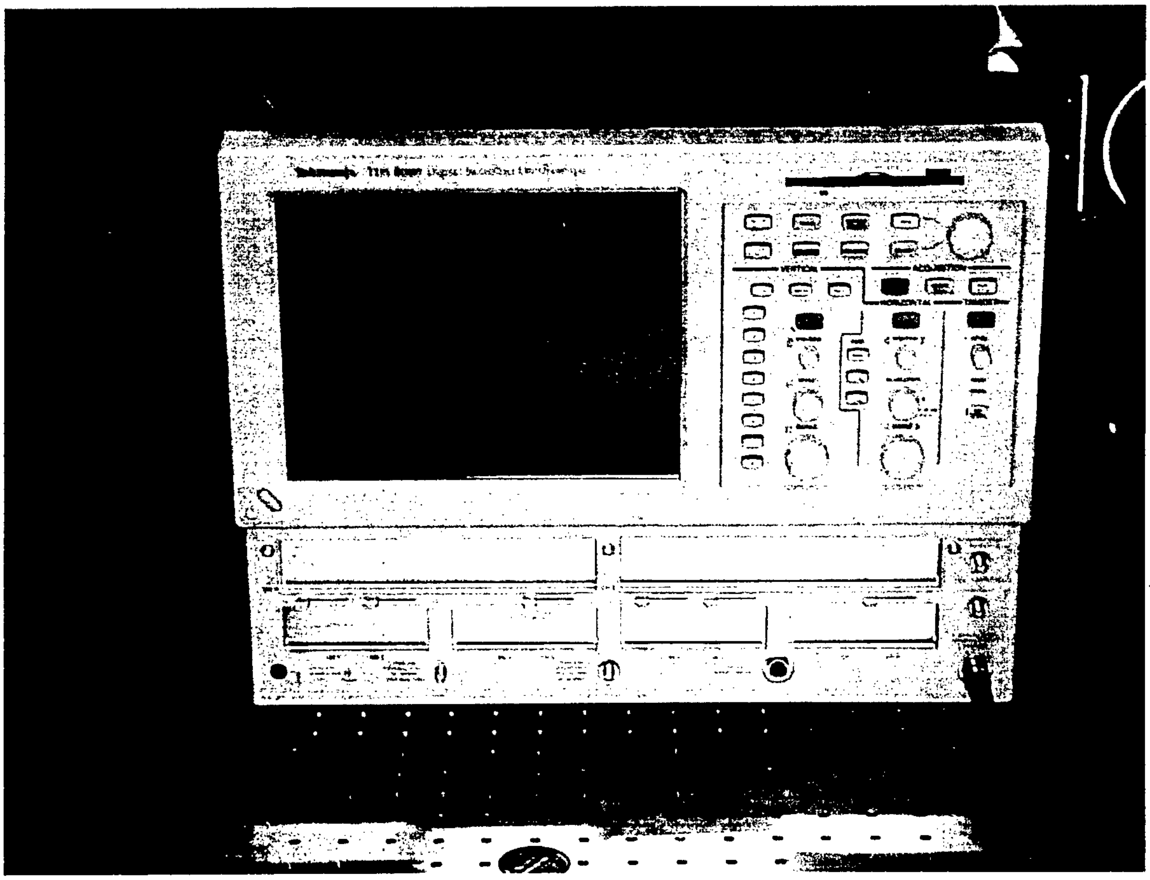


Figure: Westbond ball and wedge bonder installed in the Virginia Microelectronics Center.

Sampling scope:

A high Performance Digital Sampling Oscilloscope, Tektronix Model TDS 800, with one optical head (80C03) and two electrical heads for dual channel operation

