

UNCLASSIFIED  
SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved  
OMB No. 0704-0188

1a. REPORT SECURITY CLASSIFICATION Unclassified		1b. RESTRICTIVE MARKINGS	
2a. SECURITY CLASSIFICATION AUTHORITY		3. DISTRIBUTION / AVAILABILITY OF REPORT Approved for public release; distribution unlimited.	
AD-A213 265		5. MONITORING ORGANIZATION REPORT NUMBER(S)	
		7a. NAME OF MONITORING ORGANIZATION	
6a. NAME OF PERFORMING ORGANIZATION Research Laboratory of Electronics Massachusetts Institute of Technology	6b. OFFICE SYMBOL (if applicable)	7b. ADDRESS (City, State, and ZIP Code)	
6c. ADDRESS (City, State, and ZIP Code) 77 Massachusetts Avenue Cambridge, MA 02139		9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER N00014-83-K-0564	
8a. NAME OF FUNDING / SPONSORING ORGANIZATION Office of Naval Research	8b. OFFICE SYMBOL (if applicable)	10. SOURCE OF FUNDING NUMBERS	
8c. ADDRESS (City, State, and ZIP Code) 800 North Quincy Street Arlington, VA 22217		PROGRAM ELEMENT NO. 400x029y	TASK NO. p03
11. TITLE (Include Security Classification) Chemical Beam Epitaxy of ZnSe			
12. PERSONAL AUTHOR(S) L.A. Kolodziejcki			
13a. TYPE OF REPORT Semi-annual	13b. TIME COVERED FROM 2-1-89 TO 7-31-89	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
16. SUPPLEMENTARY NOTATION			
17. COSATI CODES		18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)	
FIELD	GROUP	SUB-GROUP	
19. ABSTRACT (Continue on reverse if necessary and identify by block number)  Work by L.A. Kolodziejcki and her collaborators is summarized here			
20. DISTRIBUTION / AVAILABILITY OF ABSTRACT <input checked="" type="checkbox"/> UNCLASSIFIED/UNLIMITED <input type="checkbox"/> SAME AS RPT. <input type="checkbox"/> DTIC USERS		21. ABSTRACT SECURITY CLASSIFICATION Unclassified	
22a. NAME OF RESPONSIBLE INDIVIDUAL Mary Greene - RLE Contract Reports		22b. TELEPHONE (Include Area Code) (617) 258-5871	22c. OFFICE SYMBOL

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# OFFICE OF NAVAL RESEARCH

SEMI-ANNUAL REPORT

for

1 FEBRUARY 1989 through 31 JULY 1989

for

**Contract N00014-88-K-0564**

**"CHEMICAL BEAM EPITAXY of ZnSe"**

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## OBJECTIVE

The objective of the program is to determine optimum growth parameters for the chemical beam epitaxy of ZnSe. In addition microstructural, optical, and electrical characterization of the material will be performed to assess the material's quality and potential; comparisons will be made with material grown by molecular beam epitaxy.

## PROGRESS

The chemical beam epitaxy (CBE) system is currently being assembled at EMCORE Corporation in New Jersey. Due to both delays in the assembly of the hardware, as well as delays in readying the laboratory for installation of the equipment, a revised delivery date of November 17, 1989 has been agreed upon. The vacuum subsystem is complete and the chambers are undergoing an extensive heating and cooling cycling life-test of the welds and ultrahigh vacuum seals. The gas manifold has been assembled having the capability of providing gases of In, Ga, Zn, Se and As to the reactor. The introduction and bakeout chambers have been assembled. The robotic rotating arm in the transfer chamber has been completely fabricated and the computer software has been debugged; the final step will be to place the arm in the vacuum chamber. There have been no major problems with the assembly of the various subassemblies of the CBE hardware. Thus far the CBE system is expected to operate as originally expected.

The funding for the analytical chamber has been secured through an equipment grant from the National Science Foundation (\$75K), a University Research Initiative contract from Defense Advanced Research Projects Agency (\$75K), and a substantial donation from EMCORE Corporation. The analytical chamber will have an Auger Electron Spectroscopy (AES) capability. However, the *future* capability of the analytical chamber has been greatly increased by designing the vacuum chamber for the future addition of electron beam guns for metal evaporation, a reflection high energy electron diffraction gun with phosphor screen, two laser ports, and argon ion sputtering. The new analytical/metallization chamber will allow *in situ* metallization studies, as well as analysis by AES of surfaces which have been irradiated with a coherent photon beam. (The analytical/metallization chamber will not be delivered with the CBE reactor.) With the addition of the analytical/metallization chamber module the entire CBE facility consists of four modules; the layout of the system will still provide for expansion of two additional modules. These additional modules are anticipated to consist of another growth chamber (proposal pending with DARPA) and an *in situ* patterning process module.

