Metallic subwavelength grating on GaN-based edge emitting lasers

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***Abstract*—Metallic subwavelength gratings as limit-element linear array can provide the great improving output performance of optical light emitter. We investigated that the device with metallic subwavelength grating can be used to modulate the beam of edge-emitting laser with a patterned facet. Utilizing GaN-based semiconductor laser as a model system, the defined metallic subwavelength slits and gratings is a type of superior reduction method of beam divergence and coupling into other optical components effectively. We believe this study will be helpful for development of the novel light emitting devices in the blue or UV region.**

I. Introduction

The beam divergence generated by the semiconductor laser is diffraction limited to the plane normal to the active core. In the previous design, beam spot from edge emitting laser were focused with various optical lens and mirrors for alignment. However in order to suppress the vertical beam divergence, such designed device would require firmly high voltage operation associated with lack of heat dissipation. Therefore patterned metallic subwavelength gratings referred to resonant optical dipole [1, 2] has been utilized to alter to the near-field optical pattern of light emitter via making it probable to produce much smaller spots [3, 4]. So far the proposed idea has been illustrated in several material system and applied on different application of optoelectronic devices [5, 6]. Besides as for the development in the short-wavelength region, it still has been fewer design to apply to GaN-based system. Here we perform the appropriate structure with subwavelength slits and gratings could be efficiently taken advantage of superior far-field pattern design and reduced sufficiently of free-space beam divergence.

II. Design and Consideration

In this work, a beam divergence is diffraction-limit from the leaving radiative optical wave via catching vertical components of surface modes of covered metallic grating to pass a slit. The distance to the slit and the period of patterned grating are both quite essential. The former is controlled to couple the active area output into surface waves, and the latter one is functionality of point sources spread the energy into the far-field space. Hence the ultimate result can be characterized as Fraunhofer plane as a result of an interference effect. Moreover, the grating period has been investigated, and the beam is collimated in y-direction due to one-dimension design.

For the purpose of giving a narrow beam divergence, several main features, including the thickness and the width of the slit, the period size and grating number, and the distance of the slit from the active core are to be optimized in the calculation.

III. Results and Discussion

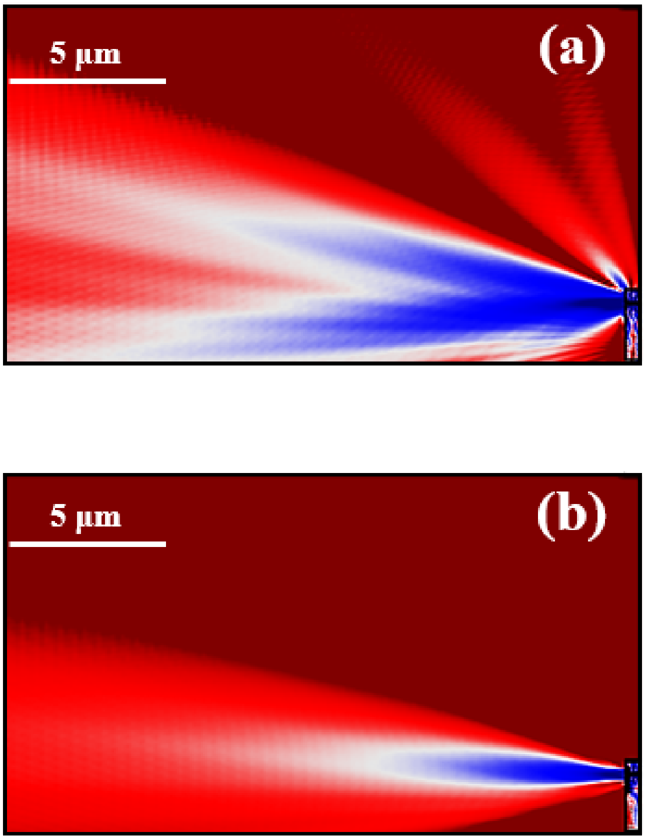

Fig. 1. (a) 2D calculation of the intensity distribution of an original unpatterned GaN-based design. (b) 2D calculation of the intensity distribution of a small-divergence GaN-based design.

We showed two-dimension computer-aided simulations were calculated by finite-difference time-domain method to realize designed structure associated with beam collimation. Firstly the slit is sculptured forthright on bare laser emitter facet, and then the follow-up metal coating are deposited. The metallic layer on the laser facet would be one of the principal

978-1-4799-8379-7/151$31.00 ©2015 IEEE

issue to realize it. The film thickness may limited by the skin depth, thus the relation between the thickness and the optical losses should be examined.

