Side-emitting metallic waveguide lasers with InGaAsP MQWs

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***Abstract*— Metal-coated cavities can be used to fabricate lasers with nanometer-scale dimensions. So far, these lasers were fully enclosed by metal and emitted their light, scattered from within the cavity, through the substrate on which they are fabricated. In this paper we present the first side-emitting metal-insulator-metal waveguide laser.**

Keywords:

I. Introduction

The arrival of the first electrically pumped metal-coated nano-laser has opened a whole new range of possibilities for integrated optics. It has been shown that despite high internal losses, lasing is possible in metallic or plasmonic cavities with dimensions well below the diffraction limit of light [1,2,3,4]. Cavities with moderate Q-values can reproducibly be fabricated and lasing can be achieved at very low currents (μA range). Due to the small size and high pump density, it is possible that future metallic nano-lasers will have switching speeds in the THz range.

Integration of these lasers with other optical components is difficult, since they are fully enclosed by a metal layer of several hundreds of nanometers thick. Side-emission of metal-coated lasers is desirable. In this paper we demonstrate the first side-emitting metallic waveguide laser.

II. Fabrication

The side-emitting, metal-coated lasers are fabricated on an n-doped InP substrate on which a InP/InGaAsP/InP heterojunction is grown; in the 510 nm thick InGaAsP layer, 8 InGaAs quantum wells of 4.1 nm thickness are incorporated. The structures are defined by electron beam lithography in a 140 nm thick PMMA resist layer at 30 kV. The pattern is inverted by covering the sample with 30 nm of Cr and performing lift-off in acetone. The chrome pattern is then transferred to a 440 nm SiO_2 hard mask layer by etching the SiO_2 for 30 minutes with a pure CHF_3 process in our RIE reactor. The sample is etched in a CH_4/H_2 ICP-RIE process to transfer the patterns to the semiconductor layer stack. After dry etching the structures, surface damage, caused by the dry etching, is removed by repeatedly oxidizing the sidewall surface and etching away the oxidized material. A 20 nm thin SiN_x layer is then deposited to protect the sidewalls and to electrically insulate the silver cladding from the semiconductor stack. After the whole structure is covered in silver and the electrical contacts have been fabricated, the structures are cleaved and the facets polished with an Ar^+ cross-section polisher, resulting in Fabry-Perot cavities of 65 μm long and with a core width of 200 nm.

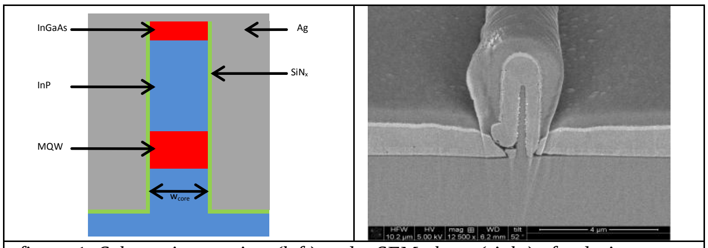

figure 1: Schematic overview (left) and a SEM photo (right) of a device cross-section. The waveguide width is 220 nm.

III. Simulation Results

Simulations show that, in a metallic waveguide with perfect rectangular shape, two modes are sustained. From these simulations an estimate of the propagation loss can be made. We find that the propagation loss is in the order of 0.14 dB/μm for the TE polarization and 0.09 dB/μm for TM polarized light. In reality, the propagation loss is expected to be even higher.

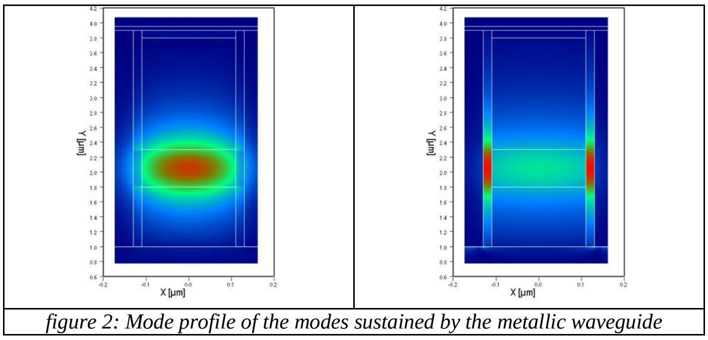

figure 2: Mode profile of the modes sustained by the metallic waveguide

IV. Measurements

A schematic overview of the measurement setup is shown in figure 3. Groups of 8 devices are placed inside a cryostat and cooled down to a temperature of 80K. Current was sent through the devices, while monitoring the voltage across the device and the spectral output of the device. Light emitted by the devices is collected by a microscope objective with a 17 mm working distance and 0.42 N.A. and coupled into a single mode fiber.

