

Micro-Integrated Super Broadband Stellar Simulator Optical Calibration Sources

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ABSTRACT—This project involves the development, fabrication, and testing of miniature solid-state high-stability integrated super broadband semiconductor optical emission sources for field and in-flight calibration of stellar photometers and spectrometers. In this project, we will combine expertise in the area of SiC avalanche light emitting diodes fabrication available through our Houston-based collaborator, Integrated Micro Sensors Inc.—a firm currently working on a related NSF-funded project—with our new achievements in III nitride materials growth, characterization, and processing to demonstrate a prototype device with the specified characteristics.

OPTICAL SPECTROSCOPY IS A POWERFUL TECHNIQUE TO analyze emissions from galaxies and explore stellar populations. Existing lamps and blackbody simulators used for optical calibration are power hungry, bulky, and can be used only in laboratory conditions. At present, no miniature and stable solid-state optical calibration sources are available for simulation of the stellar-related radiation measured by photo and spectrometric equipment in a broad optical range of the spectrum.

Avalanche electroluminescence-based LEDs have numerous advantages over lamps and injective LEDs including unusually broad emission spectrum, lack of spectral dependence on the input current, similarity to solar radiation spectrum, high thermal and temporal stability, and miniaturization in size.^{1,2} Intra-band hot electron transitions participating in the avalanche process result in unusually broad spectrum and stable optical emission, which can be used either to simulate standard spectra of various class stars or for broad-band calibration of photodetectors in spectroscopic and photometric applications.

Goals

The band gap of ternary compounds based on III nitrides can be tuned from 0.7 to 6 eV allowing for optoelectronic devices capable of performing in a spectral range from 200 nm to 1.77 μm . Spectral tuning of such devices can be provided by changing the composition of the active layers in these devices as well as by integrating layers of various materials on a single chip. For example, the possibility of III nitride growth on either sapphire, silicon carbide, or silicon can result in devices that would take advantage of the characteristics of each of the materials used in the device structure.³ A new approach relies on the employment of stacked III nitride materials with band gaps increasing from the bottom, allowing for optical emission virtu-

ally in the range from 0.2 to 5 μm as shown in Fig. 1.

As a first step toward realizing the essential structures of the device, our first project task was focused on the optimization of the growth of GaN and AlGa N layers with various Al content on Si and sapphire substrates using Radio-Frequency Molecular Beam Epitaxy (RF MBE).

Results

The III-Nitride layers in our investigation were grown in a custom-made molecular beam epitaxy (MBE) chamber equipped with standard effusion cells for Group III and dopant flux delivery, which includes Ga, Al, In, Si, and Mg. Active nitrogen species are generated by an EPI Uni-Bulb radio-frequency (RF) plasma source. The sample manipulator is compatible with 2" diameter substrates and operating temperatures of 900°C. The chamber is pumped with a 2200 L/s turbomolecular pump and reaches a base pressure of $<5 \times 10^{-10}$ Torr.

In order to reliably fabricate avalanche LED structures emitting in the UV/VIS spectral range, we worked on controlling the Al mole fraction in Al $_x$ Ga $_{1-x}$ N. The main difficulty in this area lies in that the simple ratio of Al/(Al+Ga) flux ratio is a very poor estimation on the actual incorporation fraction. If strictly growing by the ratio (Al+Ga) / N, three-dimensional RHEED patterns and hence poor quality films are usually obtained. Results for Al $_x$ Ga $_{1-x}$ N deposited on both Si and c-plane sapphire have demonstrated two-dimensional growth with "x" equal to 17% (3.74 eV), 30% (4.03 eV), and 68% (5.05 eV). Shown in Fig. 2 are the RHEED images of two AlGa N layers demonstrating the difference between the newly developed growth conditions and those previously used. The

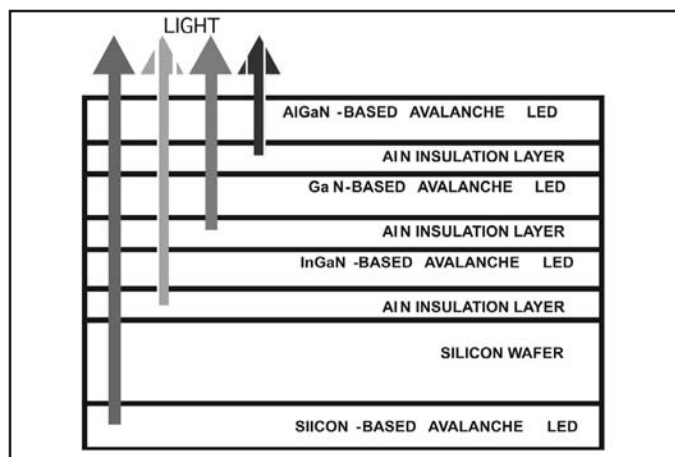


Figure 1. Employment of stacked III nitride materials with band gaps increasing from the bottom, allowing for optical emission in a broad spectral band.