The laboratory which will house the CBE system is currently undergoing extensive

remodeling. Figure 1 shows the architectural drawing of the completed laboratory. The remodeling for this project encompasses major renovation of three separate laboratories into one large lab space consisting of a total of 1200 sq ft. (The complete renovation project consists of a 2400 sq ft laboratory space which has been funded by M.I.T. (\$400K)) A changing room will separate the lab from the unclean environment of the corridor of the building. Also included in the laboratory is a substrate preparation facility which consists of two specially designed laminar flow clean room hoods: one is for solvent use and one is for acid use. The solvent hood was purchased under this contract with funds from the third year allocation. An extensive toxic gas monitoring plan has been designed to guarantee a safe environment for the project staff, as well as to ensure the safety of the building occupants. The demolition for the laboratory is approximately 85% complete at this time. The general contractor has committed to having the laboratory space completely ready for the CBE hardware by November 17, 1989 provided no major obstacles arise. The final items currently under investigation are the storage of the toxic gas in toxic gas cabinets and the plumbing of the arsine, hydrogen, and nitrogen to the CBE reactor. Once these last pieces of hardware are purchased the laboratory will be ready to begin the long awaited experiments.

An offer of employment is currently pending to fill a research specialist position for the laboratory; the engineer will be responsible for maintenance and repair of all hardware associated with the lab. The major project supervisor from EMCORE Corporation will rotate with another engineer from the company for six months to work in the CBE lab to keep the equipment running and to train the M.I.T. staff.

Upon receipt of the epitaxy hardware, experiments will be underway to begin testing procedures of the specially designed, one-of-a-kind instrument to familiarize the research team with the operation of the machine. Following the initial training period experiments will commence in the chemical beam epitaxy of ZnSe using metalorganics of Zn and Se. The use of both visible and ultraviolet laser illumination will be implemented to assist in the growth. Ga and arsine will also be available initially for n- and p-type dopants, in addition to the use of In, Ga, and arsine for the growth of lattice matched buffer layers of InGaAs to ZnSe, all grown on GaAs substrates.



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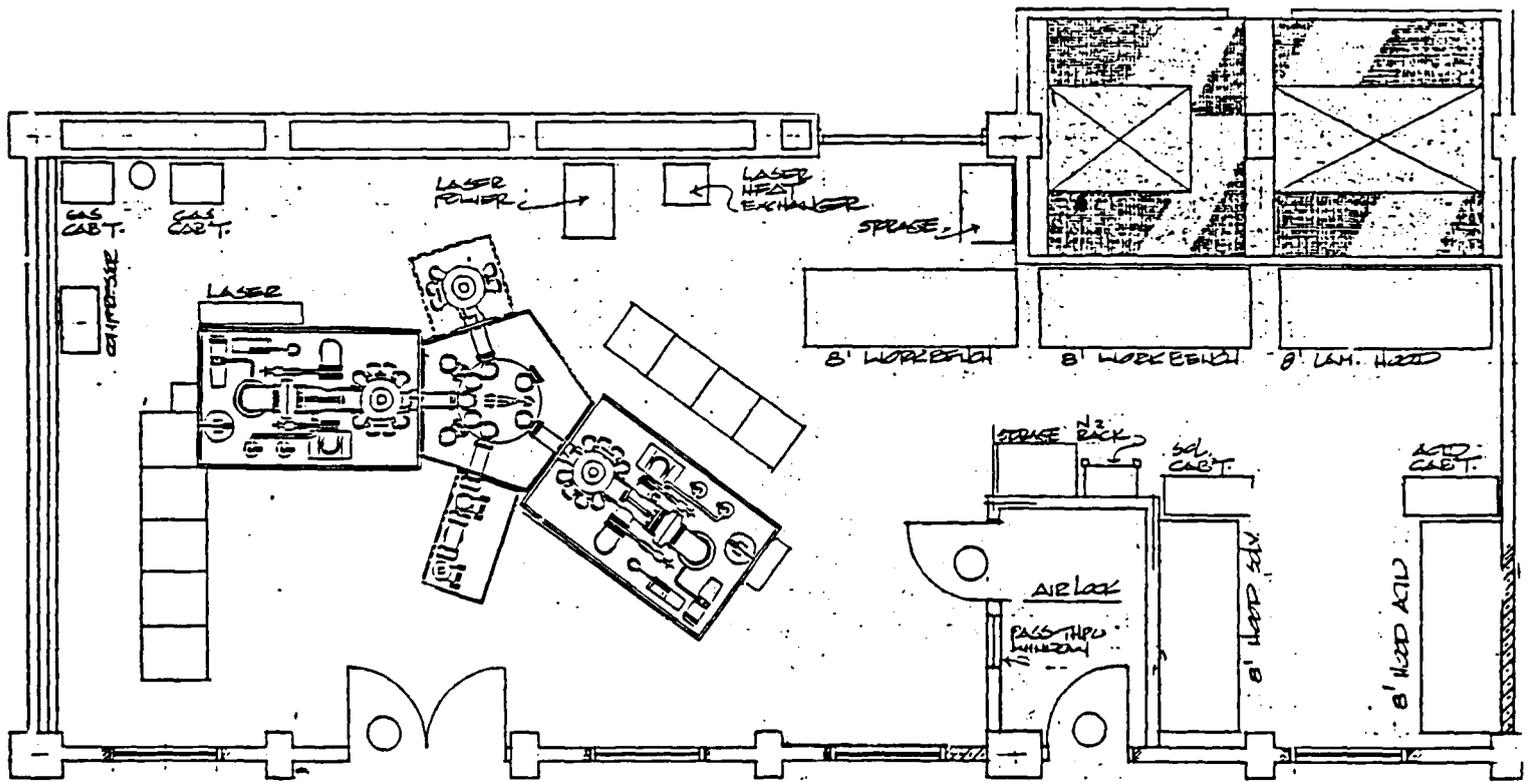


