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Plasmon enhanced green GaN light-emitting diodes

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High-efficiency gallium nitride (GaN) based blue light-emitting diode (LED) paves the way for solid state lighting to take the place of the conventional incandescent bulbs and fluorescent light tubes. Compared to the traditional light sources, solid state lighting is more efficient, more flexible in spectral design, more compact etc. The III-nitride (GaN, InN etc.) semiconductors are attracting a lot of research effort because the combination of both could emit light with wavelength range from UV to infrared. Basically one material platform could provide all the solutions to light sources. However huge amount of material development is needed before high efficiency devices are achieved. Among them, one effort area is the so called 'green gap', i.e. low efficiency for green color LEDs due to the large piezoelectric field in the quantum wells (QWs) when the In composition is high. From the material growth point of view, the efficiency of green LED is being improved by growing the GaInN material on non-polar or semi-polar surface of sapphire substrate. In parallel with the material growth effort, surface plasmons are implemented by taking use of the interaction between metals and active areas to increase the efficiency.

In this paper, our work on using silver (Ag) nanoparticles (NPs) to enhance the efficiency of the green LEDs is reviewed. Both random and periodic Ag nanoparticles are studied. The random Ag nanoparticles are formed by thermal annealing of thin films. Periodic Ag nanoparticles are formed through nanosphere lithography. For both cases, emission enhancement is demonstrated. For periodic Ag nanoparticles, a photoluminescence enhancement of 2.7 is observed with a nanodisk diameter of 330 nm. It is found that an optimal pitch exists for a given particle size. For the random Ag nanoparticles, low temperature photoluminescence (LTPL) was measured and internal quantum efficiency (IQE) enhancement by the surface plasmons was derived. Excitation power dependence of IQE enhancement is derived as well from the PL measurement under different excitation power densities. It was found that the strong PL enhancement was partly due to LSP-QW coupling, and partly due to excitation source enhancement from the Ag NPs, and separating these effects we noted an IQE improvement due to LSP-QW coupling at 530 nm emission from 19.4% to 44.1% using large sized Ag NPs at 756 W/cm². It was also found that the IQE enhancement is strongly dependent on excitation power density, yielding highest enhancement factors at low free carrier densities. Where an IQE enhancement by a factor of 2.3 was observed at 756 W/cm², an enhancement factor of 8.1 was observed at 1 W/cm².