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Achieving p-type conduction in GaN has poised the material a power semiconductor on all fronts. Record conversion efficiencies and power densities in LEDs render it a platform of GW installation base. After commercial success as a blue light emitter, the emphasis now rests on the expansion of its capacity as a full spectrum direct emitter --- and absorber. Green and amber LEDs will allow full control of lighting quality and specificity in photochemistry. In early results we find evidence of temperature performance crucially superior to those of the incumbent. Next, we explore the same GaInN/GaN quantum wells as a concentration solar cell converter. While definitely limited to the short wavelength range so far, we find respectably high spectral conversion efficiencies and outstanding temperature stability. Such performance, however, is just early indication of what else lies ahead in terms of power electronics in the form of lateral and vertical transistor. In early results we monolithically integrate LED and transistor.

**Aiming for a wide Bandgap**

There is something unique about semiconductors in that they require utmost crystalline perfection, frequently over the length scales of micrometers, so that they work the way we envision them. Things seem very different in organic semiconductors, where layers seem to be applicable at any sequence and randomly deposited yet they still keep their respective properties as conductor, emitter, or absorption layer. A lot of properties are maintained in inorganic semiconductors also in the amorphous state but their flexibility in complex device structures is highly limited. Moreover, compound semiconductors of the Arsenide and Phosphide type seem rather benign in their epitaxial growth behavior, but they are highly susceptible to surface states that may act as a relevant recombination path for non-equilibrium carriers. The search for a wide bandgap semiconductor of sufficient energy to enable blue light emission has led to the study of group-III nitride GaN as early as the 1970s. Yet, the material was always n-type, no doping effort seemed good enough
to add the p-type hole conduction and the material for the most part fell in the shadow of the rapid success of GaAs. Ever increasing record carrier mobilities in the group-III arsenides led to an ever faster diodes and transistors, yet for the blue light its bandgap still was way too small. Then there were the II-VI compounds, chief among them ZnSe, ZnS and ZnMgSeS. The bandgap is sufficiently large in those for blue light emission but crystalline bond strengths proved way too weak to hold up even against the energy of its own bandgap photons leading to a rapid dark line defect generation that then even accelerated the material’s self-destruction as an efficient light emitter. Now, amazingly, all those aspects are not an issue in wide bandgap GaN and its alloys with AlN and InN. The material proved always n-type, until the structure defect density could be reduced to levels of still some very high $10^{10} \text{ cm}^{-2}$ and it could be doped p-type by Mg. That immediately triggered the first purple blue LED and from there on it was a very rapid development.\textsuperscript{1} Around 1995 the group-III nitrides have gained sufficient momentum as a light emitter to overtake the II-VIs as the material of choice to deliver both, wide bandgap and performance in almost any aspect as useful for higher power density transistors, light emitters, and even concentration solar absorbers.

**Direct Emitting LEDs**

Tuning the optical bandgap all across the visible spectral region is the first step to direct emitting LEDs of any desired narrowband color, the combination of which can emulate any desired spectrum. Human vision and wellbeing in fact is very well adapted and accustomed to a daily variation of the natural light spectrum. Emulation of the same would therefore appear to be a most natural choice in recreating human's wellbeing also in situations of artificial lighting. The challenges of implementing longer wavelength LEDs by GaInN alloys of higher InN fraction, however, led to a performance and efficiency advantage for combinations of blue emitting LEDs with a partial conversion to a broader yellow band emission, the combination of which can also give the impression of white light to the human eye. As a static solution, however, this approach does not allow for any user-level spectral control. Vendors instead have accommodated consumer preferences by offering different static spectral combinations jointly characterized on the scale to coordinated color temperatures, reminiscent of the spectrum of a blackbody radiator of such temperature. Common to all those, however is a singular peak near 450 nm of the blue LED excitation source. Recent human impact studies of light of such blue wavelength portion has been shown to lead to suppression of melatonin in the human blood stream after sunset.\textsuperscript{2} This in turn is being associated with a disturbed night sleep pattern and therefore has led to the recommendation not to use blue LED lit displays or light sources in the hour before going to sleep. Quite obviously this should pose a severe hindrance in versatility and market penetration of blue LED powered energy efficient white light sources. The alternative therefore should be spectral control of the light source such as envisioned by combinations of direct emission LEDs.

**LEDs with Integrated Driver Electronics**

While the operation point of a tungsten filament of incandescent lamps is self-stabilizing under constant voltage operation, an LED requires constant current operation. LED operation from an AC power distribution network therefore requires current limitation circuitry and buffering to smoothen out the 60 Hz source frequency. Socket compatible LED replacement lamps therefore require incorporation of a driver module
the lifetime of which matches that expected of the LED, namely some 20,000 hrs. Executed in conventional Si technology under poor ventilation conditions this poses quite some challenges primarily for the electrolytic capacitors. As a first step, we aim at a nonpolitical integration of driver transistors with the group-III nitride LED epi material itself.\(^3\)

**Solar Harvesting in High Flux Multi Junction Cells**

The tunable wide optical bandgap in the group-III nitrides also poses the opportunity to serve as a topping junction within a stack of multiple junction solar cells. Scooping photons of highest energy and delivering them at a high contact voltage in this way can reduce the thermal load on any consecutive solar junctions and thereby enhance overall efficiency and thermal resilience. The high thermal stability of GaInN/GaN junctions in our experiments allow for solar concentration of up to 150x or elevated chuck temperature of up to 400°C with an overall increase in output efficiency over direct solar flux at room temperature.\(^4\)

**Summary**

Wide bandgap group-III nitrides have emerged as the workhorse in all electronics of high power density. The combination of a strong electronic bond, a large and variable electronic bandgap and low surface recombination velocities contribute to a system of high electro-optical power conversion, both in the direction of light emission and in the reverse as a solar junction. In the form of power transistors the material is also emerging as an all in one LED driver system. Beyond first generation blue LED dominated white light generation we iterated the advantages of direct emission LEDs covering the green amber and red spectral region for better user level tenability of the emission spectrum.

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