Novel substrates
to reduce cost and increase
throughput of blue LED production
Blue LED mass production cost reduction and throughput increase based on novel low cost substrates

**General approach**
TDI proposes to (1) increase throughput of blue LED mass production without capital cost increase, (2) reduce manufacturing cost, and (3) improve LED characteristics by the use of novel cost-effective substrate materials for blue LED fabrication.

The proposed substrates are low cost GaN-on-sapphire templates consisting of a sapphire substrate and high quality n-type GaN epitaxial layer. This GaN layer is from 2 to 5 microns thick and doped with silicon to provide good electrical conductivity (see Specification in Appendix A). As explained in this paper, the use of GaN-on-sapphire templates in mass production of blue LEDs reduces LED growth time by more than 30% and allows an increase in production throughput from 30 to 50% without any capital expenditure. It also reduces rough material consumption and improves process yield. We believe that the use of such templates provides a significant competitive advantage for blue LED production.

TDI is in a position to produce and supply thousands of high quality GaN-on-sapphire templates per month using proprietary growth technology. TDI seeks large volume customers to supply with low cost GaN-on-sapphire templates on a regular basis. TDI is willing to discuss customer target price for GaN-on-sapphire templates to meet the needs of both customer and TDI.

**How GaN-on-sapphire templates benefit blue LED mass production**
The typical MOCVD growth process for blue LED fabrication is performed using sapphire substrates and includes the following steps:
1. Loading sapphire substrate into the MOCVD growth machine.
2. Heating the substrate up to sapphire pre treatment temperature (from 1000 to 1100°C).
3. Sapphire substrate pre treatment in ammonia and/or other gas atmosphere.
4. Cooling the substrate down to deposit a low-temperature nucleation layer (~ 600°C).
5. Growth of GaN low-temperature nucleation layer.
6. Heating the sapphire substrate with the nucleation layer up to growth temperature (~1000°C).
7. Growth of 2 to 4 microns of thick GaN buffer layer to ensure electrical conductivity of the blue LED. **This growth step takes from 2 to 4 hours.**
8. Growth of multi-layer LED structure including cladding layers, multiple quantum-wells, and p-type layers (total thickness of LED structure is about 1 micron).
9. Cooling down and unloading the substrate from the growth machine.

With TDI’s new GaN-on-sapphire templates, Steps 2, 3, 4, 5, 6, and 7 are eliminated (Figure 1 and 2). The blue LED device structure may be grown DIRECTLY on the GaN template surface without sapphire pre treatment (nitridization), GaN low temperature nucleation deposition, and thick GaN buffer layer growth. This approach will provide the following benefits:
- **Reduction of MOCVD growth process time and cost.**
- **Increase MOCVD machine throughput.**
- **Reduction of rough materials (TMG, ammonia) consumption.**
- **Reduction of MOCVD reactor temperature cycling, downtime and maintenance cost.**
- **Improve device characteristics due to the homoepitaxial nature of the growth.**
- **Improve wafer and device yield due to the elimination of complex growth steps.**
A detailed description of the benefits of GaN-on-sapphire templates for blue LED production is given in pages 3 to 5.

**Figure 1.** Time-temperature scheme of conventional MO-CVD growth process (blue line) to fabricate blue LED on sapphire: a – heating and sapphire pre treatment (nitridization), b – cooling and low-temperature GaN nucleation layer growth, c – temperature ramp up to growth temperature, d – growth of thick GaN buffer layer, and e – growth of LED device structure.

For the proposed approach with TDI’s new GaN-on-sapphire templates, steps a, b, c, and d are not necessary and growth of the LED device structure may be started from stage e as shown by the red line.

**Conventional approach for blue LED fabrication**

- **Sapphire substrate**
- **GaN nucleation layer**
- **Sapphire substrate**
- **GaN buffer layer**
- **GaN nucleation layer**
- **Sapphire substrate**
- **AlGaN/GaN LED structure**
- **GaN buffer layer**
- **GaN nucleation layer**
- **Sapphire substrate**

**Proposed approach**

- **Sapphire substrate**
  - Nitridization at 1100°C
- **Low temperature GaN nucleation layer growth**
- **Growth of GaN buffer layer for 2 to 4 hours**
- **Growth of LED device structure**
- **AlGaN/GaN LED structure**
- **Gan-on-sapphire template**

**Figure 2.** Scheme for blue LED fabrication using conventional approach (left) and proposed approach (right).
Benefits of GaN-on-sapphire templates for blue LED mass production

Use of templates provides the following benefits for LED epi wafer manufacturer*: 

- MOCVD growth time reduction
- LED throughput increase
- MOCVD growth equipment lifetime increase
- Downtime reduction
- Maintenance reduction
- Material quality improvement
- Device and epitaxial wafer yields increase
- Cost reduction

MOCVD growth time reduction

Growth time for LED structure is reduced because some steps of MOCVD growth process (steps number 2, 3, 4, 5, 6, and 7 given in page 1) are eliminated. In the proposed process, GaN-on-sapphire templates are loaded in a MOCVD reactor and the LED device structure is grown directly on the GaN surface of the GaN-on-sapphire template. The total saving in growth process time depends on the particular MOCVD growth procedure and is estimated to range from 2 to 3 hours corresponding to a 30 to 60% reduction in growth process time.

