Progress of Solid State Lighting Technology in Taiwan

Yung S. Liu, Jung-Tsung Hsu, Jim Chi. Shyi-Ming Pan and Te-Chung Wang,
Opto-Electronics & Systems Laboratories (OES)
Industrial Technology Research Institute (ITRI)
195 Sec.4, Chung Hsing Rd., Hsinchu 310, Taiwan, ROC.
Tel: 886-3-591 3525; email: liuys@itri.org.tw

ABSTRACT

This paper reviews the current status of the solid state lighting technology development at the Opto-Electronics & Systems Labs. (OES), Industrial Technology Research Institute (ITRI) and recent industrial activities in the related areas in Taiwan.

Keywords— Optoelectronics, GaN, solid state lighting, LED, nano-photonics, compound semiconductor, optoelectronics industry, Taiwan

1. INTRODUCTION

Since the first commercial MOCVD reactor was installed in 1987 at ITRI and the first MOCVD company, UEC, was formed in 1993 for making compound semiconductor epilayers, the MOCVD industry in Taiwan has grown very rapidly since 1998. Currently, it is estimated there are over 20 companies actively engaged in manufacturing opto-electronics and RF components with over 200 MOCVD reactors installed for commercial production; about 40% of them used for making GaN products in LEDs. In 2002, according to Industrial Technology Information Service (ITIS), the total revenue of the LED products made by companies in Taiwan exceeding USD$1B and Taiwan is currently ranked as the top three LED producers in the world.

The research and development programs on the compound semiconductors for industrial applications in Taiwan had been initiated since 1980’s with most of the government R&D funding spent at the Industrial Technology Research Institute (ITRI) under the sponsorship of Ministry of Economic Affairs (MOEA). The GaN-related programs began in mid-1990’s for developing blue, green LED and later GaN-based white LED.
Currently, the GaN program at ITRI are focusing on development of high power and high efficiency GaN-based LED devices for display and lighting applications.

2. SOLID STATE LIGHTING RESEARCH AND DEVELOPMENT AT ITRI

GaN LED related research programs at ITRI could be divided into two phases. In the first phase from 1995 to 2000, the main activities were to establish the epi-technology to grow InGaN LED using MOCVD technology, and to develop LED chip processes, such as contacts, dry etching and chipping processes. In addition to technology development work going on at ITRI, the technology transfer to local companies were being carried out in the same time. The close interactions between ITRI and local industry had contributed to the rapid growth of the MOCVD industry during this period.

The second phase took place since 2001, in addition to the process development, the ITRI program started to address the issues related to packaging technologies as well as lighting applications critical to energy conservation. Technologies on special package designs for lighting application as well as packaging technologies using flip-chip for high power devices were developed. The program has been coupled more close to the lighting industry and LED-based lighting equipment. Demonstrations using solid state lighting for replacement of conventional lighting sources for energy saving and environmental conservation have also begun in this phase.

2.1. High efficiency and high brightness InGaN LED

GaN LED related programs at ITRI started in 1995 with the installation of a GaN MOCVD system. GaN/InGaN hetero-junction LED devices were successfully developed by the end of 1997, and by 1998, QW LED devices with an output power over several mW were routinely produced in our laboratory.

It was recognized early the importance of finding a good transparent contact layer for the GaN LED device. Using oxidation of Ni/Au alloy, a very good Ohmic contact material to p-type GaN was obtained in our laboratory (OES/ITRI). [1,2] The specific contact resistance could be as low as $4 \times 10^{-6}$ cm$^2$, as shown in Fig. 2a due to the formation of NiO/Au structure observed in TEM. In addition, we observed that the transparency of NiO/Au is much better than Ni/Au which was most commonly used in GaN devices at the time. Fig. 2b showed
that the transparency of NiO/Au which was measured to be over 65% at 470 nm and 75% at 530 nm. After the application of transparent contact layers NiO/Au on the LED device, very uniform light emitting from the LED was observed as shown in Fig 1c, as comparing with other contacts fabricated by other methods shown in Figs. 1a and 1b.

![Fig. 1 The LED output from various contacts. (see text).](image)

![Fig. 2 Contact resistances and transmission spectra of the transparent contact layer of p-GaN](image)

Proc. of SPIE Vol. 5187 201
2.2. Multi-chip Module Packaging Technology

For general lighting applications, packaging of high power devices to generate white light and to produce a higher flux output from a single chip are critical challenges. Light output from a commercial LED lamp is usually less than 100 mW; a value far less than that generated from a traditional light source. To improve the light output from LED devices, a cluster of LEDs using a dozen or hundreds of LED lamps is required for outdoor display and for lighting applications. However, heat conduction problems have to be resolved.