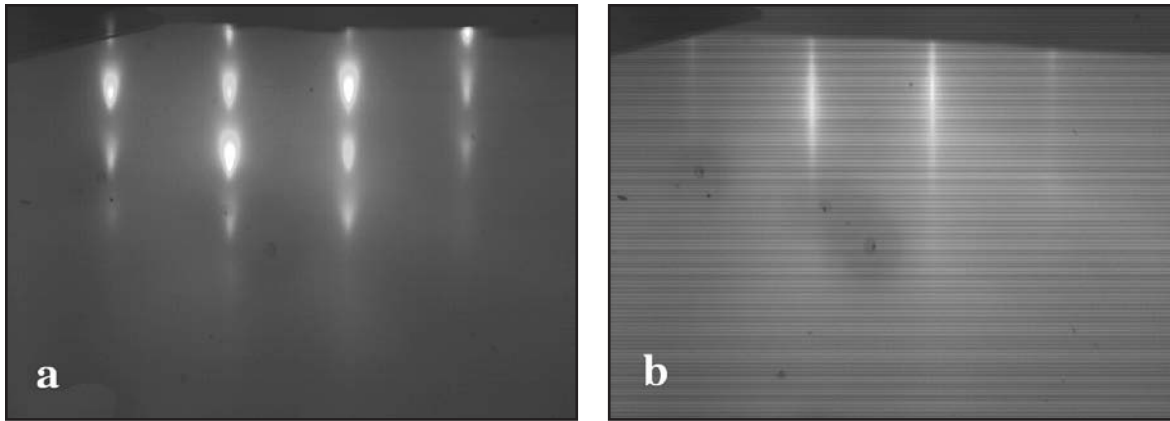


Figure 2. RHEED images taken from $AlGaN$ layers under (a) un-optimized and (b) improved growth conditions.

bandgap of the $AlGaN$ layers was determined using spectroscopic ellipsometry and confirmed by x-ray diffraction measurements. Some of these results are shown in Fig. 3. Thus reliable growth parameters for fabrication of two-dimensional $Al_xGa_{1-x}N$ films over the compositional range from $0 < x < 75\%$ have been developed. Similar conditions are currently used for the fabrication of solar-blind $AlGaN$ -based photodetector structures.

Conclusion

$AlGaN$ layers of various Al mole fractions were grown to demonstrate compositional control over the bandgap range 3.4 eV to 5.2 eV ($\sim 0 - 75\%$ Al). Use of these growth conditions for fabrication of $AlGaN$ devices will be undertaken in the upcoming tasks.

References

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Publications

Starikov, D., C. Boney, R. Pillai, and A. Bensaoula. "Solar-Blind Dual-Band UV/IR Photodetectors Integrated on a Single Chip," *Technical Proceedings of the 2006 NSTI Nanotechnology Conference and Trade Show (Nanotech 2006)* 3.1 (2006): 74-77.

Presentations

Boney, C., P. Misra, and A. Bensaoula. "Dependence of Impurity Incorporation on the Growth Temperature during GaN MBE Growth," North American MBE Conference, Durham, NC, Oct. 8-11, 2006.

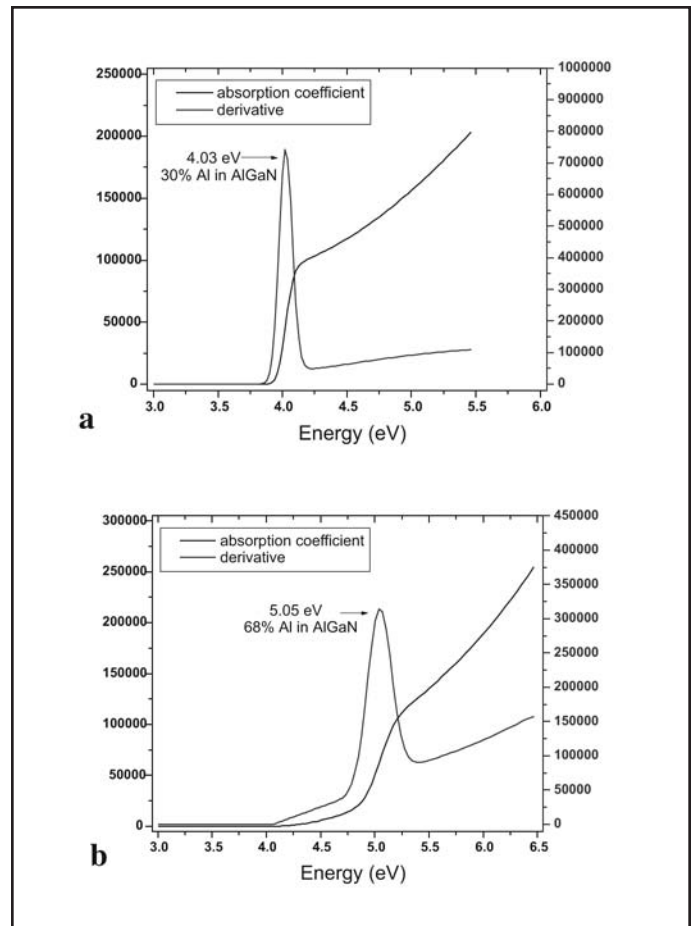


Figure 3. Value of the absorption coefficient α as a function of energy determined by spectroscopic ellipsometry. Also shown is the derivative of α indicating the position of the film bandgap. (a) 30% Al in $AlGaN$ and (b) 68% Al in $AlGaN$.

Proposals and Funding

- Bensaoula, A. "Integrated Broad-Band Optical Calibration Sources for Star Simulation," NSF Phase II SBIR Project (IMS/CAM). \$130,000. (Submitted.)
- Bensaoula, A. "Solid-State High Temperature Jet Engine Fire Detector," Air Force Phase II SBIR Project, (IMS/CAM), 2005-2007. \$750,000.