**InGaN Based Light Emitting Diode and Laser Diode
The Present and the Future**

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**Abstract**

The III-nitrides AlN, GaN and InN with related alloys form an interesting class of wide bandgap materials, which are likely to be the basis of a strong development of a novel family of semiconductor devices, LED and LD. The entire spectral region from green to UV can be covered InGaN which, represent the main active layer for III-N based LEDs and LDs. In addition to that InGaN band gap contains localized states that contribute as radiative recombination centers and prevent capture of the electrons and holes by nonradiative recombination centers associated with threading dislocation. The aim of this paper is to review the recent progress in InGaN based LED and LD.

**I. Introduction**

Light Emitting Diodes (LEDs) are solid state devices which emit light when electrical current passes through them. In LEDs made of semiconductors, the color of the light depends on the bandgap of the semiconductor material, proceeding from red through orange, yellow, green, blue and violet as the gap increases. Figure (1) represent the correlation between different types of semiconductors and the associated spectrum.

The brightness of the light intensifies with increasing current, and frequently passes beyond a threshold current, where the light is amplified. Then reflections – or mirrors - at the end of the cavity form an oscillator, and the light is emitted in an intense monochromatic beam in the direction determined by the mirrors. The light that was spread in all directions has become coherent and collimated. It shines in one direction and the light emitting diode has become a laser.

The brightness and durability of light-emitting diodes (LEDs) make them ideal for displays and traffic light. Semiconductor laser diodes (LDs) have been used in numerous device applications from optical communication systems to compact disk (CD) players. These applications have been limited, however, by the lack of materials that can emit blue light efficiently. Full-color displays, for example, require at least three primary colors, usually red, green, and blue, to produce any visible color. Such a combination is also needed to make a white light-emitting device that would be more durable and consume less power than conventional incandescent bulbs (material heated-tungsten- by some way-electric current- and emits light) or fluorescent lamps (Electric discharge in a gas filled tube, usually mercury, emits UV light which bombard the fluorescent wall of the...
container and emits white light). The shorter wavelength means that the light can be focused more sharply, which would increase the storage capacity of magnetic and optical disks. Digital versatile disks (DVDs), which came onto the market in 1996, rely on red aluminum indium gallium phosphide (AlInGaP) semiconductor lasers and have a data capacity of about 4.7 gigabytes (Gbytes), compared to 0.65 Gbytes for compact disks. By moving to violet wavelengths emitted by III-N based semiconductors, the capacity could be increased to 15 Gbytes. The violet III-N based LDs could also improve the performance of laser printers and undersea optical communications. Such III-N based semiconductors have a direct band gap that is suitable for blue light– emitting devices. The band gap energy of aluminum gallium indium nitride (AlGaInN) varies between 6.2 to 2.0 eV, depending on its composition, at room temperature (RT). Thus, by using these semiconductors, green to ultraviolet (UV)-emitting devices can be fabricated. Schematic diagram of LED is shown in figure (2).

![Figure 1](image1.png)

**Fig. 1** various ternary and quaternary materials used for LEDs with the wavelength ranges indicated.

![Figure 2](image2.png)

**Fig. 2** Schematic representation of blue/green SQW InGaN LED
II. PRINCIPLES OF LED AND LD

LED is essentially consists of an active layer of semiconductor material sandwiched between n-type and p-type semiconductor cladding layers. When a voltage is applied to the junction, electrons from n material injected to the conduction band of the active layer, while holes from the p-type semiconductor are injected into the valance band. Light emission takes place in the active layer when electrons at the bottom of the conduction band recombine with holes at the top of the valance band as shown in figure (3). If many more electrons and holes are injected into the active layer, population inversion could be reached.

