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ROBERT R. McCORMICK SCHOOL OF
ENGINEERING AND APPLIED SCIENCE

Center for Quantum Devices (CQD)
Dr. Manijeh Razeghi, Director

June 3, 1996

Dr. Yoon-Soo Park
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800 N. Quincy Street
Arlington, VA 22217-5660

Subject: **DURIP Equipment Grant #N00014-95-1-1139**
Scanning Electron Microscope (SEM)

Dear Dr. Park:

Please find enclosed three (3) copies of the Final Technical Report for the above referenced DURIP (Defense University Research Instrumentation Program) equipment grant.

Please feel free to contact me if you have any questions, comments, or need additional information.

Best regards,

Manijeh Razeghi gm

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cc: NU Office of Research and Sponsored Programs

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Since the arrival of the Scanning Electron Microscope (SEM), the Center for Quantum Devices was able to further improve progress in the development of high-power laser diodes, long wavelength infrared detectors, mid-infrared lasers (2-5 um), QWIPs, and further exploit GaN, AlN, and AlGaN films.

The SEM system was utilized in diverse areas in the optoelectronics field. For instance, the system was used in the investigation of the buried ridge laser fabrication by monitoring the post-etching surface roughness, detecting contamination, and induce defects along the mesa sidewalls during the processing and after regrowth of the confinement layer over the 1 um active region. One important factor important factor in the progress of the buried-ridge lasers is the mesa height, orientation and dimension of the narrow 1 um active region. The SEM was used to monitor the surface roughness, height, orientation and dimension of the mesa sidewalls. The SEM will further be used for MOPA's.

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Summary Report of Scanning Electron Microscope

Since the arrival of the scanning electron microscope (SEM) system, the Center for Quantum Devices was able to further improve progress in the development of high-power laser diodes, long wavelength infrared detectors, mid-infrared lasers (2-5μm), QWIPs, and further exploit GaN, AlN, and AlGaN films.

The SEM system was utilized in diverse areas in the optoelectronics field. For instance, the system was utilize in the investigation of the buried ridge laser fabrication by monitoring the post-etching surface roughness, detecting contamination, and induce defects along the mesa sidewalls during processing and after regrowth of the confinement layer over the 1μm active region. One important factor in the progress of the buried-ridge lasers is the mesa height, orientation and dimension of the narrow 1μm active region. The mesa formation is greatly dependent upon the crystal orientation, that is, in the 110 direction the mesa sidewalls can be anisotropic and the $1\bar{1}0$ direction they can be isotropic. The scanning electron microscope have been used to monitor the surface roughness of structure and analysis of the etched 1μm-wide mesas to determine the height, orientation and dimension of the mesa sidewalls.

Also, photodetectors in the wavelength range 200-380 nm using high quality GaN, AlN, and AlGaN films are being investigated which requires nanoscale characterization to observe the results after growth. The monitoring and investigation of novel nitrogen sources and p-type doping possibilities in these films is of primary importance.

Lasers in the 2-5 μm and 7-9 μm range are required for the optical monitoring and detection of atmospheric pollutants, low loss fluoride based fibers for long haul communications and for medical applications. The Center have grown and characterized the antimony based laser structures emitting in the 2-5 and 7-9 μm region with the assistance of the SEM to detect and observe the interface of the epitaxial layers. Furthermore, the system has been into use 100% in conducting and observing doping, contact formation, and processing of InTlSb long wavelength detectors, InGaAsP/GaAs lasers, and InAsSb/InAs mid-infrared lasers.

The results achieved up to now has been made possible by the utilization of SEM system, and by daily communication and frequent detailed discussions between the researchers and students involved into every step of the manufacturing and investigation.

The SEM system will be further used in the investigation and production of MOPA's. High power diffraction limited semiconductor lasers are needed for applications including free space optical communications and frequency doubling. These master oscillator power amplifiers will require distributed Bragg reflector (DBR) and distributed feedback (DFB) lasers to be monolithically integrated together. Such nanoscale integration will require the use of scanning electron microscopy to optimize the epitaxial structure and gratings on the DBR and DFB lasers and to characterize the total integrated system.

Scanning Electron Microscope

The Center for Quantum Devices (CQD) purchased an Hitachi S4500 field emission scanning electron microscope (SEM) as part of the 1996 Defense University Research Instrumentation Purchase Program. This microscope has been installed in the cleanroom facilities of CQD, and is utilized for characterization of epitaxial layers, photolithographic processing steps, and completed devices.

Characterization of Epitaxy

CQD has five metalorganic chemical vapor deposition (MOCVD) reactors and two molecular beam epitaxy (MBE) systems operating simultaneously. These epitaxial layers produced from each reactor must be characterized, and the SEM is an integral part of this characterization. It is primarily used for measuring epitaxial layer thicknesses on cross-sections of wafers which cannot be measured by a selective etch and profilometer system. This cross-sectional viewing capability allows the measurement of thicknesses of very small layers, such as the quantum well active layers of laser samples, or the superlattice structure of photodetector samples.

Characterization of photolithography / processing

In order to produce lasers or photodetectors for device testing, CQD uses sub-micron photolithography tools to produce complex resist patterns. Each resist step and subsequent etch step requires optimization in order to produce vertical sidewalls in the reisist and minimum mask undercut after the etch. This optimization can only be carried using the resolution of the SEM to image the processed wafer. The S4500s ability to work at very low voltages makes imaging such insulating materials as photoresist and silicon dioxide possible.

Characterization of devices (and their failures)

Once the devices have been fabricated, each is tested and the SEM allows visible inspection of those samples which fail. This testing is especially important in the optimization of high power laser structures. Each laser bar can be driven to failure, and then inspected using the SEM to determine where the failure occurred. This allows the limiting characteristic, such as contact metallization or heat sink bonding to be determined. Subsequent devices can be processed differently to improve the results.