To overcome those problems, previous work has demonstrated that high power LED devices with a normal light output more than 20 lumens. [3] Nevertheless, it has been shown that use of big size chips always produces 10-30% loss in the external quantum efficiency. And, the loss increases as the chip size becomes bigger. On the other hand, comparing with a multiple of LED lamps, the heat dissipation from a large-sized chip is concentrated more in the chip area. Special packages capable of handling several watts are necessary for the high flux LED. Excellent package design for low thermal resistance is required.

Since 2001, we have developed the packaging technologies specifically for LED lighting and promoted the LED white light technology for general lighting and illumination applications. A multi-chips LED module using dozens of LED chips with the standard chip size had been designed for lighting application under the project. Heat considerations and optical devices, including reflector and focusing lens, are considered in the design of the new module. [4]

---

Fig. 3(a) A multi-chip LED module stacked by four 2 x 2 units, every single unit has 2 x 2 LED lamps, and every LED lamp has several LED chips. Fig. 3(b) Schematic of a single LED in the LED module shown in Fig. 3a.
Figure 3(a) is a schematic design for a multi-chips LED module. Multiple of LED chips are mounted directly to a substrate with good thermal conductivity and dissipation, and reflectors and lens for LED chip are designed in the module. The schematic diagram of the LED unit has been shown in Figure 3(b). Reflectors using a plastic molded structure were coated on the interior surfaces and designed to have a good collection of the horizontal light from LED. A flower-shaped lens was formed in the plastic molded structure to align all the light vertically to the substrate.

Two kinds of prototypes have been developed using a molded plastic design and the photographs are shown in Figs 4a and 4c. The LED module shown in Fig.4a was named #331, because the module consists of 3 x 3 LED chips, and optical treatment is separated for every chip. The dimension of #331 module is 5 mm thick, 17x17 mm² in area, and 1.85 gm in weight, which is about the same size of traditional big-lamp with 9 pieces of 5 mmφ lamps. The typical power consumption is about 1 watt for #331, which is about 1.5 times increased. The LED module consisting of sixteen #331 units have been made for lighting testing and shown in Fig. 4b. Fig.4c is another LED unit named as #114, which is a single optical unit with 4 LED chips. They are GaN chips coupled with phosphors, and could also be a mixture of red, yellow, green, blue chips. For the convenience of assembly, #224 LED unit has been also done, i.e. 2 x 2 x 4 LED chips are integrated and optical treatment is separated for every 4 chips. The typical operation power for #224 module is designed to be 2 watts, and the dimension is about 2 cm in each side. The LED module consisting of four #224 units have been shown in Fig. 4d.
For the LED modules, the output power of an assembled module depends on the performance of LED chips used for the package. If a white LED with an efficiency of 15 lm/W is used; a typical light intensity of a 9W LED module is found about the same as that of a 20W-halogen lamp.

3. Solid State Lighting Industrial R&D Consortium-

In view of the vast potential in the white light LED program and responding to the other national programs worldwide on white light LED, Taiwanese LED companies formed a R&D alliance in 2001. ITRI played an active role in helping organizing this industrial R&D alliance with companies specialized in the epitaxy, chip fabrication and the packaging assembly segments of the LED industry. Since the LED lighting with its benefit in electricity saving and the associated reduction in the environment impact, and long life, the benefit of LED lighting is a convincing case for the government of Taiwan to partially sponsor the R&D alliance. There are ten companies in the consortium including the Forepi, Epistar, Tyntek as the epitaxy and chip suppliers, Ledtech, Everlight, Brightled, Paralight, Kingbright, Optotech for the package and assembly segments.

The goal of the R&D consortium is to increase the efficiency of the LED and decrease the cost of the technology to make the LED lighting a viable source for lighting applications. The specific goal of the consortium is by 2005 to demonstrate 100 lm/W efficiency in the laboratory and a target for manufacturing capable of 50 lm/w efficiency. The R&D activities are organized as follows:

- UV LED epitaxy and chips with large (~1mm²) and small sizes.
- LED chip arrays with RGB chips.
- Phosphors
- High refractive index and UV transparent materials for packaging
- Optical design for lamps
- Failure analysis
- Measurement labs
- Market analysis.

Currently, the program has completed the first phase of the project to form the teams and agree upon the work. The program currently is going to extent for two years.
ACKNOWLEDGMENTS

The author would like to thank the Ministry of Economic Affairs of the Republic of China for financially support, the number of projects were 92-EC-17-A-07-R7-0310 for the laser part, 92-D0216 for the LED part and 91-D0120 supported by the Energy Commission of MOEA. The author also wants to thank a very capable team in the Nano-Photonics Center, Optoelectronics & Systems Labs, of ITRI that have contributed to much of the technical work described in this paper.
References


