Metal coated DBR/DFB lasers

Citation for published version (APA):
Marell, M. J. H., Hill, M. T., & Smit, M. K. (2009). Metal coated DBR/DFB lasers. In S. Beri, P. Tassin, G. Craggs, X. Leijtens, & J. Danckaert (Eds.), *Proceedings 14th Annual Symposium of the IEEE Photonics Benelux Chapter, 5-6 November 2009, Brussels, Belgium* (pp. 221-224). Brussels University Press.

Document status and date:
Published: 01/01/2009

Document Version:
Publisher’s PDF, also known as Version of Record (includes final page, issue and volume numbers)

Please check the document version of this publication:

- A submitted manuscript is the version of the article upon submission and before peer-review. There can be important differences between the submitted version and the official published version of record. People interested in the research are advised to contact the author for the final version of the publication, or visit the DOI to the publisher's website.
- The final author version and the galley proof are versions of the publication after peer review.
- The final published version features the final layout of the paper including the volume, issue and page numbers.

Link to publication

General rights
Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal.

If the publication is distributed under the terms of Article 25fa of the Dutch Copyright Act, indicated by the “Taverne” license above, please follow below link for the End User Agreement:

www.tue.nl/taverne

Take down policy
If you believe that this document breaches copyright please contact us at:

openaccess@tue.nl

providing details and we will investigate your claim.

Download date: 04. Oct. 2023

Metal coated DBR/DFB lasers

M.J.H. Marell, M.T. Hill and M.K. Smit[1]

[1] Eindhoven University of Technology, Dept. of Electrical Engineering, Den Dolech 2, 5600 MB,
Eindhoven, The Netherlands

Metallic nano-cavities can be used to fabricate lasers of sub-wavelength dimensions. Currently, these lasers emit their light through the substrate. This complicates measurements of these devices and their integration in optical systems. Side-emission offers a way to circumvent these problems. We plan to implement side-emission via distributed feedback; this allows accurate tuning of a cavity's resonant wavelength and its emissive properties. In this paper we will give an update of the work that has been done.

Introduction

Sub-wavelength confinement of light in passive plasmonic devices, such as waveguides, has received considerable attention in the last couple of years [1, 2, 3]. For a long time it was believed that, due to the high optical loss, it was impossible to achieve lasing in a plasmonic cavity. However, Hill and colleagues have shown that it is possible to reproducibly fabricate plasmonic cavities with moderate Q-factors and that it is also possible to sustain a lasing mode inside such a cavity [4, 5].

The devices made by Hill are circular and rectangular shaped, with dimensions down to 80 nm, and are fully enclosed in silver. The devices are characterized by collecting light scattered through the substrate on which they are fabricated. To open the way for integration of these lasers in optical systems, side-emission is required. We believe that distributed feedback is suitable to enable side-emission in plasmonic cavities and propose to implement this via incorporation of vertical groove gratings in the cavity.

Basic device architecture

The general device architecture is shown in figure 1. The metallic nano-lasers are fabricated on a semi-insulating susbrate with an InP/InGaAs/InP double hetero junction.

An ultra-thin Si_3N_4 ($\leq$ 20 nm) electrically isolates the semiconductor structure from the metal cladding. This Si_3N_4 layer also passivates surface damage caused by the etching of the devices.

After the insulation is applied, the whole structure is encapsulated in silver. The silver cladding also serves as the electrical n-contact of the device; the p-contact is located next to the device to allow scattering of light through the substrate. So far, the devices were always circular or rectangular shaped.

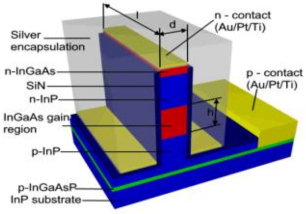

figure 1: Schematic device overview

Side-emitting metallic waveguide lasers

The first side-emitting lasers are simple Fabry-Perot type cavities. After cleaving, the end facet was polished in a cross-section polisher (figure 2); the width of the waveguide core is 240 nm. Figure 3 shows the lasing spectrum at a current of 0.8 mA. Lasing operation was achieved at a temperature of 80K.