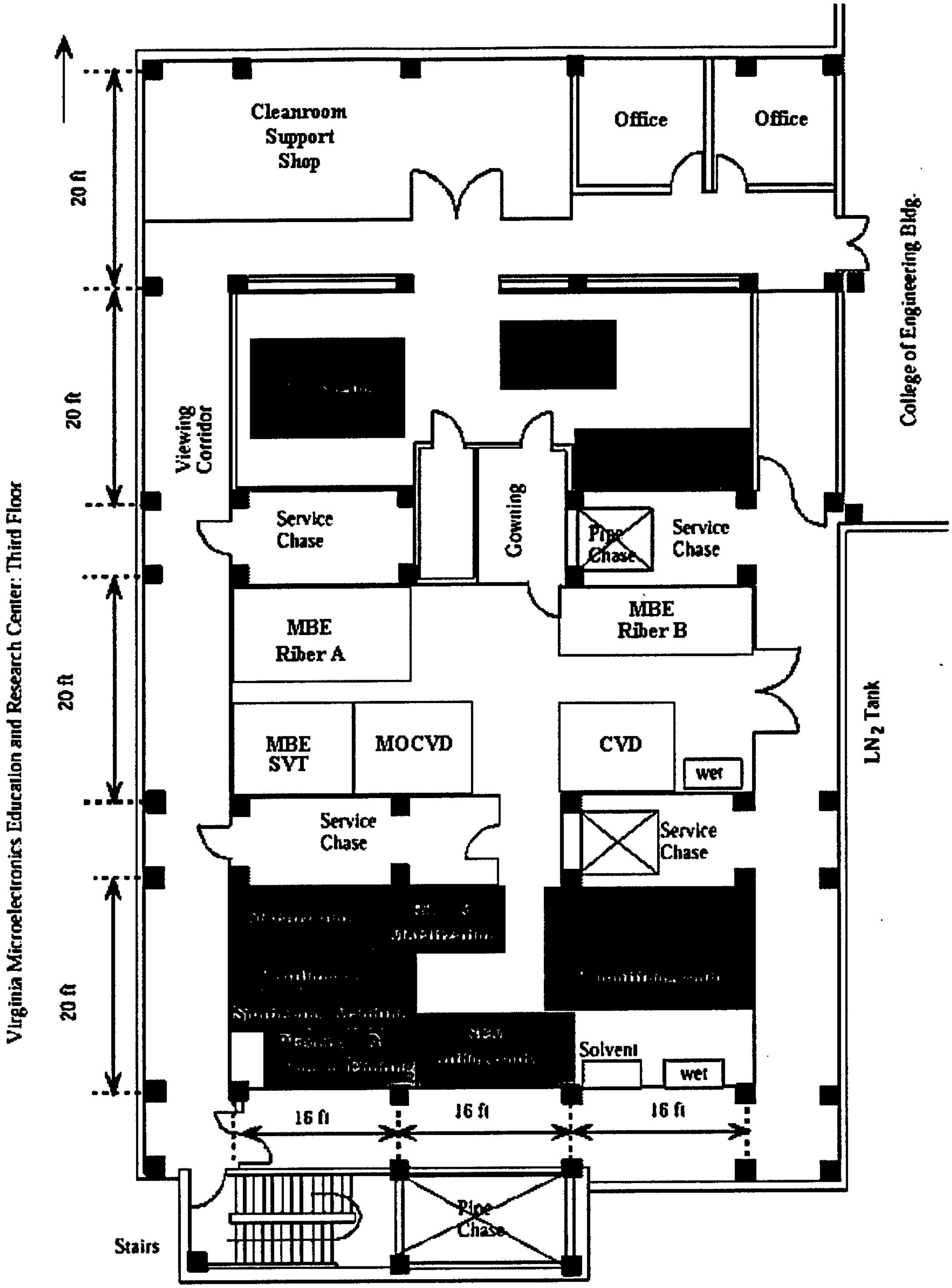
(80E01) has been acquired to add temporal capabilities. The detector for this purpose is a ICCD 200 ps cooled CCD, and or a Metal-Semiconductor-Metal High Speed (5 GHz) detector. The laser used is a diode pumped Ti Sapphire pulsed laser with temporal capability of 1 –30 ps. See the picture below of the Tektronix Model TDS 800 sampling scope in our laboratory.



MOCVD deposition chamber

A vertical MOCVD deposition chamber is being built by McAllister Technical Services of Coeur d'Alene, Idaho. This system will utilize the gas mixture chamber fabricated by Emcore Corporation which we already have. The system utilizes materials, specifically those used for heaters and sample holders, etc., that are resistant to harsh chemical environments such as high temperatures in the presence of ammonia and hydrogen. Appropriate differential pumping, shielding and cooling are provided for smooth and maintenance free operation over long periods of time. Interactive and animated system and component designs are in our possession but are not provided as part of this document. The new deposition chamber was necessitated because the existing sample holder and heater do not stand well in the harsh environment mentioned above, despite manufacturers claims. In order to utilize the existing system, we had to operate under ceiling temperature of 950 °C which is inadequate both in terms of annealing the low temperature buffer layer and in terms of growing GaN of the quality required. Temperatures above 1050°C are required. The new system is designed for a ceiling temperature of 1200 °C with 1100 °C being the maximum operating temperature we anticipate of using.

The floor plan of the clean room and Electrical measurement capabilities are shown in the following diagram. For an interactive version of it, please visit the URL for our laboratory http:// www.engineering.vcu.edu/fac/morkoc



Floor plan of the clean room and Measurement Laboratory

Budget allocation and detailed equipment purchases

Morkoc, Hadis — Equipment Grants — Updated:

Acct. #	Agency	Agency #	Start	End		Amount
5-28695	AFOSR	F49620-01-1-0253	4/1/2001	3/31/2002		$120,271.00
	Sampling Scope - Tektronix, Inc. - est. $56,000 Less SoEgr Part for Instructional Lab				*P395283*	*$55,283.25 complete ($47,674.50)*
	Metal-Semiconductor-Metal High Speed Detector - est $5000				*R418473*	*$5,000.00 complete*
	DC Parameter Analyzer - est. $47,000				*P395196*	*$54,607.95 complete*
					P396399	*$2,018.00 complete*
	Wire Bonder - est. $22,325 (see cost sharing)					
**	*Effusion Cells - originally slated for 5-28686*				*R427911*	*$10,540.00 complete*
**	*Polishing Unit - originally slated for 5-28686*				*P407473*	*$19,514.00 complete*
**	*McAllister-Prelim Design for MOCVD System*				*P454053*	*$4,950.00 ordered*
**	*South Bay Technology-Diamond Wheel Saw*				*P451980*	*$3,908.12 complete*
**	*BOC Edwards - Dry Vacuum Pump*				*P451436*	*$1,836.20 complete*
**	*McAllister-Fabrication-Wafer Treatment System*				*R454477*	*$10,321.10 ordered*
1-37162	*Cost Sharing of $21,224 (15%)*				*P396383*	*$21,224.00 complete*
	Total Expenditures/Commitments					**$120,304.12**
	Cost Sharing					**$21,224.00**
	Grand Total					**$141,528.12**
	Balance Remaining/Available for Expenditure					**-$33.12**

Biographical Sketch of the Principal Investigator

Hadis Morkoç

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Education

1973 - 1975 Ph.D. degree in Electrical Engineering, Cornell University
1971 - 1973 Ph.D. candidate in Electrical Engineering, Michigan State University
1968 - 1969 MS degree in Electrical Engineering, Istanbul Technical University
1964 - 1968 BS degree in Electrical Engineering, Istanbul Technical University

Professional experience

1997-present: Founders Professor of Electrical Engineering and Physics Department, Virginia Commonwealth University, Richmond, VA.
1995 – 1998:University Resident Research Professor, Wright Laboratory, Wright Patterson Air Force Base, OH.
1987 – 1988:Distinguished Visiting Scholar, Jet Propulsion Laboratory and California Institute of Technology, Pasadena, CA.
1978 – 1997:Assistant and Associate Professor of Electrical Engineering and Research Associate Professor of Coordinated Science Laboratory, Univ. of Illinois, Urbana-Champagne, IL.
1986 – 1997:Graduate Faculty, Dept. of Physics and Material Science and Engineering, Univ. of Illinois, Urbana-Champagne, IL.
1978 – 1979:Resident Member of Technical Staff, AT&T Bell Laboratories.
1976 – 1978:Member of Technical Staff, Central Research Laboratories, Varian Associates, Palo Alto, CA.
1975 – 1976:Postdoctoral Fellow, School of Electrical Engineering, Cornell University, Ithaca, NY.

Professional affiliations

Fellow: Institute of Electrical and Electronics Engineers (IEEE)
Fellow: American Association for the Advancement of Science (AAAS)
Fellow (life): American Physical Society (APS)
Member: Material Research Society (MRS), Optical Society of America (OSA), Eta Kappa Nu, Sigma Pi Sigma
Life member: Sigma Xi, Phi Kappa Phi
Listed in Who's Who in the Midwest, American Men and Women in Science, Who's Who in America, Who's Who in Engineering, and International Men of Achievement.

PUBLICATIONS

Some 1100 publications, 37 book chapters, 42 review and popular articles, a two-volume book on MODFETs, a book on Nitride Semiconductors and Devices (second edition is in process), editor of a three volume book on nano and biotechniques. According to Institute of Scientific Information and since 1982, the research papers of Dr. Morkoç have been cited some 15, 000 times. Moreover, in a field encompassing, condensed matter physics, electronic materials, metallurgy, ceramics, polymers, and materials chemistry, and in the five year period 1990 - 1995 and for all publications world-wide: Dr. Morkoç was listed as 18th and 4th in the total number of citations and the Citation Impact (number of citations per paper), respectively, see Science Watch, Vol. 6, No. 9, October 1995, and the Journal Science, October 20, 1995. According to the same organization, Morkoç ranked 19th among 517,111 physicists in terms of citations and citation impact between 1981 and 1997. There ahead of him were collective efforts of several physicists who shared the same last and first names. He is only one in nine who are listed in more than one category, which in his case are Engineering and Physics.

Most recent papers:

1. P. Visconti, K. M. Jones, M. A. Reshchikov, R. Cingolani, H. Morkoç, and R. Molnard, "Investigation of defects in GaN by photo-electrochemical and hot wet etching" Appl. Phys. Lett., Vol. 77, pp.3532-3535, (2000).

2. P. Visconti, K. M. Jones, M. A. Reshchikov, F. Yun, R. Cingolani, H. Morkoç, S. S. Park and K. Y. Lee, "Characteristics of Free Standing Hydride Vapor Phase Epitaxy Grown GaN with very low defect concentration", Appl. Phys. Lett., Vol. **77** (23), pp. 3743-3745, (2000).

3. M. A. Reshchikov, P. Visconti, and H. Morkoç, "Blue photoluminescence activated by surface states in GaN", Appl. Phys. Lett., vol.78, no.2, pp.177-179, 8 Jan. 2001.

