# Gd Doping in AlN and Bright Ultraviolet Light Emission

Takashi Kita

Department of Electrical and Electronic Engineering, Kobe University, 1-1 Rokkodai, Nada, Kobe 657-8501, Japan,
Email: kita@eedept.kobe-u.ac.jp

## 1. Introduction

Ultraviolet (UV) light is indispensable for various industrial processes such as lithography, polymerization, sterilization, medical treatment, and so on. For these applications, discharge lamps using mercury have been widely used in such fields so far. However, mercury is recognized as a chemical of global concern due to its significant negative effect on human health and the environment. For human life free from mercury, it is strongly desired to develop novel UV lighting source which can replace currently available mercury lamps. Recently, nitride-semiconductor based UV light emitting diodes (LEDs) are attracting strong interest. The emission wavelength of LEDs can be controlled by the optical band gap, and efficient light emission is realized by utilizing quantum structures. However, the spectral line width limited by the thermal carrier distribution near the band edge is relatively broad. Moreover, when irradiating a large area with UV light, the flux from a small LED chip must be controlled to provide uniform power distribution on the illuminated area. Such point source of LEDs with the broad band emission is unfortunately limiting the application. For photo lithography to obtain the high resolution and medical applications to avoid unexpected side effects, light panel with a narrower spectral width is demanded.

Here, we focus on narrow band UV emission at ~320 nm of $Gd^{3+}$ doped in AlN with a wide-band gap of 200 nm (6.2 eV). [1-4]

## 2. Experimental Approach and Results

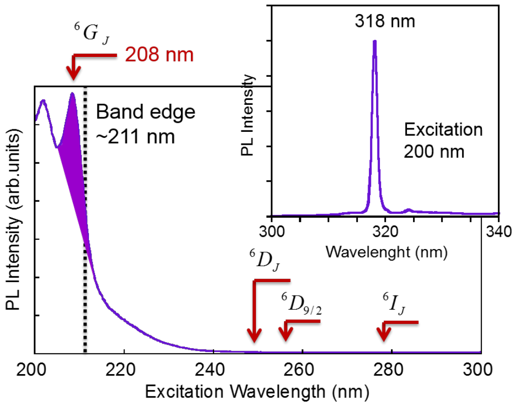

***Fig. 1*** *Cathode luminescence spectrum of* $Al_{0.99}Gd_{0.01}N$ *taken at room temperature.*

We fabricated $Al_{1-x}Gd_xN$ thin films on fused silica substrates using an ultra-pure sputtering growth technique. Optimum film growth conditions were widely examined to achieve bright luminescence. The luminescence shows an extremely narrow peak at 318 nm with the line width less than 1 nm. As shown in Fig. 1, the PL-excitation spectrum shows an intense absorption peak at 208 nm just above the fundamental band edge of AlN (~211 nm). This indicates indirect energy transfer from the host crystal to $Gd^{3+}$ ions. By changing the band-gap energy of AlN with temperature, we revealed several resonant energy transfer channels into the $^6G_J$ levels. Furthermore, we developed field emission devices using an optimized $Al_{1-x}Gd_xN$ phosphor thin film. The maximum output power more than 1 mW/cm$^2$ was achieved. [3]

## 3. Conclusions

We developed rare-earth nitride semiconductor based mercury-free narrowband UV light sources. UV phosphor thin films of $Al_{1-x}Gd_xN$ were grown by using an ultra-pure reactive sputtering technique performed under molecular-beam epitaxial quality. The narrowband emission caused by the intra-orbital electron transition in the rare-earth $Gd^{3+}$ ions appears at 318 nm. It turned out that efficient indirect energy transfer from the band edge of AlN to the excited levels of $Gd^{3+}$ ions takes place.

## 4. Open Questions

- What is the highly efficient Gd centers.
- How can we control it?
- What's influence of oxygen? Gd and Al are good getters.
- Different applications using AlGdN or GdN?

## Acknowledgements

The author greatefully thanks Y. Ishizu, K. Ichii, and S. Kitayama of Kobe University for their assistance. The work was done by collaborating with Y. Chigi, T. Nishimoto, H. Tanaka, M. Kobayashi of YUMEX Inc., and T. Ishihara and H. Izumi of Hyogo Prefectural Institute of Technology.

## References

[1] T. Kita, S. Kitayama, M. Kawamura, O. Wada, Y. Chigi, Y. Kasai, T. Nishimoto, H. Tanaka, and M. Kobayashi, Appl. Phys. Lett, **93** (2008) 211901.

[2] S. Kitayama, T. Kita, M. Kawamura, O. Wada, Y. Chigi, Y. Kasai, T. Nishimoto, H. Tanaka, and M. Kobayashi, IOP Conf. Series: Materials Science and Engineering 1 (2009) 012001.

[3] S. Iwahashi, N. Kishi, S. Kitayama, T. Kita, Y. Chigi, T. Nishimoto, H. Tanaka, M. Kobayashi, and T. Ishihara, J. Appl. Phys. **111** (2012) 083526.

[4] K. Ichii, S. Kitayama, S. Iwahashi, J. Nakamura, R. V. Sagar, T. Kita, Y. Chigi, T. Nishimoto, H. Tanaka, M. Kobayashi, T. Ishihara, and H. Izumi, J. Phys. Conf. Ser. **417** (2013) 012049.