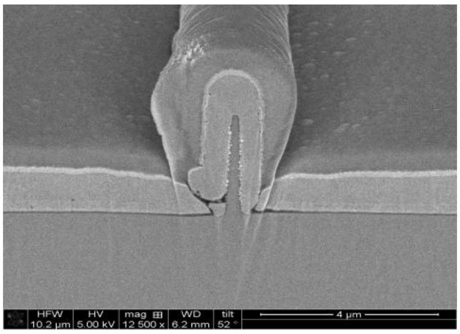

figure 2: Laser facet after Ar-beam polishing

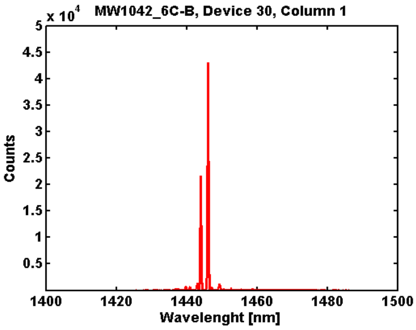

figure 3: Laser spectrum at 0.8 mA, 80K

Plasmon nano-lasers

To ensure that the propagating mode in the laser cavity is indeed the fundamental plasmon mode of the structure, the width of the waveguide has to be such that it is below cut-off of the 1st order plasmon mode and below the cut-off of the fundamental TE mode of the waveguide. For operation at 1550 nm, the waveguide widths that satisfy these conditions were determined from 2-D FDTD simulations [6] and were found to be ±140 nm, for a waveguide with a 20 nm thick Si_3N_4 insulation layer and ±150 nm for a waveguide with a 10 nm thick insulation.

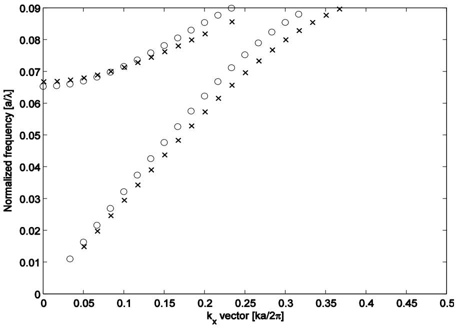

figure 4: Geometric dispersion for TM polarization. X & O indicate a 10 nm & 20 nm Si_3N_4 layer respectively, a =100 nm

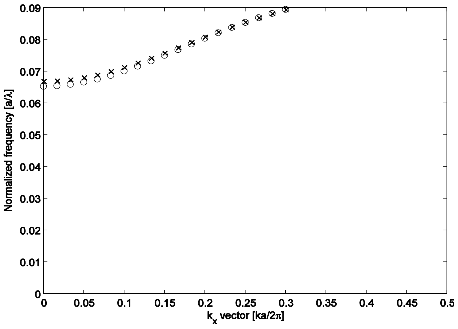

figure 5: Geometric dispersion for TE polarization. X & O indicate a 10 nm & 20 nm Si_3N_4 layer respectively, a = 100 nm

Distributed Feedback

Distributed Bragg reflectors (DBR) and distributed feedback (DFB) are widely employed in semiconductor lasers to achieve single-mode operation or to control the amount of feedback into the laser cavity.

We have determined the optimum period of a Bragg grating to be approximately 220 nm for operation at 1550 nm. Incorporating such a grating in a metallic-coated cavity, a Q of over 200 can easily be achieved.

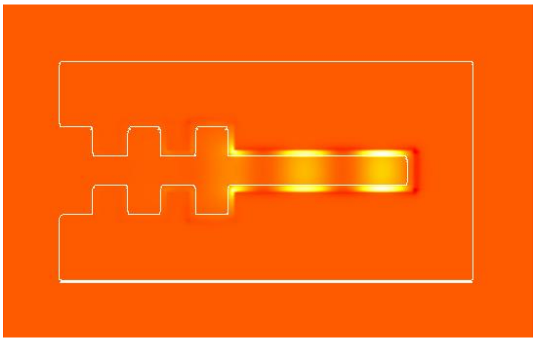

figure 6: Topview of a 3D-FDTD simulation of a 'cold'-cavity with a Bragg reflector. The period is 230 nm, the waveguide width is 100 nm and the thickness of the Si_3N_4 layer is 20 nm

Incorporation of Bragg reflectors in a nano-cavity, however, is difficult since the grating and cavity cannot be separated from each other in terms of gain. Also the cavity and grating have to be terminated very accurately, in order not to disturb the phase condition required for Bragg reflectors.

Distributed feedback lasers are less sensitive to reflections caused by termination of the laser, provided that $\kappa L > 1$ for the grating [7]. Normal DFB lasers support two modes (1st order operation), one on either side of the stop-band. Single mode operation, at the Bragg wavelength, can be forced by either applying a λ/4-shift inside the laser cavity (figure 7) or making the laser asymmetric (e.g. by covering one facet with silver and removing it from the other facet).