![Carrier injection process in LED and LD](image)

For LD, the active layer is sandwiched by the additional layers, which are called light guiding layers, and cladding layers, which have different refractive index that enable them to guide light. The ends of the light guiding layers are mirrors which reflect light back and forth through the active layer, stimulate electron hole transition when population inversion are reached. Most of III-N based light emitting devices uses InGaN as active layer instead of GaN because the difficulty of fabricating high efficiency GaN based light emitting devices. Adding a small amount of In into the GaN is very important to obtain a strong band-to-band emission at RT. The reason is related to the presence of deep localized energy states[1]. The localization induced by the In composition fluctuations seem to be a key role of the high efficiency of the InGaN-based LEDs. When the electrons and holes are injected into the InGaN active layer of the LEDs, these carriers are captured by the localized energy states before they are captured by the nonradiative recombination centers caused by the large number of dislocations. At these localized states bound excitons with high binding energy are formed and recombine radiatively. Schematic diagram of localized states of InGaN as a function of In composition are described in figure (4). Schematic representation of InGaN MQW LD are shown in figure (5).
III. HISTORY OF InGaN LED AND LD

In 1992, Nakamura and Mukai [4] succeeded in growing high-quality InGaN films that emitted strong band-to-band emission from green to UV by changing the In content of InGaN with a two-flow MOCVD method. Finally, Nakamura et al.,[5] grew InGaN multi-quantum well (MQW) structure and confirmed an enhanced strong PL intensity from quantized energy levels in InGaN quantum well layer with a thickness of 25Å. In 1994, Nakamura et al.,[6] developed blue InGaN/AlGaN double heterostructure LEDs and then developed blue/green InGaN single quantum-well (SQW) structure LEDs in 1995[7]. Then, UV/amber LEDs [8] and RT violet laser light emission in InGaN/GaN/AlGaN heterostructures under pulsed operations were achieved [9]. The latest results showed that the lifetime could be as long as 1000 [10] and 10,000 hours [11] under RT continuous wave (CW) operation. Also, high-power LDs were fabricated using
epitaxially lateral overgrown GaN (ELOG)[12]. A summary of commercially available InGaN based LED in comparison with conventional III-V LED are described in table IV-1

<table>
<thead>
<tr>
<th>Active layer</th>
<th>Color</th>
<th>Peak emission</th>
<th>Luminous efficiency (lm/w)</th>
<th>External efficiency</th>
<th>Device type</th>
</tr>
</thead>
<tbody>
<tr>
<td>AlInGaP</td>
<td>Red</td>
<td>636 nm</td>
<td>35</td>
<td>24%</td>
<td>DH</td>
</tr>
<tr>
<td>AlGaAs</td>
<td>Red</td>
<td>650 nm</td>
<td>8.0</td>
<td>16%</td>
<td>DH</td>
</tr>
<tr>
<td>AlGaInP</td>
<td>Amber</td>
<td>590 nm</td>
<td>40</td>
<td>10%</td>
<td>DH</td>
</tr>
<tr>
<td>InGaN</td>
<td>Blue</td>
<td>470 nm</td>
<td>10</td>
<td>11%</td>
<td>QW</td>
</tr>
<tr>
<td>InGaN</td>
<td>Green</td>
<td>520 nm</td>
<td>34</td>
<td>10%</td>
<td>QW</td>
</tr>
<tr>
<td>InGaN</td>
<td>UV</td>
<td>372 nm</td>
<td>0</td>
<td>7.5%</td>
<td>DH</td>
</tr>
<tr>
<td>InGaN</td>
<td>Amber</td>
<td>590 nm</td>
<td>14</td>
<td>3.5%</td>
<td>QW</td>
</tr>
<tr>
<td>ZnSe</td>
<td>Blue</td>
<td>512 nm</td>
<td>17</td>
<td>5.3%</td>
<td>DH</td>
</tr>
<tr>
<td>SiC</td>
<td>Blue</td>
<td>470 nm</td>
<td>0.02</td>
<td>0.02%</td>
<td>H</td>
</tr>
</tbody>
</table>

**IV. LED AND LD FABRICATED ON ELOG SUBSTRATE**

ELOG is a promising method to achieve quasi-free defect GaN based materials. To achieve lateral overgrowth, the GaN was deposited on the underlying GaN layer through the windows made by standard lithography and etching of a SiO₂ mask that covers the GaN epilayer [14-16]. The deposited material grew vertically to the top of the mask and then both laterally over the mask and vertically growth take place (Fig.6) until the lateral growth fronts from different windows coalesced to form a continuous layer (Fig.7).