4. F. Yun, M. A. Reshchikov, K. M. Jones, P. Visconti, H. Morkoç, S. S. Park and K. Y. Lee, "Electrical, Structural, and Optical Characterization of Free-standing GaN Template Grown by Hydride Vapor Phase Epitaxy", Solid State Electronics, Vol. **44**, pp. 2225 (2000).

5. Michael A. Reshchikov, Paolo Visconti, Hadis Morkoç, Richard J. Molnar and Cole W. Litton, "Blue Photoluminescence Activated by Surface States in GaN" International Workshop on Nitride Semiconductors, Sept. 25-27, 2000, Nagoya, Japan.

6. F.Yun, M.A.Reshchikov, P.Visconti, K. Jones, D-F Wang, Marc Redmond, Jie Cui, C. W. Litton, and H. Morkoç, "Investigation of buffer layers for GaN grown by MBE" Fall MRS, 2000.

7. M. Dietrich, A. Hoffmann, T. Riemann, J. Christen, M. Reshchikov, J. Cui, H. Morkoç' "Correlation of structure and spectral emission characteristics of GaN nano-islands", Fall MRS, 2000.

8. K. M. Jones, P. Visconti, F. Yun, M. A. Reshchikov, A. A. Baski, and H. Morkoç "Surface structure and polarization effects in GaN Thin Films as studied by Electric Force Microscopy", Fall MRS, 2000.

9. P.Visconti, M.A.Reshchikov, K.M.Jones, F.Yun, D.F.Wang, R.Cingolani, C. W. Litton, R. Molnar, and H. Morkoç "High selective photoenhanced wet etching of GaN for device fabrication and defect investigation", Fall MRS, 2000.

10. M. A. Reshchikov, J. Cui, P. Visconti, F. Yun, and H. Morkoç "Photoluminescence study of defects in GaN grown by molecular beam epitaxy" Fall MRS, 2000.

11. M.A.Reshchikov, J. Cui, F.Yun, P.Visconti, M. I. Nathan, R. Molnar, and H. Morkoç "Growth and investigation of GaN/AlN quantum dots" Fall MRS, 2000.

12. Z-Q. Fang, D. C. Look, and H. Morkoç, "Electron and hole traps in GaN p-i-n photodetectors grown by reactive molecular beam epitaxy" J. Electronic Materials, Vol. 29, No. 9, pp. L19-L23, 2000.

13. P. Visconti, M. A. Reshchikov, K. M. Jones, D. F. Wang, R. Cingolani, H. Morkoç, R. J. Molnar, and D. J. Smith, "Highly selective photo electro-chemical etching of nitride materials for defect investigation and device fabrication" J. Vac. Sci. and Technol, vol.19, no.4, pp.1328-1333, July 2001.

14. P. Visconti, K. M. Jones, M. A. Reshchikov, F. Yun, H. Morkoç, R. J. Molnar, A. Passaseo, R. Cingolani, S. S. Park, and K. Y. Lee "Investigation of the surface polarity, defects, electrical and optical properties of GaN grown by MBE. MOCVD and HVPE" Proc. of the ECS Meeting March 26-30, 2001, in "III-Nitride Based Semiconductor Electronics and Optical Devices and Thirty fourth State-of-the-art Program on Compound Semiconductors (SOTAPOCS XXXIV) pp. 52-70, Eds. F. Ren, D. N. Buckley, S. N. G. Chu, and S. J. Pearton,

15. K. M. Jones, P. Visconti, F. Yun, A. A. Baski, and H. Morkoç, "Investigation of Inversion Domains in GaN by Electric Force Microscopy, Appl. Phys.Letts., vol.78, no.17 , pp.2497-2499, 23 April 2001.

16. Z-Q. Fang, D.C. Look, P. Visconti, D-F.Wang, C-Z. Lu, F. Yun, H. Morkoç, S.S. Park and K.Y. Lee, "Deep centers in a free-standing GaN Template", Appl. Phys. Letts. Vol. 78, No. 15, pp. 2178-2181, 2001.

17. J. Jasinski, W. Swider, Z. Liliental-Weber, P. Visconti, K. M. Jones, M. A. Reshchikov, F. Yun, H. Morkoç, S. S. Park and K. Y. Lee, "Characterization of free-standing HVPE GaN" Appl. Phys. Letts, Vol. 78, pp. 2297-2299, 2001.

18. J.T. Wolan, A. Gopalkrishna, S.E. Saddow, M. Mynbaeu, H. Morkoç, M.Reshchikov, F.Yun, V. Dmitriev, and C.E.C. Wood, "Characterization of GaN MBE Epitaxial Layers Grown on Nanoporous 6H-SiC Substrates", Fall MRS, 2000.

19. M. A. Reshchikov, F. Yun, H. Morkoç, S. S. Park and K. Y. Lee, "Transient Photoluminescence of defect transitions in free-standing GaN template" Appl. Phys. Lett., Vol. 78, pp. 2882-2291, 2001.

