Distributed Bragg grating frequency control in metallic nano lasers

Citation for published version (APA):
Marell, M. J. H., & Hill, M. T. (2010). Distributed Bragg grating frequency control in metallic nano lasers. In *Proceedings ieee photonics society winter topicals meeting series 2010, 11-13 Jan. Majorca* (pp. TuD2.4-). IEEE Photonics Society. https://doi.org/10.1109/PHOTWTM.2010.5421948

DOI:
10.1109/PHOTWTM.2010.5421948

Document status and date:
Published: 01/01/2010

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

TuD2.4
11:30 - 11:45

Distributed Bragg grating frequency control in metallic nano lasers

M.J.H. Marell, M.T. Hill, M.K. Smit
Eindhoven University of Technology, Dept. of Electrical Engineering,
Den Dolech 2, 5600 MB, Eindhoven, The Netherlands
m.j.h.marell@tue.nl

Abstract **-We show that Bragg gratings can be readily incorporated into metallic nano-lasers which exploit waveguides with semiconductor cores, via modulation of the waveguide width. This provides a simple way to implement laser wavelength control.**

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 inside the cavity.

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, figures 1 and 2.

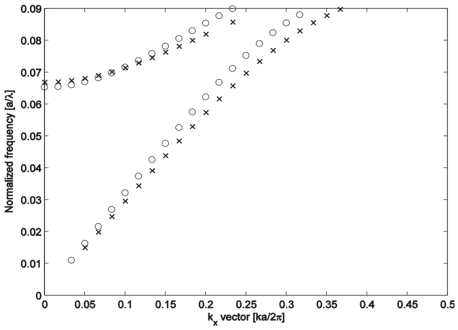

Fig. 1. Geometric dispersion for TM polarization. X & O indicate a 10 nm & 20 nm Si_3N_4 layer respectively, a =100 nm

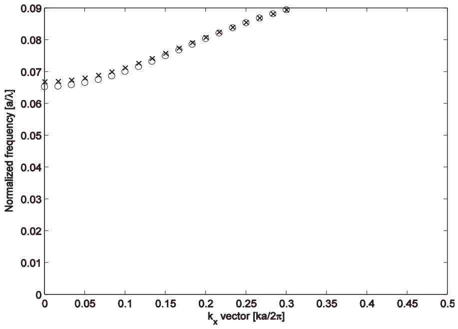

Fig. 2. Geometric dispersion for TE polarization. X & O indicate a 10 nm & 20 nm Si_3N_4 layer respectively, a = 100 nm

Distributed feedback (DFB) lasers are easier to fabricate than laser in which distributed Bragg reflectors (DBR) are incorporated. They 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 or making the laser asymmetric (e.g. by covering one facet with silver and removing it from the other facet), figure 3.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).

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. Instead we use a bilayer resist, consisting of HSQ/HPR504, to obtain the required dimensions.

First a 450 nm thick layer of HPR504 photoresist is spun on top of a SiO_2 hardmask layer. The HPR504 is then baked at a very high temperature, in order to harden it. A 80 nm thick HSQ is then spun on top of the hardbaked HPR504.

Hydroxy Silsesquioxane (HSQ) is an electron beam resist with excellent lateral contrast, but with 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 4. The dose used to obtain these dimensions is around 3000 $\mu C/cm^2$.

The HSQ is used to etch the underlying HPR504, 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 5.

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.

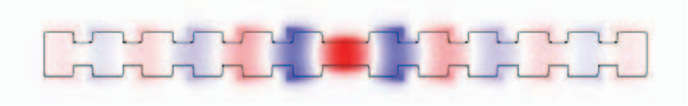

Fig. 3. Topview of the H_z-field in a 2D-FDTD simulation of a ‘cold’-cavity incorporating λ/4-shift

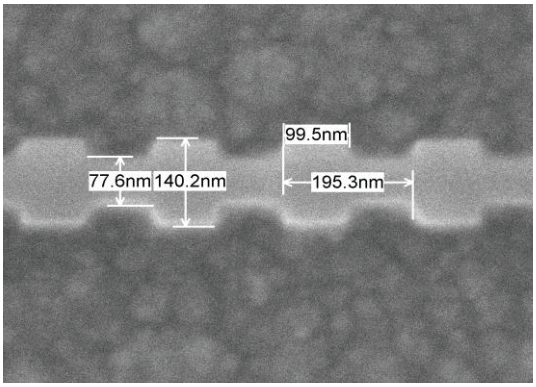

Fig. 4. Topview of HSQ resist pattern on SiO_2 after exposure and development

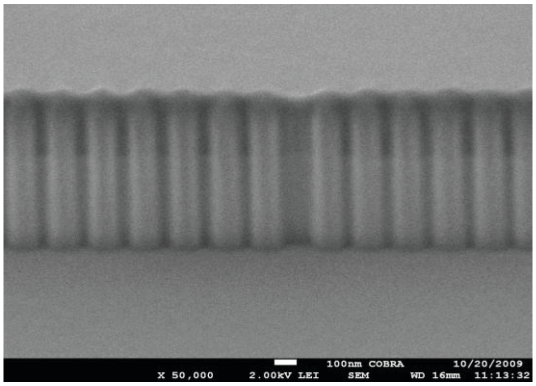

Fig. 5. Sideview of a grating in InP, the SiO_2 hardmask is still on top