Surface plasmon enhanced light emitting efficiencies of InGaN/GaN quantum wells

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Abstract: We report a dramatic increase in the light emitting efficiency of InGaN/GaN resulting from surface plasmon interaction between the quantum wells and evaporated silver layers, whereas no such enhancement was obtained from gold deposited samples.
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Since 1993, InGaN light emitting diodes have been commercialized as blue light sources [1], but their original promise as solid state replacements for light bulbs has so far been delayed as their light emission efficiencies have so far been limited. Recently, surface plasmon (SP) has received much attention to enhance the light emission of light emitting diodes (LEDs) [2]. Although coupling of spontaneous emission from InGaN into SP modes has been observed, light has not yet been efficiently extracted from plasmon structures at visible wavelengths [3-4]. Here we first report large photoluminescence (PL) enhancements from InGaN/GaN QW material coated with metal layers. By polishing the bottom surface of grown InGaN samples, QW emission can be photoexcited and measured through the back of the substrate.

InGaN QW were grown by MOCVD. 10 nm, 40 nm, and 150 nm thick GaN spacers were grown onto these QWs, and 50 nm thick Ag, Al, or Au layers were evaporated on top of the wafer surfaces. PL measurements were performed by exciting the QW with a 406nm diode laser from the back of the substrates, and collecting luminescence with a multichannel spectrometer.

Fig. 1 shows PL spectrum from InGaN/GaN QW separated from Ag, Al and Au layer by a 10nm GaN spacer. The PL peak of the uncoated wafer at 470 nm is normalized to 1. 14-fold peak intensity and 17-fold integrated intensity enhancements were observed from the Ag coated emitter. Also, 8-fold peak intensity and 6-fold integrated intensity enhancements are obtained from Al coated sample, whereas PL is not increased after Au coating. PL intensities of Al and Ag coated samples were also found to strongly depend on the distance between QWs and the metal. These results suggest that the emission enhancement after coating with Ag and Al can be attributed to strong interaction with SP.

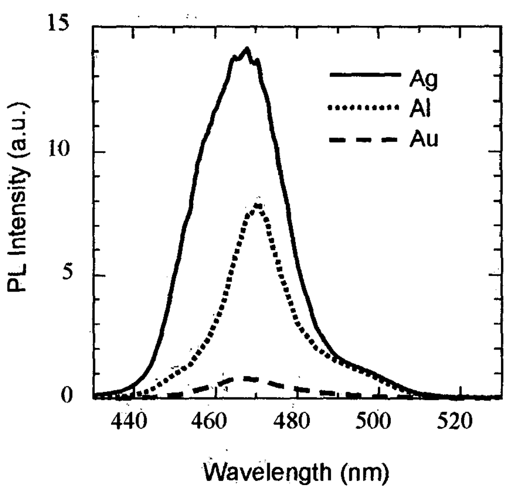

Fig. 1 PL spectra of InGaN/GaN with Ag, Al and Au layers

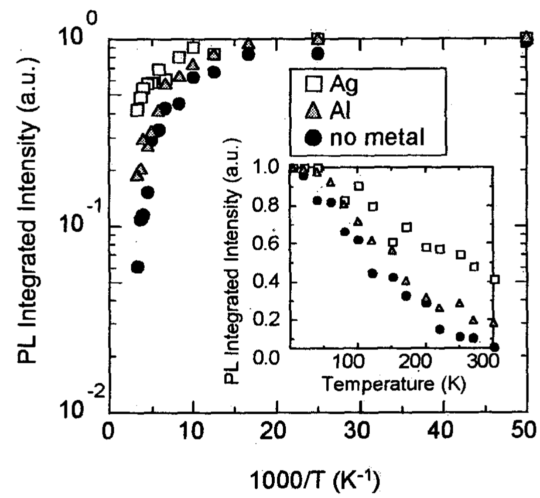

Fig. 2 Temperature dependence of PL intensities

SP-QW coupling should increases internal quantum efficiency (η_{int}) by enhancing the spontaneous recombination rate. Fig. 2 shows the linear and Arrhenius plots of the integrated PL intensities from InGaN QWs separated from Ag and Al films by 10nm spacers, and compares these to uncoated samples. $\eta_{int\ t}$ values from uncoated QWs were estimated as 6 % at room temperature by assuming η_{int} ~100% at 4.2K. These η_{int} values increased 6.8 times (to 41%) after Ag coating and 3 times (to 18%) after Al coating, explainable by spontaneous recombination rate enhancements through SP coupling.

SP coupling is one of the most interesting methods for developing efficient LEDs, as the metal can be used both as electrical contact and for exciting plasmons.

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