Recent Advances in Semiconductor Nanolasers

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Abstract: Nanolasers that integrate metal into the cavity design have pushed laser volumes much below one cubic wavelength λ_0^3. In this paper, we review this growing field and highlight recent work on the nanopatch laser.

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1. Introduction

The demonstration of nanolasers that utilize metal-optics and plasmonics has created a revolution in nanophotonics. A wide variety of fields including data storage, photolithography, integrated photonics, and biosensing stand to benefit immensely from a subwavelength source of light [1,2]. Many semiconductor nanolasers have been demonstrated that operate at room temperature [3–6], are electrically driven [1,4,6,7], and operate in continuous-wave [4,6]. Yet the physical volume of a laser, V_{phys}, is quite possibly the most important feature of the nanolaser since the fundamental size limit of these devices will ultimately illuminate what applications we can hope to enable with future development.

Using plasmonics to squeeze "large" photons into "small" plasmons can create subwavelength light sources [5,7–10]. Laser oscillations have even been observed at room temperature [5]. The ultimate goal of plasmon lasers will be to demonstrate a device that confines light into a volume of $(\lambda_{sp}/2)^3$ in a commensurately small physical volume V_{phys} as well. Yet to date, most plasmon based lasers confine light in only one or two dimensions. We believe that research into mitigating metal loss and designing nanocavities with low radiation rates in *small volumes* will both be critical for future applications.

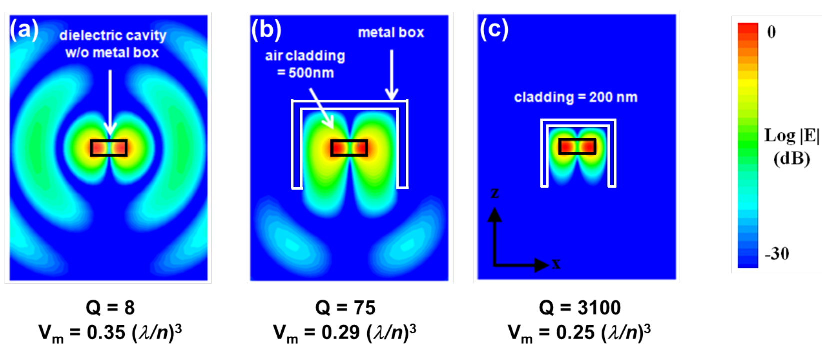

Fig. 1. In (a), (b), and (c) we show the successive reduction in radiation for a 500nm x 400nm x 200 nm semiconductor block by introducing a reflective metallic box around it. Using metal, we can acheive quality factors as high as $Q = 3100$.

In order to minimize metal loss, many groups have decided to use metal as a reflector instead of a plasmonic material [1,3,4,6,11]. Using metal to block radiation is best illustrated using a microdisk cavity (Fig. 1). As metal is introduced, a large amount of radiation is blocked. As the metal comes closer to the cavity, however, ohmic losses also increase. Thus, a tradeoff between radiation and metal losses still remains in engineering these nanocavities with small V_{phys}.

2. The Nanopatch Laser

One particular metallo-dielectric cavity is the nanopatch laser (Fig. 2) [11]. By using metal reflection on the top and bottom of a semiconductor patch, radiation is controlled effectively (while mitigating ohmic loss) and we achieve laser oscillations in the smallest physical laser volume currently known for semiconductor devices ($V_{phys} = 0.019(\lambda_0)^3$, or $0.056\ \mu m^3$). The nanopatch laser can be very accurately described analytically by using simple eigenmode analysis, and we observe lasing from the TM_{111} and TE_{011} eigenmodes (see Fig. 2) by optically pumping the devices at 77K. Currently, we have made considerable progress in creating electrically-driven nanopatch lasers as well (Fig. 2).

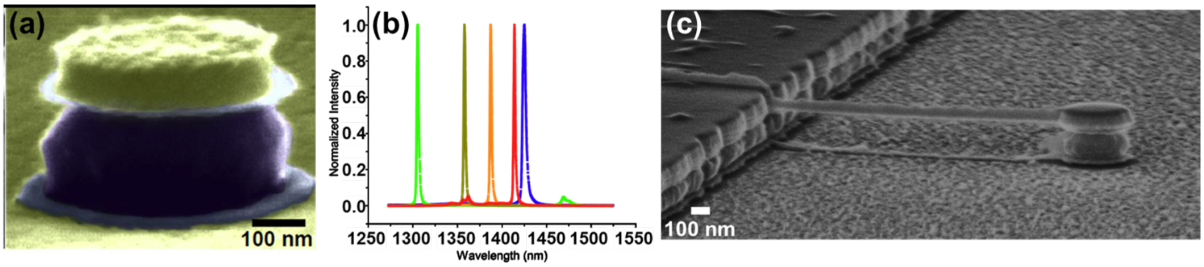

Fig. 2. In (a), we show an SEM image of a fabricated nanopatch laser. The device has the smallest physical volume for a semiconductor laser. In (b), we show lasing spectra for various device radii. In (c), we demonstrate a method to contact the top patch with a thin gold wire for electrical injection.

3. Conclusion

As the field of nanolasers advances, the challenges (and opportunities) for researchers will lie in learning how to adapt materials to reduce resistive metal loss, to increase semiconductor material gain, and to efficiently inject carriers into extremeley small volumes of semiconductor. Yet, we believe that a successful demonstration of a practical, electrically-driven subwavelength nanolaser will revolutionize many sectors of technology.

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