Enhanced Spontaneous Emission Rate of InP using an Optical Antenna

Kevin Messer, Michael Eggleston, Ming C. Wu, Eli Yablonovitch
University of California – Berkeley
253M Cory Hall, Berkeley, CA 94720
kmesser@berkeley.edu

Abstract: Experimental evidence of enhanced spontaneous emission from InP coupled to an optical antenna is presented. Photoluminescence measurements show a 120x increase in light emission from antenna-coupled devices over bare InP emitters.

1. Introduction

The spontaneous emission rate of III-V semiconductors has limited modulation rates of light-emitting diodes (LEDs) to 100s of MHz. Enhancing the spontaneous emission rate of these materials would allow LED switching speeds to become competitive with lasers, and make them a viable emitter for short-range optical interconnects. To achieve a large enhancement of the spontaneous emission rate we use an optical antenna tuned to the emission frequency of the light emitter. Recent work in this field has demonstrated the ability to modify the spontaneous emission of a variety of light emitters [1,2], but success using top-down fabricated semiconductor devices has been limited to small enhancement factors [3]. We present an optical antenna for an InP emitter that shows a 120x enhancement in light emission corresponding to a 14x increase in spontaneous emission rate.

2. Device Design and Fabrication

The optical antenna used here is a 55nm wide, 260nm long dipole antenna with an arch over the InP emitter (Figure 1a,b). The InP is 10nm tall, 12nm wide, and 250nm long with a 3nm coating of TiO_2. The InP emitters are fabricated using electron beam lithography and wet etching with an InGaAs hard mask [4]. This is followed by a second lithography step and Au evaporation with a Ge adhesion layer to form the optical antennas. Finally, to eliminate the effects of light extraction in the photoluminescence (PL) measurement, the sample is bonded with optical epoxy to a quartz slide and the InP substrate is removed.

Devices were fabricated in arrays with 1μm pitch. Several emitters were left without optical antennas (Figure 1c) so that a baseline measurement could be taken for calculating the spontaneous emission enhancement. Figures 1b and 1c show the completed devices used for PL measurements before the substrate removal process.

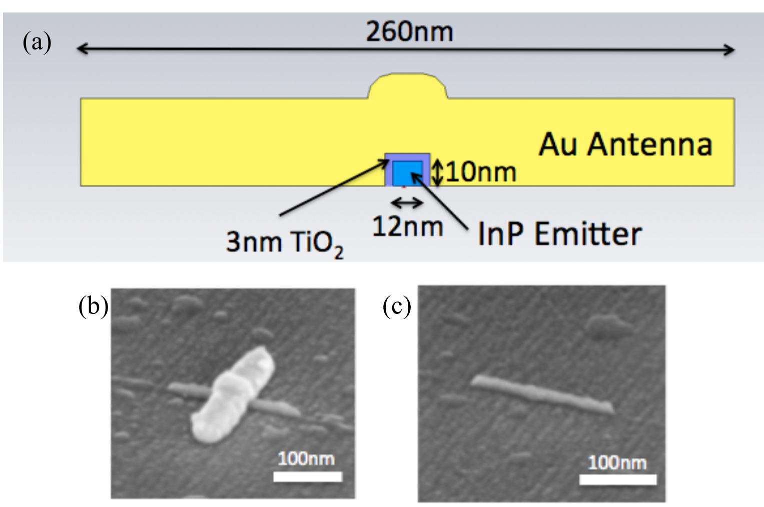

Figure 1 (a) Schematic of the cross section of the optical antenna device, (b) SEM image of an optical antenna device (before substrate removal), (c) SEM image of an InP emitter without an optical antenna (before substrate removal).

3. Experimental Results

Photoluminescence measurements were taken to determine the influence of the optical antenna on the spontaneous emission rate of the InP emitter. Surface recombination dominates the total recombination rate for all measured devices, so relative changes in quantum efficiency are a direct measurement of the change in spontaneous emission rate. The devices were pumped with a pulsed Ti-Sapphire laser tuned to 720nm, and emitted PL was detected using a liquid nitrogen cooled Si CCD.