Figure 1(a) indicates that a calculation of the intensity distribution with an unpatterned GaN-based device, illustrating the large beam divergence of the original structure. Figure 1(b) indicates that a calculation of the intensity distribution with a patterned covered metallic gratings which has totally 7 channels of GaN-based device. Based on the simulation results, the results indicate a central main beam and many weaker side beams appearing on the laser facet. Compared with the smooth planar metallic surface, the radiative wave from patterned facet of the device is contributed to the beam interference, exhibiting a strong coupling effect due to existed resonant optical dipole antennas.

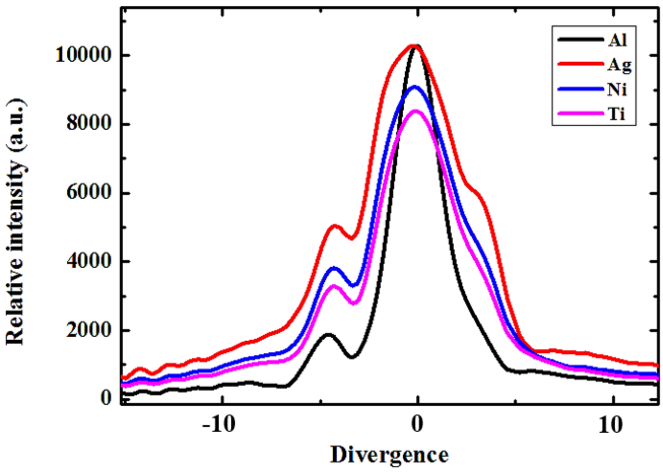

Fig. 2. Four types of covered metal materials corresponding to the simulated far-field intensity distribution of the GaN-based device with patterned metallic coating.

Figure 2 shows the simulated far-field vertical cross-section pattern for the patterned device through distinct metallic materials. The principal beam has a vertical divergence angle almost equal to 3 degree, and the average intensity of other background angles is less than ten percent of main peak intensity. The difference between the simulation results could be the factor of absorption loss effect of metallic subwavelength grating, leading to the relative intensity changed simultaneously. Therefore, the modified beam reduction was much smaller than the unpatterned case. The mentioned calculated results were supposed to develop the novel light emitters for realization of nitride photonic application.

IV. Conclusion

In summary, the GaN-based device with patterned metallic coating has been designed and characterized. The optimized parameters have been obtained by two dimensional finite element method to achieve an increased intensity in a narrow vertical angle through the structure of covered metallic subwavelength grating investigated by COMSOL Multiphysics. Furthermore, the simulated results showed a small beam spread of about 3.1 degree with patterned metal coating. We believe our realization provide a potential for application on the GaN-based photonic devices and helpful contribution to the short wavelength region in the future.

Acknowledgment

This work was supported by the Ministry of Education Aim for the Top University program and by the Ministry of Science and Technology of Taiwan under Contract No. NSC 102-2221-E-009-156-MY3.

References

[1] Mühlschlegel P., Eisler H. -J., Martin O. J. F., Hecht B., and Pohl D. W., "Resonant optical antennas," Science, vol. 308, pp. 1607-1609, June 2005.

[2] Constantine A. Balanis, Antenna Theory: Analysis and Design, 3rd ed., Wiley, 1982, pp.283-289.

[3] Cubukcu E., Kort E. A., Crozier K. B. and Capasso F., "Plasmonic laser antenna," Appl. Phys. Lett., vol. 89, pp. 093120-1 – 093120-3, August 2006.

[4] Nanfang Yu, Jonathan Fan, Qi Jie Wang, Christian Pflügl, Laurent Diehl, Tadataka Edamura, Masamichi Yamanishi, Hirofumi Kan, and Federico Capasso, "Small-divergence semiconductor lasers by plasmonic collimation," Nature Photonics, vol. 2, pp. 564 – 570, July 2008.

[5] L. Liu, Y. Liu, H. W. Qu, Y. F. Wang, H. L. Wang, Z. G. Feng, Y. J. Zhang, and W. H. Zheng, "Angled cavity photonic crystal laser diodes with tilted sidewalls for improving far-field patterns," Opt. Lett., vol. 39, pp. 2391-2394, April 2014.

[6] M. J. Miah, T. Kettler, K. Posilovic, V. P. Kalosha, D. Skoczowsky, R. Rosales, D. Bimberg, J. Pohl, and M. Weyers, "1.9 W continuous-wave single transverse mode emission from 1060nm edge-emitting lasers with vertically extended lasing area," Appl. Phys. Lett., vol. 105, pp. 151105-1 – 151105-4, October 2014.