Fig (6) A schematic diagram of the development of the side facet morphology of ELOG-GaN structure as a function of the growth time [17]
The underlying 1.5-2 µm thick GaN films were grown at 1000 °C on 0.1µm AlN buffer layer. Micro structural studies of the areas of the lateral growth indicate that the overgrown GaN layer contains small dislocation density. It is believed that ELOG reduces the dislocation density by blocking the dislocation propagation from the underlying layer using oxide mask. In ELOG, alternate stripes have high and low dislocation density. Since the device is fabricated on the GaN stripes with low density of defects, then the size of the device is limited by the width of these stripes. Also, the device fabrication requires careful alignment of the device structure with the underlying mask stripe. Therefore it is desirable to have a contiguous large area layer with a low density of defects. Nam et al.[16] were able to produce such a layer by repeating the ELOG process a second time. In the second ELOG step, the mask stripes are placed on the openings of the first mask, i.e., they cover the GaN stripes with high density of defects. The GaN layers in the second ELOG step are therefore seeded on the good GaN stripes. They grow laterally on the second oxide masks. Thus a large area GaN layer with a low defect density is obtained. ELOG contribute to a high extent in reducing the threading dislocation in GaN, for more details read the review paper of the authors about the improvement techniques of GaN [18].

Figure (8) describe the external quantum efficincy (EQE) for InGaN and GaN LED grown on both sapphire and ELOG as a function of forward current. LED For UV InGaN LED at low forward current, the external quantum efficiency is the same for LED on sapphire and ELOG. Carriers are easily captured by the localized energy states formed by the alloy fluctuation composition. At high current, carriers can overflow from the localized states captured by non-radiative recombination centers resulted from threading disocation, as a result the EQE decreased for LED grown on sapphire than on ELOG. However, EQE of GaN LED on sapphire is lower than that on ELOG even at low current. In the case of laser diode the forward current is very large, as a result many carriers can flow out to the non-radiative recombination center, so that if the TD is high the EQE will be small and the LD life time will be small, as a result using ELOG is required to decrease the TD and increase the EQE and life time of the device.
V. WHITE LIGHT LED

White light LED is urgently needed; in the near future it will replace the home lighting florescent and incandescent lambs. It can be obtained by three methods:

A. Combination of three LED with three color (red, blue and green): RGB LED.

B. One blue LED with yellow light converter: blue GaN-LED is embedded in a phosphor partially pumps the converter to emits yellow light, which combine with the blue light and give white light.

C. One UV LED with many light converters.

VI. LED AND LD APPLICATIONS

1. Increase the storage capacity of CD and DVD to 15 Gb, since the information stored in a compact disk is contained within the microscopic cavities covering the disk’s surface. Machines such as CD players use lasers to read the information from the disk. The wavelength of the laser limits the minimum size of the cavities. Currently, infrared lasers with a wavelength of approximately 820nm are used with a cavity size on the order of a micrometer. A shorter wavelength could be used with smaller cavities and would result in greater storage density. A green or blue laser with wavelengths 525nm-450nm would be essential in the next generation of high density optical storage disks. To appreciate the difficulties in developing the blue laser, a basic understanding of semiconductor lasers is necessary.

2. Full color display (outdoors display).

3. Traffic light.

4. Replace incandescent and florescence lamps (consume small power, long lifetime, absorb shocks).

5. Blue diode lasers could also double the resolution of laser printers and scanners.
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REFERENCES