20. M. A. Reshchikov, H. Morkoç, S. S. Park and K. Y. Lee, "Yellow and green luminescence in free-standing GaN template" Appl. Phys. Letts. Vol. 78 (No. 20), pp. 3041-3044 (2001).

21. D. Huang, F. Yun, P. Visconti, M. A. Reshchikov, D. Wang, H. Morkoç, D. L. Rode, L. A. Farina, Ç. Kurdak, K. T. Tsen, S. S. Park and K. Y. Lee, "Hall mobility and carrier concentration in GaN free-standing templates grown by hydride vapor phase epitaxy with high quality" Solid State Electronics, Vol. 45(5), pp.711-715 (June 2001).

22. M. A. Reshchikov, P. Visconti, K. M. Jones, H. Morkoç, R. J. Molnar, and C. W. Litton, "Recombination at surface states in GaN" Spring 2001 MRS meeting April 2001, San Francisco.

23. M. A. Reshchikov H. Morkoç, and R. J. Molnar, "Photoluminescence and Excitation spectra of Deep Defects in GaN", Spring 2001 MRS meeting April 2001, San Francisco.

24. F. Yun, P. Visconti, K. M. Jones, A. A. Baski, H. Morkoç, A.Passaseo, Piscopiello, M. Catalano and R. Cingolani, "Characterization of Inversion Domains in GaN by Wet Chemical Etching and Electric Force Microscopy", Spring 2001 MRS meeting April 2001, San Francisco.

25. P. Visconti, M. A. Reshchikov, F. Yun, K. M. Jones, H. Morkoç, A. Passaseo, E. Piscopiello, A. Pomarico and R. Cingolani, M. Lomascolo, M. Catalano, "Structural, optical and electrical properties of GaN films grown by metalorganic chemical vapor deposition on sapphire" Spring 2001 MRS meeting April 2001, San Francisco.

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27. P. Visconti, K. M. Jones, M. A. Reshchikov, R. Cingolani, H. Morkoç, R. J. Molnar, and D. J. Smith, "Defect investigation of GaN thin films etched by

photo-electrochemical and hot wet etching by atomic force and transmission electron microscopy", Spring 2001 MRS meeting April 2001, San Francisco.

28. P. Visconti, M. A. Reshchikov, K. M. Jones, F. Yun, R. Cingolani, H. Morkoç S. S. Park and K. Y. Lee, "Characterization of very low defect-density free-standing GaN substrate grown by Hydride-Vapor-Phase-Epitaxy", Spring 2001 MRS meeting April 2001, San Francisco.

29. D. Huang, P. Visconti, K. M. Jones, M. A. Reshchikov, F. Yun, A. A. Baski, T. King and H. Morkoç, "Dependence of GaN polarity on the parameters of the buffer layer grown by molecular beam epitaxy" Appl. Phys. Letts., Vol. 78, pp. 4145-4147, June 2001.

30. A.A. Baski, K.M. Jones, P. Visconti, F. Yun, and H. Morkoç, "Electric Force Microscopy Studies of GaN Films to Determine Local Surface Polarity", A conference in Canada.

31. G. Webb-Wood, Ü. Özgür, H. O. Everitt, F. Yun, T. King, and H. Morkoç, "Ordinary and Extraordinary Refractive Indices of AlGaN films in the Entire Composition Range", Proc. of International Conference on Nitride Semiconductors, July 2001 Denver CO USA.

32. D. Huang, P. Visconti, M. A. Reshchikov, F. Yun, T. King, A. A. Baski, C. W. Litton, and H. Morkoç, "Dependence of GaN polarity on the parameters of the buffer layer grown by molecular beam epitaxy" Proc. of International Conference on Nitride Semiconductors, July 2001 Denver CO USA.

33. P. Visconti, F. Yun, D. Huang, K. M. Jones, M. A. Reshchikov, R. Cingolani, H. Morkoç, J. Jasinski, W. Swider, and Z. Liliental-Weber, "Investigation of defects and surface polarity in GaN using hot wet etching together with Atomic Force and Transmission Electron Microscopy and Convergent Beam Electron Diffraction" Proc. of International Conference on Nitride Semiconductors, July 2001 Denver CO USA.

34. Y. Shishkin, R.P. Devaty, W.J. Choyke, Feng Yun, T. King and H. Morkoç, "Near Bandedge Cathodoluminescence Studies of AlN Films: Dependence on MBE Growth Conditions" Proc. of International Conference on Nitride Semiconductors, July 2001 Denver CO USA.

35. F. Yun, D. Huang, M. A. Reshchikov, T. King, A. A. Baski, C. W. Litton, J. Jasinski, Z. Liliental-Weber, and H. Morkoç, "A Comparative Study of MBE-grown GaN Films Having Predominantly Ga- or N-polarity" Proc. of International Conference on Nitride Semiconductors, July 2001 Denver CO USA.