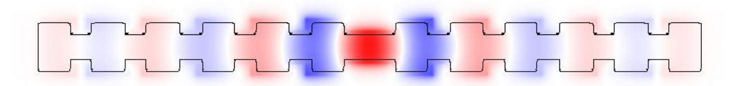

figure 7: Topview of the H_z-field in a 2D-FDTD simulation of a 'cold'-cavity incorporating λ/4-shift

We have determined the optimum period for operation at 1550 nm to be ±220 nm for a core waveguide width of 80 nm and the total width of the grating is chosen to be 130 nm (=80 nm core + 50 nm grating).

Fabrication

Definition of the devices by means of EBL in combination with lift-off is impossible for devices with these dimensions. The feature size is in the same order of magnitude as the thickness of the metal layer normally used to perform lift-off with.

Hydroxy Silsesquioxane (HSQ) is an electron beam resist with excellent lateral contrast, but with a rather low sensitivity [8, 9]. We use this resist to define devices with the desired dimensions. A top view of such a resist pattern, after litho and development is shown in figure aa. The thickness of the HSQ layer is 80-120 nm. As can be seen from figure aa, the small dimensions can be obtained without problems. The dose used to obtain these dimensions is around 3000 $\mu C/cm^2$.

The HSQ is used to etch an underlying metal layer, which in its turn is used to transfer the pattern to a SiO_2 hardmask layer, by means of a pure CHF_3 process in a dedicated reactive ion etcher (RIE). This hardmask can then be used to etch the semiconductor material in a CH_4/H_2 ICP-RIE.

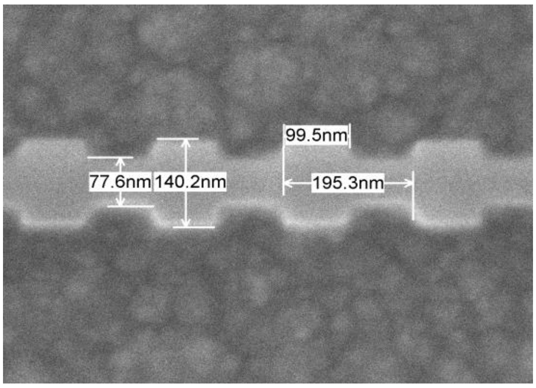

figure 7: Topview of HSQ resist pattern on SiO_2 after exposure and development

Conclusions and outlook

Side-emission of metallic-coated laser cavities is possible. Distributed feedback is suitable to achieve single mode operation of these cavities. We have determined the approximate maximum width of the structure to guarantee plasmonic behaviour. We have also determined the grating dimensions required for operation at the desired wavelength of 1550 nm, taking into account the restrictions for plasmonic behavior.

Simulations need to be refined incorporating gain, dispersion and fabrication imperfections. Finally, we have also shown that is possible to achieve the resolution required for the fabrication of these devices in our lithography process.

References

[1] B. Pradé, J.Y. Vinet, and A. Mysyrowicz, "Guided optical waves in planar heterostructures with negative dielectric constant" Phys. Rev. B., vol. 44, no. 24, 13556 - 13572, 1991.

[2] J.A. Dionne, L.A. Sweatlock and H.A. Atwater "Plasmon slot waveguides: towards chip-scale propagation with subwavelength-scale localization", Phys. Rev. B. , vol 73, 35407, 2006.

[3] Z. Han, and E. Forsberg, "Surface plasmon Bragg gratings formed in metal-insulator-metal waveguides", IEEE Photonics Technology Letters, vol. 19, no. 2, 91-93, 2007.

[4] M.T. Hill et al., "Lasing in metallic-coated nano-cavities" Nature Photonics, vol. 1, 589-594, 2007.

[5] M.T. Hill, M.J.H. Marell et al., "Lasing in metal-insulator-metal subwavelength plasmonic waveguides", Optics Express, vol. 17, no. 13, 11107 – 11112, 2009.

[6] A. Farjadpour, D. Roundy, A. Rodriguez, M. Ibanescu, P. Bermel, J.D. Joannopoulos, S.G. Johnson, and G. Burr, "Improving accuracy by subpixel smoothing in FDTD," Optics Letters 31 (20), 2972–2974, 2006.

[7] J. Buus, M.C. Amann, and D.J. Blumenthal, "Distributed Feedback Lasers," in Tunable laser diodes and related optical sources, 2nd edition, John Wiley & Sons, New Jersey, USA, pp. 59-68.

[8] D. Lauvernier, J.P. Vilcot, M. François, and D. Decoster, "Optimization of HSQ resist e-beam processing technique on GaAs material", Microelectronic Engineering, vol. 75, 177-182, 2004.

[9] M. Gnan, S. Thoms, D.S. Macintyre, R.M. De La Rue, and M. Sorel, "Fabrication of low-loss photonic wires in silicon-on-insulator using hydrogen silsesquioxane electron- beam resist", Electronics Letters, vol. 44, no. 2, 2008.