Figure 1. Architectural drawing of the 1200 sq ft laboratory at M.I.T. which will house the chemical beam epitaxy system. Completion date provided by general contractor is November 17, 1989.

## PUBLICATIONS

### a. Papers Published in Referred Journals

- Q. D. Qian, J. Qiu, M. R. Melloch, J. A. Cooper, Jr., R. L. Gunshor, and L. A. Kolodziejski, "Electrical Characterization of the Epitaxial ZnSe/ Epitaxial GaAs Interface," *Applied Physics Letters*, vol. 54(14), pp. 1359-1361, 1989. (Supported by Office of Naval Research, Defense Advanced Research Projects Agency)
- M. Vaziri, R. L. Gunshor, L. A. Kolodziejski, S. Venkatesan, R. F. Pierret, and R. Reifenberger, "Optical and Electrical Characterization of ZnSe Doped with Gallium," *Journal of Vacuum Science and Technology*, vol. B7, pp. 253, 1989. (Supported by Office of Naval Research, Defense Advanced Research Projects Agency, and Air Force Office of Scientific Research)
- S. Venkatesan, R. F. Pierret, J. Qiu, M. Kobayashi, R. L. Gunshor, and L. A. Kolodziejski, "Deep Levels in Ga-Doped ZnSe Grown by Molecular Beam Epitaxy," *Journal of Applied Physics*, 15 October 1989 Issue. (Supported by Office of Naval Research and Defense Advanced Research Projects Agency)

### b. Books (and sections thereof) in Publication

- R. L. Gunshor, L. A. Kolodziejski, M. R. Melloch, N. Otsuka, and A. V. Nurmikko, "II-VI/III-V Heterointerfaces: Epilayer-on-Epilayer Structures" in Growth and Optical Properties of Wide-Gap II-VI Low Dimensional Structures, T. C. McGill, C. M. Sotomayor Torres, and W. Gebhardt, Eds., Plenum Press: New York, 1989, pp. 229-238.
- L. A. Kolodziejski, R. L. Gunshor, A. V. Nurmikko, and N. Otsuka, "Exciton Self-Trapping in ZnSe/ZnTe Superlattice Structures" in Growth and Optical Properties of Wide-Gap II-VI Low Dimensional Structures, T. C. McGill, C. M. Sotomayor Torres, and W. Gebhardt, Eds., Plenum Press: New York, 1989, pp. 269-279.
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Switzerland: Trans Tech Publications, 1989, Vol. 21, pp. 199-230, 1989.

- R. L. Gunshor, L. A. Kolodziejski, A. V. Nurmikko, and N. Otsuka, "Molecular Beam Epitaxy of II-VI Semiconductor Microstructures," in Semiconductors and Semi Metals, R. Pearsall, Ed., Boston: Academic Press, 1989, galley stage.

- L. A. Kolodziejski, R. L. Gunshor, A. V. Nurmikko, and N. Otsuka, "MBE of Magnetic and Semimagnetic II-VI Semiconductors," in Molecular Beam Epitaxy, R. F. C. Farrow and J. R. Arthur, Eds., New York: Noyes Publishers, 1989, submitted.

c. Invited Presentations at Topical or Scientific/Technical Society Conferences

- A. V. Nurmikko, R. L. Gunshor, and L. A. Kolodziejski, "Excitons and Phonons in Widegap II-VI Compound Semiconductor Superlattices," presented at the *SPIE Symposium on Lasers and Optics*, Los Angeles, 1989.

- R. L. Gunshor, L. A. Kolodziejski, M. Kobayashi, A. V. Nurmikko, and N. Otsuka, "Wide Gap II-VI DMS Superlattices: MBE Growth and Characterization," presented at the *Spring Meeting of the Materials Research Society*, San Diego, 1989.

- R. L. Gunshor, M. Kobayashi, L. A. Kolodziejski, and A. V. Nurmikko, "Wide Gap II-VI Heterostructures," presented at the *International Conference on II-VI Semiconductors*, Berlin, 1989.

- R. L. Gunshor, M. Kobayashi, L. A. Kolodziejski, A. V. Nurmikko, and N. Otsuka, "MBE of Wide Bandgap II-VI Compounds," presented at the *International Conference on Crystal Growth*, Sendai, Japan, 1989.