36. Hadis Morkoç, "III-Nitride semiconductor growth by MBE: Recent issues", Journal of Material Science: MEL, Ed. Safa Kasap AFOSR, ONR, and NSF.

37. D. Huang, C. W. Litton, M. A. Reshchikov, F. Yun, T. King, A. A. Baski, and H. Morkoç, "Improvement in Crystal Quality of GaN Films with Quantum Dots as Buffer Layers Grown on Sapphire Substrates by Molecular Beam Epitaxy", Proc. of International Symposium on Compound Semiconductors, Sept. 2001, Japan

38. D. Huang, C. W. Litton, M. A. Reshchikov, P. Visconti, F. Yun, T. King,[1] A. A. Baski, J. Jasinski, Z. Liliental-Weber, and H. Morkoç, "Characterization of GaN/AlN Films with Different Polarities Grown by Molecular Beam Epitaxy on Sapphire Substrates" Proc. of International Symposium on Compound Semiconductors, Sept. 2001, Japan

39. T. A. Eckhause, Ö. Süzer, A. Manasson, Ç. Kurdak, F. Yun and H. Morkoç, "Study of Energy Relaxation and Heat Flow in GaN and GaN/AlGaN Heterostructure Using Thermal Noise Measurements", Fall 2001 Materials Society Meeting, November 2001,Boston, USA.

40. M. A. Reshchikov, D. Huang, H. Morkoç, and R. J. Molnar, "Photoluminescence study of Zn in GaN", Fall 2001 Materials Society Meeting, November 2001, Boston, USA.

41. M. A. Reshchikov, H. Morkoç, S. S. Park and K. Y. Lee, and R. J. Molnar, "Photoluminescence study of deep-level defects in undoped GaN", Fall 2001 Materials Society Meeting, November 2001,Boston, USA.

42. M. A. Reshchikov, D. Huang, F. Yun, H. Morkoç, and C. W. Litton, "Excitons bound to structural defects in GaN", Fall 2001 Materials Society Meeting, November 2001, Boston, USA.

43. Hadis Morkoç, "GaN-Based Modulation Doped FETs and Heterojunction Bipolar Transistors" in Recent and Evolving Advanced Semiconductor and Organic Nano-technologies, Academic Press, Ed. H. Morkoç, in press.

44. Hadis Morkoç, Aldo Di Carlo, and R. Cingolani, "GaN-Based Modulation Doped FETs" Low dimensional nitride semiconductors" edited by B.Gil, Oxford University Press, Oxford UK, in press.

45. T. K. Joihal, R. I. R. Blyth, E. Branca, R. Cingolani, A. Pesci, M. Pedio, M. Lomascolo, L. Ottaviano, A. Botchkarev, and H. Morko, "Bulk Defect Driven Restructuring of the GaN (0001) Surface: A Core Level Photoemission Lowe-Energy Electron Diffraction Study of [0001] Oriented GaN thin-films grown on Si (111).

46. Ümit Özgür, Grady Webb-Wood, Henry O. Everitt, Feng. Yun, and Hadis Morkoç, "Systematic measurements of $Al_xGa_{1-x}N$ refractive indices", Appl. Phys. Letts., pending.

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C. Recent Collaborators:

R. T. Williams (Wake Forest Univ.); C. W. Litton, D. C. Look. D. Reynolds, C. W. Litton (Air Force Laboratories); K. T. Tsen, S. Mahajan and D.J. Smith (Arizona State);J. Jasinski and S. Liliental-Weber (Univ. of California and Lawrence Berkeley Laboratory); R. Cingolani, (University of Lecce, Italy), D. Smith and K. T. Tsen, (Arizona State); F. Pollak (Brooklyn), A. DiCarlo, Rome University, S. S. Park and K. Y. Lee (Samsung), H. Everitt, H. C. Casey and S. Teitsworth (Duke University), R. J. Molnar (Lincoln Laboratory), R. Alfano (CUNY), Dan Rode (Washington University), R. Feenstra (Carnegie Mellon), T. S. Kuan (SUNY Albany), W. J. Choyke and R. Devaty (University of Pittsburgh).

D. Graduate students sponsored by PI:
T. Lehrer, G. Martin, D-G. Park, J. Reed, Z. Fan, C. Lu, G.B. Gao, G. Popovici, B. Sverdlov, F. Hamdani, A. Salvador, S.N. Mohammad, A. Botchkarev, H. Tang, S. Unlu, J. Chen, T. Strite, and D. Diatzua

E. Graduate advisor: Prof. L. F. Eastman, Cornell University

Synergistic Activities: The PI has established an undergraduate course in advanced concepts in semiconductors. In conjunction with that course, he trained 9 undergraduate courses on aspects of GaN ranging from growth, lithography, fabrication to analysis. He established the first ever GaN meeting iin the world which has spiraled into major meetings in the world, was instrumental in establishing other domestic and international meetings in GaN and related materials and devices for the dissemination of information. He wrote reports on the status and prospects on wide bandgap semiconductors, which were distributed very widely, and played a critical role in the popularization GaN. He wrote, and continues to do so, critical review papers, book chapters and a book on the topic. He also presented many seminars at numerous institutions, including many business concerns, across the globe to spread the message. He is currently editing a three volume book for Academic Press which brings together scientists from the physical, chemical and biological sciences to treat the topics that are likely to dominate the scientific and technological discourse. Last but not least, he collaborated with some 20 groups across the globe with varying backgrounds to advance the engineering and science of GaN.