By selecting the polarization of both the pump laser and collected PL, we are able to measure how the antenna impacts both the pumping and emission properties of the InP emitter. Figure 2a shows an increase in PL of 120x from an antenna-coupled device when both the pump and emission polarizations are directed along the axis of the antenna. To measure the effect the antenna has on pumping the devices, we turn the emission polarizer perpendicular to the axis of the antenna and see only an 8.5x increase in PL (Figure 2b). Removing the pump enhancement from the result leaves a net increase in emission of roughly 14x, which is due to the increased spontaneous emission rate of InP near the antenna.

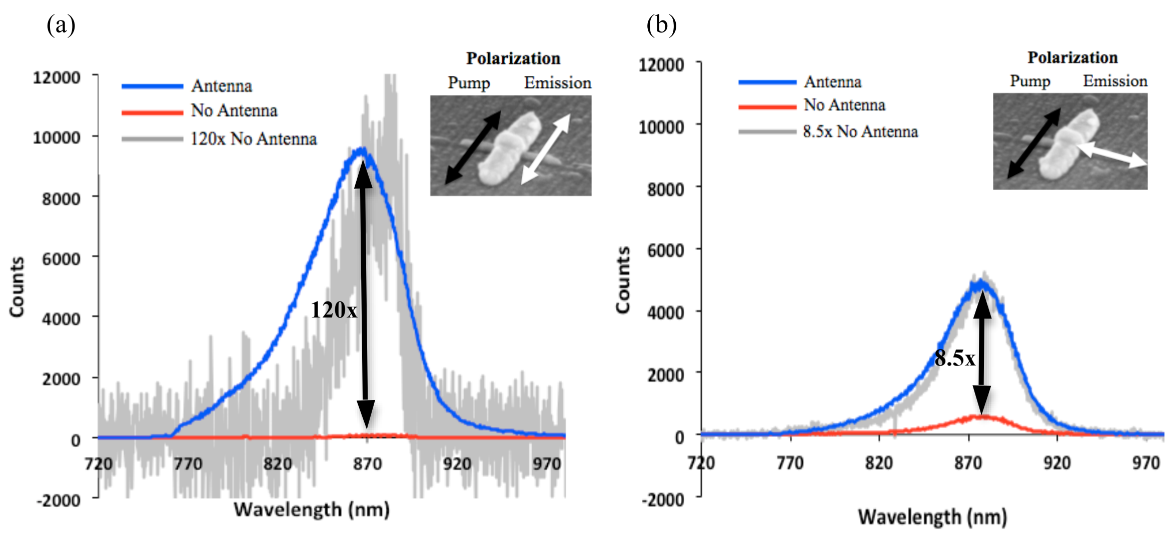

Figure 2 (a) Photoluminescence signals with both pump and emission polarizers directed along the axis of the antenna. (b) Photoluminescence signals with the pump polarizer directed along the axis of the antenna and the emission polarizer directed perpendicular to the axis of the antenna.

4. Conclusion

An optical antenna for enhancement of spontaneous emission from InP has been fabricated, and photoluminescence measurements indicate a minimum enhancement factor of 14. Further increases in spontaneous emission rate enhancement could make LEDs faster than lasers.

5. References

[1] Kinkhabwala et al., "Large single-molecule fluorescence enhancements produced by a bowtie nanoantenna," *Nature Photon,* Oct. 2009.

[2] Lee et al., "Spontaneous emission enhancement of a single molecule by a double-sphere nanoantenna across an interface," *Opt. Express* 20, pp. 23331-23338, 2012.

[3] Arbel et al., "Light emission rate enhancement from InP MQW by plasmon nano-antenna arrays," *Opt. Express* 19 (10), pp. 9807-9813, 2011

[4] Koch et al., "Anisotropically etched deep gratings for InP/InGaAsP optical devices," *J. Appl. Phys.,* **62** (8), pp. 3461, 1987