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Novel Plasmon Nano-Lasers

Martin T. Hill, Milan Marell
COBRA Research Institute, Eindhoven University of Technology, P.O. Box 513, 5600 MB Eindhoven,
The Netherlands. Email: m.t.hill@ieee.org

***Abstract*—We will discuss some of the latest developments in metallic and plasmonic nano-lasers. Furthermore we will present our latest results on further miniaturization of electrically pumped plasmonic nano-lasers and also DFB Plasmon mode devices.**

I. INTRODUCTION

Recently there has been a significant number of results reported on lasing in metallic and plasmonic nano-structures. In particular both for devices based semiconductor gain medium [1-5] and a number based on dye gain mediums [6]. Only a few years ago it was considered that metallic nano-structures would never be suitable for making nano-lasers and that the size of the smallest lasers will always be limited by diffraction.

Will such small lasers have any use? With laser size now no longer limited by diffraction, the modulation or switching speed of these nanolasers can potentially reach into the THz region [7], at low power consumption, which will be of interest for short-range optical communication and switching applications. The availability of ultrasmall high-speed SPP sources will also open up the way to complex nanoscale optical systems based on plasmonics. Finally, having now independent lasers that can be formed into arrays of sub-wavelength pitch, may open up new possibilities for sub-wavelength scanning and optical atom traps.

For many applications there will be a requirement for continuous operation at room or higher temperatures with good device lifetimes, and efficient electrical pumping of the laser gain medium. If these challenges can be met, then spasers [8] or plasmonic nanolasers will be widely employed diverse areas.

II. ELECTRICAL PUMPED MIM STRUCTURES

Our approach to making metallic/plasmonic nano-lasers has been to encapsulate semiconductor hetero-structure pillars in a thin insulator, then a metal cladding (figure 1). The cross-section of these pillars is defined by lithography before the pattern is transferred into the expitaxially grown semiconductor material. This approach has also been successfully pursued by other groups. In particular the approach allows us to electrically pump the gain medium, by distancing the electrical injection contact points from the place where the optical mode interacts with the noble metal. Another aspect of the encapsulated hetero-structure approach is that many different cavity and waveguide types can be formed by just changing the cross-section of the pillar in the lithography step. In the past we have constructed small round pillars exhibiting a HE11 (hybrid electric) resonant mode [1], and also Metal-Insulator-Metal waveguides structures [2].

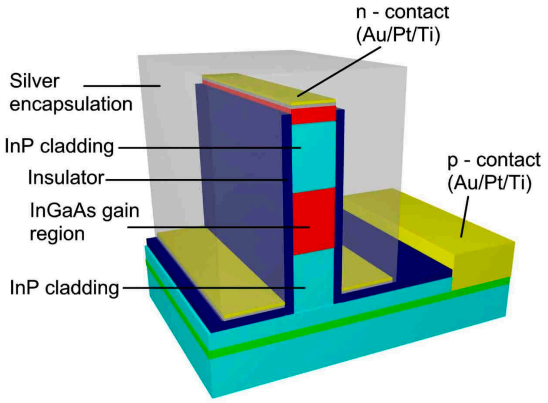

Fig. 1. Structure of metal encapsulated nano-lasers.

Our future focus involves making both smaller and more complex electrically pumped MIM waveguide devices. One of the key requirements in future plasmonic lasers will be precise control over the operation wavelength and the form of the optical mode. In conventional semiconductor lasers precise wavelength control is often achieved via Bragg gratings used to form distributed feedback (DFB) or distributed bragg reflector (DBR) lasers. A method proposed in the literature to form Bragg grating reflectors in MIM waveguides is to modulate the waveguide width [9]. This method has been employed by us to create plasmonic DFB nano-lasers. The modulation of the MIM waveguide width is achieved by modulating the semiconductor waveguide core width during the lithography. Figure 2 shows one of these waveguide cores before metal encapsulation.

III. REDUCED SIZE MIM STRUCTURES

Our ultimate aim is to further reduce both the size of the optical mode and the active region down to a few tens of nano-meters in two dimensions. This is possible in the encapsulated heterostructure concept with slight modifications. In particular we have indented the sidewall

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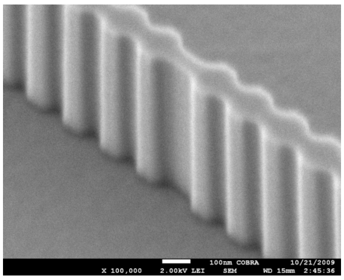

Fig. 2. Semiconductor core with modulated width to used to form plasmonic DFB lasers.

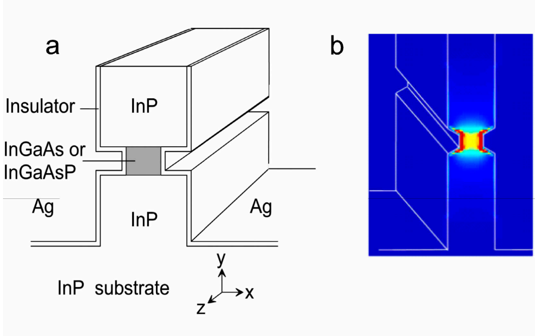

Fig. 3. a) Structure of an active surface plasmon polariton gap waveguide. Lithography, dry etching and selective wet etching can be used to form the three dimensional nano structure. Metal can be deposited by evaporation around the form to complete the waveguide and provide a top electrical contact. b) Plot of $|E|^2$ from FDTD simulation of such a structure, showing tightly confined mode.

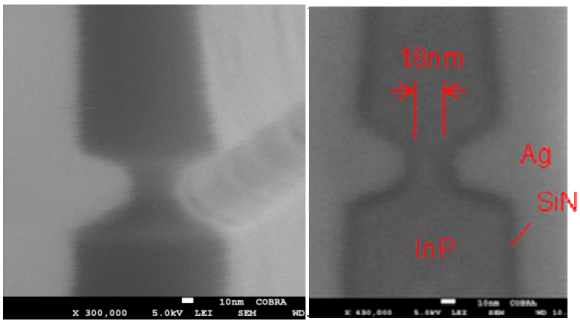

Fig. 4. Left, actual fabricated semiconductor InP/InGaAS semiconductor core. Right, cross-section of a completed waveguide which has been encapsulated in silver.

around the active region as shown in figure 3. The indentation strongly localizes the optical mode in the vertical direction [10-11], while the metal sidewalls confine the mode in the horizontal direction. A plot of the simulated electric field magnitude is shown in figure 3b.

Key issues in constructing such devices are: the shaping of the sidewalls via chemical processes. Sidewall roughness reduced to the nano-meter scale. The deposition of high quality conformal silver layers. Finally, the coating of the semiconductor form with thin dielectric layers This is in particular is a critical step as a significant amount of the modal energy can be contained in the dielectric layer between the semiconductor and the metal. The goal here is to make the dielectric layer as thin as possible and also with a high refractive index to minimize the energy contained in it.

Figure 4 shows scanning electron microscope images of a bare waveguide core with a sidewall indentation. Furthermore figure 4 shows a completed waveguide that has been encapsulated in dielectric, then silver. In the presentation we will show results from both DFB plasmonic laser devices and also indented sidewall devices.

IV. CONCLUSIONS

Rapid progress is being made in the miniaturization of lasers to sizes below the diffraction limit. It is likely that in the near future such devices will be useful in important applications. Our approach in based on encapsulated electrically pumped hetero-structures, and in particular we are focusing on employing the MIM waveguide structure as a basis for our devices.

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