Facilities available in the Virginia Commonwealth University Microelectronics RESEARCH LABORATORY (Inclusive of the Hall apparatus)

The micro and nano-electronics research and education is performed in the Virginia Microelectronics Center (VMC), a 27,000 square foot four-story building. The first floor of the VMERC is devoted to silicon technology and undergraduate education. The necessary equipment is being installed as provided by Motorola, Inc. The sponsored research programs are conducted on the third floor of the VMREC which has approximately 2500 square feet of class 1000 space. Even though the laboratory receives new tools continually, already, an MBE system designed for depositing nitride semiconductors has been installed and calibrated. The SVT Reactive MBE system is also equipped with a RF nitrogen source for maximum flexibility. In addition, the workhorse, perhaps the most well known MBE system in the world that the group of Prof. Morkoç has used since 1979, is producing device quality layers. This Riber 1000 MBE system has been converted to reactive MBE system. On the deposition side again, a custom MOCVD system designed for semiconductor nitrides has installed, and optimization runs are in progress. This custom MOCVD system has a gas manifold and deposition reactor which were manufactured by EMCORE Corporation and SVT Associates, respectively. The system gives the group the added flexibility and advantage for nitride research. It has tremendous latitude in terms of gas delivery and eliminates much of the interdependence among the parameters that often hampers conventional MOCVD systems. The group also was fortunate to have received a third MBE system as a gift from Bell Laboratories, Lucent Technologies. On the fabrication side, the research laboratory is equipped with photo and electron beam lithography systems and metallization and etching facilities. The LEO 440 microscope has a 2 nm resolution in the imaging mode and is layered with a Nabity pattern generation system. The research oriented RF dry etching system that was designed in the plasma group at Wright Patterson Air Force Research Laboratory. This system is designed for convenience and low damage and easily configurable for plasma diagnosis for an easy correlation of plasma parameters to etching characteristics.

Through and NSF MRI program, we have added a Philips X'pert MRD high resolution (10 arcsec which can be upgraded to 5) X-ray diffraction system in 1999. X-ray diffraction (XRD) is a versatile analytical technique used in our research to analyze structural properties of crystalline materials. At VCU the system will be used for high resolution applications – such as rocking curves of heteroepitaxial layers; diffraction space maps of thick hetero-epitaxial structures and partially relaxed structures; reflectivity measurements of layer thickness, interface/sample quality and density, and structural properties of nano-structures. The X'Pert - MPD system utilizes specially developed PREFIX (pre-aligned, fast interchangeable) optical modules which enable you to switch from application to application by simply swapping the optical module. Dedicated analytical instrument performance is ensured due to the wear-free reference surfaces on the PREFIX modules. The MRD cradle provides the versatility of an open Eulerian cradle, an x-y stage and z translation to accommodate applications needing utmost accuracy.

Another tool, KLA Tencor Alpha Stepper 500 surface prolifometer, is capable of mapping th e surface topology. This is a very versatile system for precise measurement of very thin step heights on wafers and small samples. Flexible software allows analysis of up to 39 surface parameters with simultaneous display. Moreover, we added a Digital Instruments Nanoscope III multimode AFM with STM capability which is pivotal in characterization layer growth including structural defects and charge states.

Extensive optical characterization facilities, which allow PL, absorption and reflectance measurements in semiconductor nitrides and other samples, also exist. The recently acquired Ti-Sapphire laser with Second Harmonic Generation (SDH) and Third Harmonic Generation (TDH) allows tunable wavelengths in the ranges of 700-100nm and 235-500 nm with picosecond temporal capabilities. In addition, He-Cd, N and Ar lasers are also available. The detection scheme is based on photon counting with excellent signal to noise ratio. The laboratory also has several cryostats. A diamond anvil cell with its associated optics, optical sources, a fast CCD detector, and 1.25 m spectrometer is in the process of being commissioned.

Recently, we added a Lake Shore Model 7504 Hall Effect Measurement System with automatic data acquisition in the temperature range of 10-300 K and magnetic fields up to nearly 1 T. This instrument is used to determine carrier concentrations and mobilities in semiconductors, and allows the determination of scattering processes taking place. A Keitley 4200 parameter analyzer, which is PC based, with below fA and above 1A current measurement capability, and coupled with a Karl Suss PM 8 shielded probe station provides an accurate and rapid evaluation of I-V characteristics. In addition, a temperature dependent I-V and C-V measurement capability is available with metrics software and Keithley electronic switch box for versatility in the choice of instrument connected to the device under test.

