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Gallium Nitride Materials and Devices III

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Introduction

This conference was christened as a tribute the long and productive career of Dr. G. L. Witt in 2006, and has continued very successfully in 2007 and again in 2008. As mentioned in the introduction for the 2006 GaN Materials and Devices, attainment of p-type GaN in late 1980s, and development of InGaN and lateral epitaxial overgrowth techniques broke open the logjam preventing researchers from demonstrating the many attractive attributes of GaN in devices for decades. Rapidly, even with materials nowhere near the perfection that would normally be prerequisite other materials, both optical and electronic devices with record-breaking or not previously available performance/property have been obtained.

Today, the GaN-based light emitters adorn automobiles, traffic lights, moving signs, outdoor displays, handheld electronics, and background lighting in many consumer electronics including flat panel televisions. Already, the more extensive applications of GaN light emitters in televisions and hand held devices containing displays are being felt in the marketplace. All LED outdoor white lighting applications are already in full swing with high-brightness, large-area, wafer-bonded LEDs producing optical power levels in excess of 200 mW with efficacies in excess of 100 l/W in large excitation levels. High end LEDs exhibit efficacies approaching 200 l/W and are being achieved by increasing number of LED manufacturers. Indoor general lighting applications seem to be a question of time which can be shortened with relaxation of somewhat artificially set color rendering index. For ultra high efficiency lighting systems in the 400 l/W range 4 LED approaches are being explored. It's ironic that the efficiency of heating and electric motors are higher than 70% while that of fluorescent lighting and incandescent lighting are in the range of 25% and 5%, respectively. Over one third of the energy use in the US is in lighting and will approach some 1000 TW/h in the year 2020.

With LED lighting, this increasing trend can be turned around and US consumption will actually decline if LED lighting (goes by the name solid state lighting or SSL) is adopted. Clearly incandescent and fluorescent lighting have been around for a long time and it is very unlikely that the efficacies that are available now will really see much of a discernable change in the future. In addition, fluorescent bulbs are not as reliable as touted in real use as in tests and the filaments in them degrade with repeated switching cycle not to mention the Hg contained in them. Against this background GaN based LEDs, particularly for general lighting applications, truly represent the hottest device today and will soon save many Terra Watts of power per year from being wasted. The four LED (namely red, yellow, green, blue) approach is considered the most efficient approach while meeting the present color rendering index guidelines (approaching 97%) but requires source line widths of about 1nm not to mention the stringent requirements on the wavelength of the sources used. The weak point at this point is the low efficacy for high brightness green LEDs, the so-called “green gap.” As expected, efforts are underway to tackle this problem head on. Despite, and in fact because of, these challenges, these are exciting times for GaN based LEDs as they are expected to be the dominant device in the next several decades.

GaN-based lasers also are making their presence known with the introduction of Sony’s PlayStation III by Sony late in 2006. With control over the content and hardware, the high-definition video systems appear to be on their way to use the BluRay technology developed by Sony which relies on GaN lasers. It is established that high-quality lasers with acceptable longevity must be grown on native substrates and or templates. This eliminated much of what could be construed as artificial problems associated with the use of lattice mismatched substrates and paved the way for tackling the real laser problems such as facet damage. It should be mentioned that in the edge emitting lasers used for these applications, one facet is coated with high reflectivity coating and does not allow light extractions. However, the emitting facet is coated with anti reflection coating for efficient photon extraction. It is this facet that undergoes damage with use. The time tested techniques such as leaving a section of the laser bar unpumped near this facet led to lifetime of over 10,000 hours at 60 mW power operation at room temperature. This performance is sufficient for the above mentioned applications. However, it would be unwise to assume that the push for better performance and longevity will end anytime soon.

Coming on the scene very strongly is the GaN based heterojunction FETs. Just to give a flavor, one GaN chip is now able to produce CW power levels above 700 W at 2GHz and some 10 W in the millimeter wave region for applications in the wireless and agile radar. It appears that the base stations for mobile communication systems will be solely the domain on GaN power amplifiers. There are, as always, problems, however, which must be dealt with. Although fine tuning of the processes as well as the device structure has continually improved power levels, cut off frequencies (both current gain and power gain cut off frequencies above 200 GHz), and noise figures, there are some fundamental reliability issues that are facing the community. Much of this problem is predicated on the high piezoelectric, pyroelectric, ionic nature of GaN coupled with very high drain voltages used. Even with the use of gate plates to spread the electric field some, hot electron coupling with phonons generate large densities of hot phonons which do not decay to acoustic phonons efficiently limiting carrier velocity and maintaining high lattice temperatures. Furthermore, the electrons injected into the trap levels on the surface from the gate causes the formation of a virtual gate and its extension toward the drain which is one of the causes of the drain current droop or lag. The RF stress conditions cause catastrophic degradation with TEM images in some cases showing structural damage underneath the drain side of the gate. The tensile strain present in the layers due to growth on SiC substrates in addition to the above mentioned problems, seem to be exacerbating the situation. The next few years will be interesting in that efforts to produce high resistivity GaN wafers for FETs are underway and when successful, the tensile strain issue mentioned previously will be out of the game.

The SPIE conference on GaN Materials and Devices was organized to disseminate the latest results and provide an opportunity for researchers from around the world to engage in discussions to advance this exciting field even further. Many world renowned invited speakers from Asia, Europe, and USA set the stage with discussions of lattice matched barriers to GaN as opposed to problematic AlGaN, the latest developments in magnetic ion doped GaN for ferromagnetism, methods to extract photons from GaN such as texturing the emission surface, flip chip mount, plasmon coupling, and photonic crystals, processes limiting internal quantum efficiency, push for higher efficacies in LEDs, particularly at the moment blue/yellow phosphor varieties, longevity in lasers and methods to increase it, high frequency and high power GaN based FETs, FET reliability, and applications of GaN to switching applications. The latter is significant as if and when successful, GaN will take away the last remaining application of SiC devices. This comes on top of the moves to use GaN as opposed to SiC for GaN epitaxy for FETs. Very high quality contributed papers augmented and enhanced the truly exceptional image set forth by the invited speakers. Most importantly, the meeting served the purpose of bringing experts in the field together for friendship and informal discussions of issues relevant to GaN and related materials and devices.

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