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Dielectric coating and surface plasmon enhancement of multi-color quantum-well structures

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***Abstract*—We fabricate a multi-colored quantum-well structure as a prototype towards monolithic white light-emitting diodes, and modify the emission intensities of different colors by introducing dielectric and Ag nanoparticle coating.**

Keywords— White LED; Surface plasmonics; Ag nanoparticles

I. INTRODUCTION

The development of white light-emitting diodes (LEDs) has become an important issue for light applications due to their long lifetime, small size, and low power consumption. The creation of white light out of monochromatic visible spectrum emitters can be based on phosphor converted white LEDs (blue+yellow) [1]. However, using phosphor converters complicates the LED process and increases the manufacturing cost; hence a phosphor free approach is desirable. Monolithic phosphor free approaches to achieve white LED have been researched over the past few years using III-nitrides [2-4]. Due to quantum-confined Stark effect the increasing indium composition results in a decreasing emission intensity at longer wavelengths.

We investigate the photoluminescence (PL) of a multi-colored quantum-well light-emitting structure, and demonstrate a simple method to modify and improve the PL emission spectrum using dielectric coatings and self-assembled Ag nanoparticles (NPs).

II. EXPERIMENTS AND RESULTS

A light-emitting structure with three quantum-wells of different In-composition is grown by MOCVD to achieve three different colors as shown in Fig. 1a. The PL spectrum of the as-grown structure is shown in Fig. 1b (dash-black), however, only two peaks are visible at λ_1 = 570 nm and λ_2 = 500 nm. The spectrum shows the total PL collected from both sapphire and GaN side emission, with sapphire side excitation.

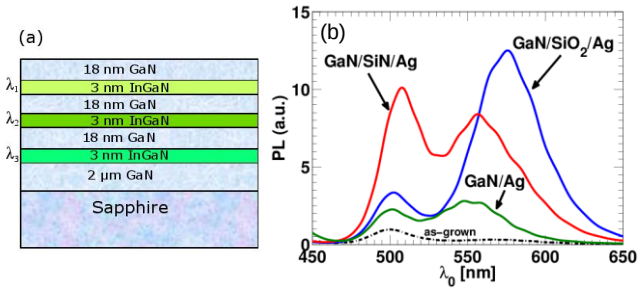

Fig. 1. a) The multiple-color InGaN/GaN QW structure where $\lambda_1 > \lambda_2 > \lambda_3$. b) Total PL spectra of the as-grown QW (black dashed). Comparison is made between 20 nm SiO_2 and SiN thin film together with Ag NP coating.

Fig. 1b shows the effect of introducing Ag NPs on the GaN surface to improve the PL emission (GaN/Ag). The QW with λ_1 is enhanced more than that of λ_2. Enhancements are the result of localized surface plasmon (LSP) coupling with QWs, and this interaction decreases with distance between Ag NP and excitons, therefore a stronger enhancement is obtained for the closest QW with λ_1. This effect equalizes the peak intensities of the two QWs, which is a desirable effect when aiming for monolithic white LEDs.

Forming self-assembled Ag NPs on the dielectric coated samples gives the PL spectra as shown in Fig. 1b. With a dielectric layer of lower refractive index, the scattering efficiency of Ag NPs will be improved resulting in a stronger PL intensity [5]. With SiO_2 the enhancements are seen to occur at long wavelengths, while for SiN a more uniform enhancement is obtained. Integrated PL enhancements by Ag NPs relative the as-grown sample are 3.1, 14.0 and 14.4 for bare GaN, SiO_2 and SiN coated samples, respectively.

III. SUMMARY

In conclusion we have grown a multi-color quantum-well structure to emulate a monolithic white LED, and investigated how the emission peaks can be enhanced and equalized using dielectric coating and Ag NPs. While SiN coating shows a uniform enhancement over the emission wavelength range, SiO_2 coating with Ag NPs shows large enhancement at longer wavelengths. This is a promising method to engineer the emission peaks of different QWs in a monolithic white LED design.

IV. ACKOWLEGDEMENTS

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