The deposition and fabrication laboratories enjoy conveniently delivered utilities such as gaseous and liquid nitrogen, process vacuum, compressed dry air, process cooling water, DI water, scrubbed and regular exhausts, and much more. The airflow system for class 1000 is designed to diffuse the air in a way to be extremely quiet. This combined with all the roughing pumps and compressors being located in service bays lend to a very comfortable and environmentally friendly laboratory space in which to work. Moreover, the group has electrical and optical characterization laboratories giving the researcher full access to a full range of equipment to carry out research without leaving the laboratory. The group has a long term working relationship with many specialists across the country and abroad for research requiring expertise and training not available on site.

For more details, pictures, and layout of the laboratories, please visit http://

www.engineering.vcu.edu/fac/morkoc

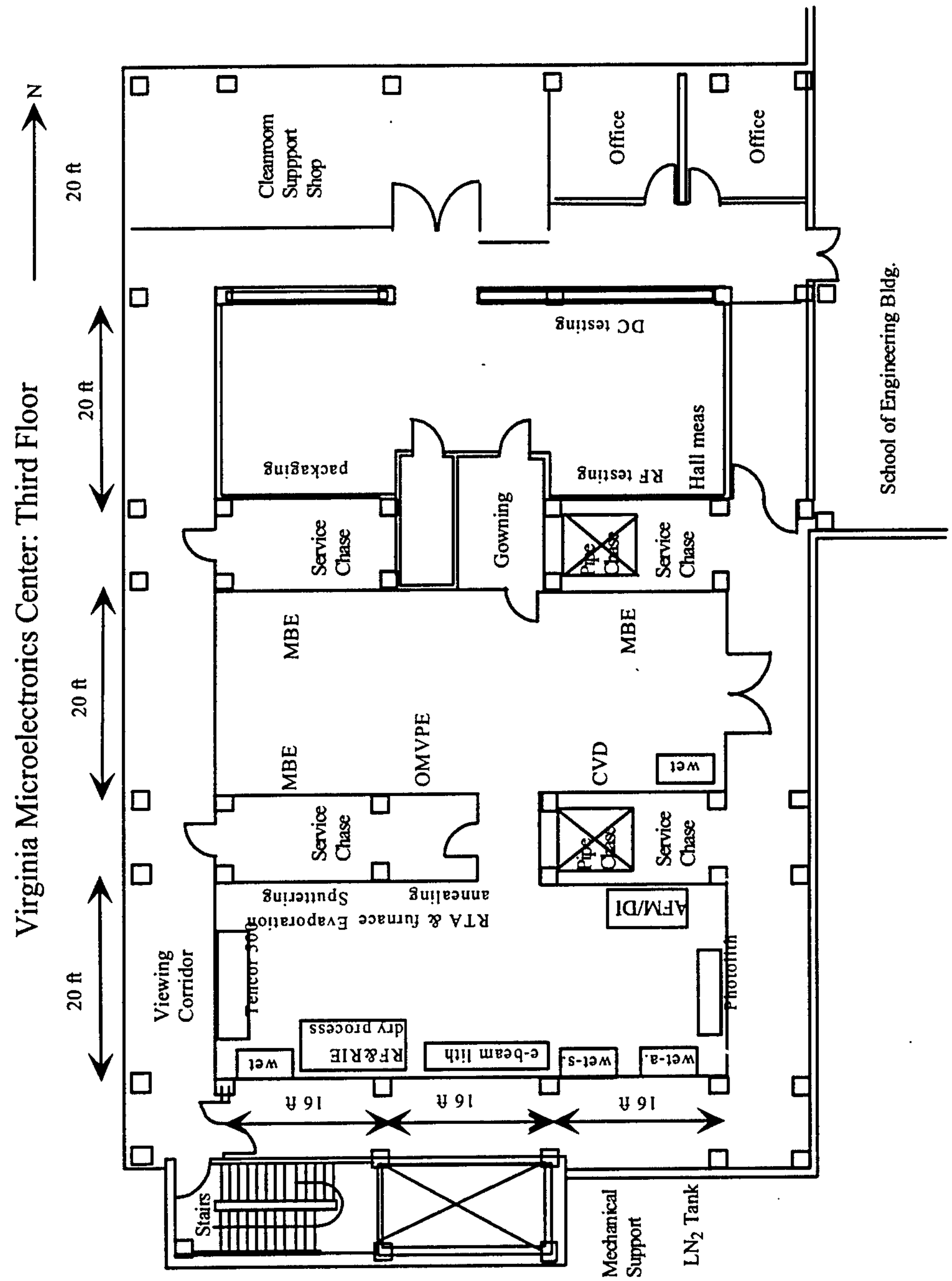

Fig. 1. Layout of the research present equipment and clean room in the Virginia Microelectronics Center. Layout of the research present equipment and clean room in the Virginia Microelectronics Center.