LED throughput increase

Due to the reduction in MOCVD growth time, it is possible to significantly increase the number of growth runs per given time period. We estimate a 30 to 50% increase in the number of growth runs. Furthermore, an additional throughput increase is expected related to the reduction in maintenance time required between epitaxial runs to clean the growth chamber from parasitic deposition that accompanies LED structure growth. Such deposition occurs on the growth chamber wall and other parts of growth zone. When a GaN-on-sapphire template is used for blue LED fabrication, the thick GaN buffer layer is not grown in MOCVD system, thus the amount of parasitic deposition is significantly lowered resulting in shorter downtime for growth chamber cleaning.

Therefore, by using the same capital equipment, a LED manufacture would produce more growth runs and subsequently fabricate from 30 to 50% more blue LED wafers per given time period.

MOCVD growth equipment lifetime increase

Blue LED growth by a conventional MOCVD process on a sapphire substrate requires rapid changes in substrate temperature. These changes are necessary because the growth steps include the initial sapphire nitridization at high temperature (~1100°C), followed by a low-temperature GaN nucleation layer grown in the temperature range from 500 to 600°C, and then the GaN

* exact figures of MOCVD time reduction and other parameters improvement depend on specific recipe of MOCVD process.
buffer and device structure itself must be grown at high temperature (Fig. 1). Frequent temperature cycling of growth chamber parts (heater, sample holder and others) results in low lifetime of these costly elements and requires frequent parts exchange. If any of these parts breaks during LED growth run, the whole LED wafer set is lost. Note that for a production type MOCVD machine, the sample heater itself may cost much more than $10K.

**Uptime increase (Downtime reduction)**

The epitaxial growth process for GaN-based LED structures is associated with a parasitic deposition of materials on the internal parts of a growth chamber. The amount of parasitic deposited material is proportional to growth duration. The internal parts of a reactor require periodic cleaning. The use of GaN-on-sapphire templates significantly reduces the growth duration. These result in less parasitic deposition and thus increases the number of deposition runs before reactor cleaning is required. In other words, the uptime for the MOCVD reactor between cleaning maintenance almost doubles. This subsequently increases the number of LED growth runs and epi wafer throughput for each MOCVD reactor.

**Maintenance reduction**

The use of GaN-on-sapphire templates as substrates for blue LED production results in a growth time reduction, parasitic deposition reduction, and an increase in growth chamber equipment lifetime leading to a reduction in maintenance cost.

**Material quality improvement**

The quality of the LED structure is critically dependent on proper sapphire nitridization, low-temperature nucleation layer parameters, temperature ramp-up to growth temperature, and defect formation during thick GaN buffer growth. All these steps are required to grow a high quality GaN-based LED structure on a foreign sapphire substrate and overcome the large lattice mismatch between sapphire and GaN. A small deviation from optimal process parameters often produces high defect density material in the LED structure. Epitaxial wafer yield critically depends on these growth steps. It is not possibility for a MOCVD grower to inspect the quality of the GaN buffer layer deposited during the MOCVD run prior to the formation of the full LED structure. If the quality of the GaN buffer is poor, the whole LED epitaxial run is wasted.

*By the use of a GaN-on-sapphire template, all the above critical MOCVD growth steps are eliminated.* The GaN-based LED structure is grown directly on the GaN surface of the template. The quality of GaN LED structure is ensured by pre growth inspection of the GaN-on-sapphire template.

**Device and epitaxial wafer yields increase**

Due to technological difficulties of MOCVD growth of GaN-based structures, LED epi wafer yields are less than those for other compound semiconductor LEDs. The proposed GaN-on-sapphire templates will cause an increase in device yield for high brightness blue LEDs primarily due to material quality improvement (see above) and MOCVD process simplification. Elimination of sensitive growth steps which are extremely susceptible to process parameter fluctuation results in an increase in LED epi wafer yield.
**Cost reduction**

The use of GaN-on-sapphire templates instead of regular sapphire substrates provides a **significant cost reduction** for each fabricated epi wafer. This cost reduction is based on the following:

- reduction of rough material consumption,
- lower maintenance cost,
- lower labor cost per growth run due to shorter growth process duration,
- longer growth equipment lifetime,
- lower growth equipment depreciation,
- increase in epitaxial runs, epitaxial wafers and device yield.

Users of the template will also have cost benefit related to **higher brightness** expected for blue LED grown on the templates.

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**Overall,** TDI proposes to use GaN-on-sapphire templates for blue LED volume production. Use of these templates is believed to increase blue LED production throughput, improve device performance and yield, and reduce manufacturing cost. **TDI is willing to discuss customer target price and specification for GaN-on-sapphire templates to meet the needs of both customer and TDI.**

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Photo of 2 inch diameter blue LED wafer fabricated on GaN-on-sapphire template.
Appendix A

Schematic view of GaN-on-sapphire template

<table>
<thead>
<tr>
<th>GaN layer</th>
<th>Sapphire substrate</th>
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</thead>
</table>

Template Specifications

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
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</thead>
<tbody>
<tr>
<td>Diameter</td>
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<tr>
<td>Substrate</td>
<td>c-plane sapphire</td>
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<tr>
<td>Thickness of GaN epitaxial layer, µm</td>
<td>3 - 5</td>
</tr>
<tr>
<td>GaN surface</td>
<td>as grown</td>
</tr>
<tr>
<td>GaN orientation</td>
<td>(0001)</td>
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<tr>
<td>GaN Conductivity</td>
<td>n-type</td>
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<tr>
<td>Doping impurity</td>
<td>silicon</td>
</tr>
<tr>
<td>Concentration (N_d - N_a), cm(^{-3})</td>
<td>((1-3)\times10^{18})</td>
</tr>
</tbody>
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