Surface Plasmon Enhanced Emission from InGaN LEDs.

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Motivation—Spontaneous emission of light from a semiconductor is generally thought to be characterized by a constant rate such that the efficiency of light emission is fixed for a wide range of experimental conditions. However, there are a number of methods to change the radiative recombination rate by altering the photonic density of states. By increasing the number of available final photon states for a transition, the probability for that transition can be changed. In a properly designed structure, surface plasmons can be used to increase the photonic density of states thereby increasing the radiative recombination rate resulting in an overall increase in efficiency for InGaN LEDs.

Accomplishment—Surface plasmon related enhancements to luminescence can only be observed when the metal film supporting surface plasmons is placed extremely close (< 75 nm) to an emitter. Since the field from a surface plasmon mode falls off exponentially from a metal-dielectric interface, emitters must be placed as close as possible to this interface. In our case, a single InGaN quantum well (QW) is grown very near the surface of a sample such that metal can be deposited in close proximity to the QW. The emission wavelength of the QW must also be close to the surface plasmon resonance in order to change the photonic density of states. Photoluminescence measurements have shown increases in both the total luminescence and the PL decay time for samples with a deposited metal film.

An electrically injected device showing surface plasmon enhanced emission is much more difficult due to the constraint that the QW be placed very close to the metal surface. Figure 1 shows a schematic diagram of our design for an electrically injected InGaN surface plasmon LED. A considerable amount of growth related research was required in order to grow extremely thin p-GAN material that would also form a robust contact layer for hole injection. In this design the metal film acts as an Ohmic contact to the thin p-GaN and lateral patterning of the metal is used to extract surface plasmon modes from the semiconductor. In this way, the metal film is used to increase both the radiative and the extraction efficiencies.

Light emitting diode wafers with a single QW were grown by metal-organic vapor phase epitaxy with different p-GaN thicknesses. Material with a very thick p-GaN layer is not expected to show surface plasmon enhancements since the QW is far from the metal interface. Figure 2 shows light vs. current curves for an InGaN surface plasmon LED with emission at 450 nm with a p-GaN thickness of 50 nm compared to a control LED with a standard thickness p-GaN layer (200 nm). The inset of the plot shows the enhancement factor as a function of drive current. At low current where there is increased non-radiative recombination, enhancements as high at 15 times have been observed, whereas at higher current, where solid state lighting devices will operate, an enhancement of about 7 times has been observed due to surface plasmon effects.

Significance—Poor internal quantum efficiency continues to be a problem for InGaN LEDs particularly for emission at green and yellow wavelengths. This work shows that surface plasmons can be used in a practical device structure to enhance efficiency. Surface plasmon mediated emission has the potential to dramatically improve the efficiency of longer wavelength green and yellow emitters for solid state lighting applications.

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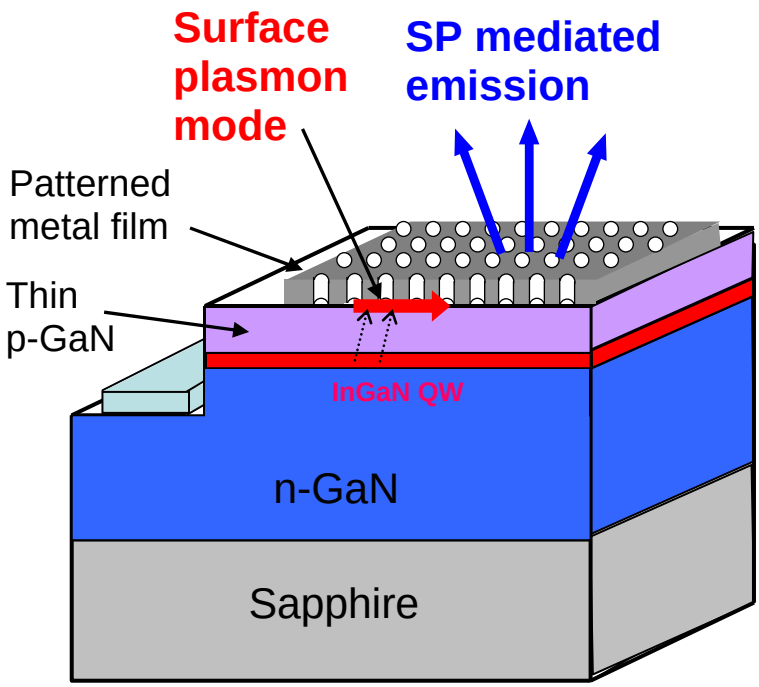

Figure 1. Schematic diagram of an electrically injected InGaN surface plasmon LED showing a patterned metal film for extraction of surface plasmon modes.

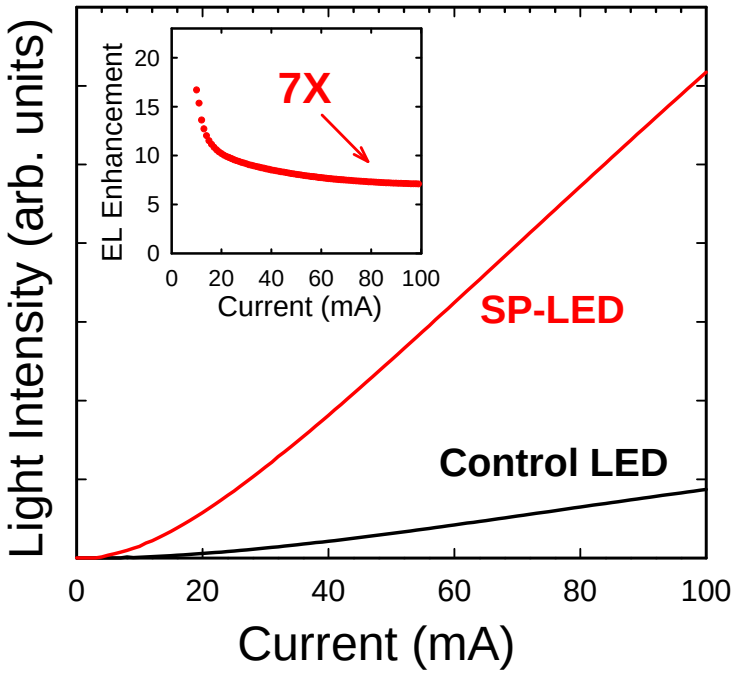

Figure 2. Light vs Current for a surface plasmon LED (SP-LED) compared to a control LED. The inset shows the enhancement due to surface plasmons as a function of current.