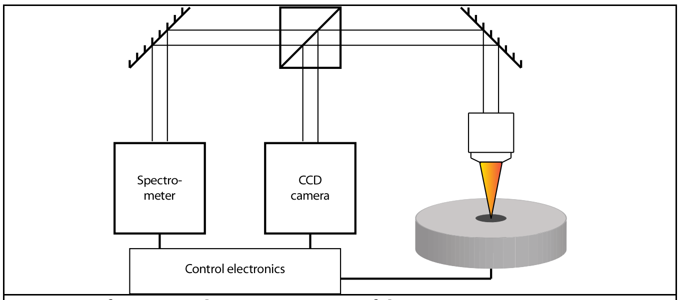

figure 3: Schematic overview of the measurement setup

From figure 4 & 5 it can be seen laser operation is achieved starting at a threshold current of approximately 75 µA. The light collected from the devices is TE polarized, due to the width of the waveguide and better overlap of the electric field with the quantum wells. The measured L-I curve shows super-linear behavior due indicative for typical Fabry-Perot lasers.

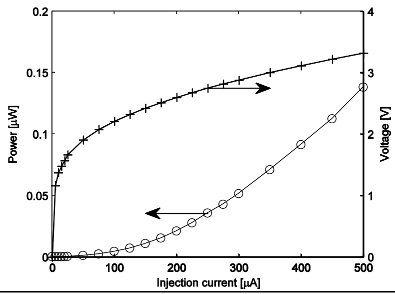

figure 4:I-V and L-I curve of metallic waveguide laser

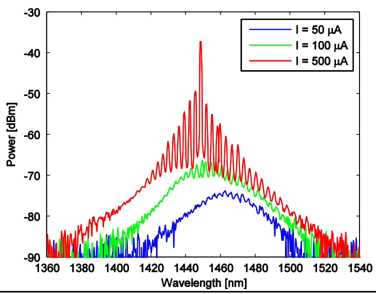

figure 5: Powerspectra of metallic waveguide laser

The wavelength of the main laser peak is located close to 1450 nm. The considerable blue shift is due to the high current density inside the device, the high gain required for lasing and the low operating temperature. The output power level at the wavelength peak 0.14 µW (in-fiber).

At I_{pump} = 500 µA, the power level in the main laser peak is 30 dB above the background ASE level. Figure 7 shows high resolution scans of the highest spectral peak for three values of the injection current. The FWHM decreases from 0.719 nm at I_{pump} = 150 µA to 0.102 nm at I_{pump} = 500 µA.

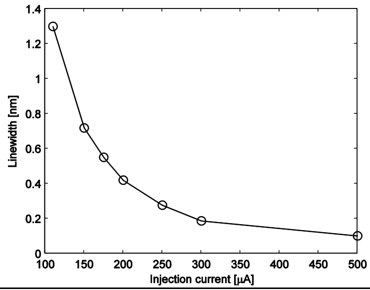

figure 6: Linewidth vs. injection current, measured at main lasing peak

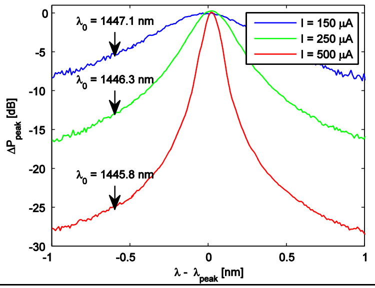

figure 7: Comparison of main laserpeaks at various injection currents

The wavelength of the peaks is 1447.1 nm, 1446.3 nm and 1445.8 nm respectively. The smallest linewidth measured for these devices is 68 pm, but is possibly smaller due to the limited resolution of the spectrum analyzer. The Fabry-Perot cavity modes are spaced 3 nm apart, which corresponds to a FSR = 444 GHz.

V. Conclusions and Outlook

We have shown that side-emission of a nanometer-sized, metallic waveguide laser is possible. Lasers based on metallic waveguides can operate at very low injection currents, similar to their fully enclosed counterparts (albeit currently at cryogenic temperatures only).

Work on truly plasmonic side-emitting lasers, with waveguide widths down to 80 nm, is in progress. Better performance is expected due to a more optimal shape of the waveguide's cross-section and a bulk active layer. Results on these lasers are expected soon.

VI. References

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