Innovative Developments in GaN-based Technology

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Abstract

GaN-based materials have been intensively investigated in recent years because of their potential applications for optoelectronic devices operating in the short wavelength spectral range and in high power, and high temperature electronic devices. The III-nitride semiconductors form a continuous alloy system with direct band gaps ranging from 0.7 eV for InN, to 6.2 eV for AlN with 3.4 eV for GaN. This energy range is suitable for band-to-band light generation with colors ranging from infra-red to ultraviolet (UV) wavelengths. GaN-based materials are also ideal for the fabrication of high responsivity and visible blind UV detectors because of their unique properties such as wide and direct band gap, high absorption coefficients, and sharper cutoff of the wavelength detection. The high breakdown voltage of these materials makes them ideal for high power applications and their high saturation velocity is for high speed device operation. Applications include power amplifiers for wireless base stations, low noise amplifiers, and high power switches. The large band gap means that the performance of GaN transistors is maintained up to higher temperatures than silicon transistors. Sensing devices are another important application of nitride materials especially for harsh environments as these materials are thermally and chemically stable.

Intensive material studies and simulation work have been carried out on III-nitride semiconductors (GaN and related alloys). Amorphous, microcrystalline, nanocrystalline, and epitaxial III-nitrides have been investigated for a wide variety of applications. Novel growth technology, processing techniques, treatments and optimization of device fabrication parameters have been carried out to enhance material quality and device performance. High quality III-nitrides thin films were successfully grown by plasma-assisted molecular beam epitaxy (PAMBE) on Si substrates. LEDs, photodetectors (light sensors), MOS capacitors, pressure sensors, and gas sensors based on these materials have been fabricated and characterized in our lab. Alongside the experimental work, theoretical work has also been carried out to investigate the performance characteristics of GaN-based light emitting diode (LED), multi-quantum well (MQW) laser structures, and vertical cavity surface emitting laser (VCSEL). Besides that, study on transparent conducting oxides as electrodes for optoelectronic devices has also been carried out to enhance the performance of LED.

Porous semiconductor materials have attracted special interest since the discovery of strong photoluminescence in porous Si. Another attractive application of porous semiconductor materials is epitaxial growth, as they retain the crystalline structure of the original material and yet is relaxed and can serve as a template for heteroepitaxial growth of lattice-mismatch materials. Nanostructured porous GaN, ternary, and quaternary III-nitrides (InGaN and InAlGaN) with different mole fractions have been fabricated by three different techniques, namely, metal-assisted UV electroless etching, laser induced etching, and DC as well as novel AC-assisted photo-electrochemical etching. Sensors fabricated from these films have showed significant improvement of performance. Novel growth technique such as low temperature microwave-assisted chemical bath deposition (MA-CBD) has been employed to grow ZnO/GaN heterojunction LED. Also, a novel and low cost "NORLED" (NanO-Rod LED) device which emits in the UV region was fabricated using ultra long ZnO nanorods that were grown on the p-GaN substrate, by a direct heat substrate-modified chemical bath deposition (DHS-MCBD) growth process. These methods seem to be promising for fabricating p–n heterojunction nanorod devices. The UV emission is expected to provide high energy to excite phosphor to produce white LEDs for solid state lighting applications. The prospects for III-nitrides are enormous, and these materials are expected to dominate the optoelectronics and electronics market in the years to come.