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Numerical simulation of GaAs/AlO$_x$ high index contrast sub-wavelength gratings for GaAs-based vertical cavity surface emitting lasers

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Vertical cavity surface emitting lasers (VCSELs) are widely used in many applications because of their superior performances, such as low threshold current, small divergence angle, circular beam profile, two-dimensional array configuration and low power consumption [1–5]. However, VCSEL has some defects, such as multimode operation and unstable polarization, which seriously affect its actual performance. Therefore, some methods were introduced in order to improve its mode and polarization properties. Polarization in VCSELs can be controlled given polarization-dependent gain/loss regions in VCSELs, such as surface relief [6], external-cavity feedback [7], and sub-wavelength grating [8]. Also, high index contrast sub-wavelength grating (HCG) attracts researchers' attention for its ability to control both mode and polarization.

The predominant characteristic of a HCG is that the fringes of high index grating are completely surrounded by low index medium (generally air or silicon dioxide), which forms a large index difference. By adjusting the grating material, thickness, duty cycle and other parameters, its reflectivity can reach more than 99 %. It can be used to replace the P-type distributed Bragg reflectors (DBRs) of a VCSEL, which can greatly reduce the series resistance and absorption loss of the device. The HCG mirror can not only decrease the thickness of VCSEL, but also fix polarization. The typical HCG for VCSEL based on GaAs is mostly composed of GaAs/air or Si/SiO$_2$ [9, 10]. The suspended GaAs/air HCG has some disadvantages, such as complicated fabrication process and poor mechanical stability, while for the HCG with Si/SiO$_2$ it is difficult to achieve a precise control of its thickness. A GaAs/AlO$_x$ HCG for a mid-infrared VCSEL based on GaSb has been proposed in [11, 12]. However, a metamorphic growth deteriorates the HCG performance, and the device laser operation couldn't be observed because of a lack of reflectivity of HCG [12].

In this paper, we propose and analyze numerically the GaAs/AlO$_x$ HCG with the same material system as the half-VCSEL. It can be integrated with VCSEL through one-time epitaxial technology, which is of great significance to obtain high quality wafers. Figure 1 shows the schematic diagram of a HCG, including grating layer, stress buffer layer and low index sub-layer. HCG is composed of GaAs and AlO$_x$. The AlO$_x$ as the low index sub-layer ($n \approx 1.6$) may be obtained from AlAs by oxidation. The large index difference between the AlO$_x$ and GaAs grating layer ($n \approx 3.538$) will be beneficial to increase the width of the reflection band. Due to a large index contrast and near-wavelength dimensions, there exists a wide wavelength range where only two modes have real propagation constants in the z-direction. The two modes carry similar energy but opposite phases at the HCG output plane, thus causing destructive interference. Finally, the transmission is canceled and all of the energy must be reflected [13]. To improve the stability of HCG, the GaAs layer is not completely etched to form the grating layer and the stress buffer layer.

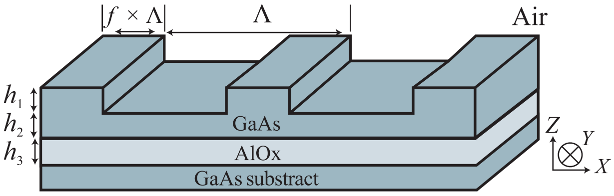

Fig. 1. (Color online) Schematic diagram of HCG: period Λ, fill factor f, grating layer h_1, stress buffer layer h_2, low index sub-layer h_3

Based on the RCWA method, a GaAs/AlO$_x$ TE-HCG mirror for GaAs-based VCSEL is simulated and investigated numerically. The results show that the fill factor and grating thickness are the most critical parameters, because they determine the reflectivity and bandwidth. Furthermore, the stress buffer layer also af-

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fects the reflection properties of HCG, whose high reflection band changes periodically with the buffer thickness. However, there is only a little deterioration in the shape of high reflection band even if the fill factor difference between the upper and lower of the grating is up to 5 %. Therefore, the GaAs/AlO$_x$ HCG not only makes it easier to integrate with VCSEL, but also can effectively avoid the deterioration of its reflection performance. Moreover, it can be prepared with less difficulty due to its large period, shallow etching depth and large morphology tolerance. Meanwhile, its sensitivity to the incident angles is good for VCSEL to operate with single-mode. The HCG has a large reflection bandwidth up to 97 nm at around 940 nm ($\Delta\lambda/\lambda_0 = 10\,\%$) with its TE reflectivity more than 99.5 % and TM reflectivity lower than 90 %. VCSEL integrated with HCG will undoubtedly have the characteristics of smaller size, single mode, and polarization stability. It can match perfectly the tunable diode laser absorption spectroscopy for gas detection.

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1. Z. Zhen-Bo, X. Chen, X. Yi-Yang, Z. Kang, L. Fa, and S. Guang-Di, Chin. Phys. B **21**, 3 (2012).
2. P. S. Yeh, C. C. Chang, Y. T. Chen, D. W. Lin, J. S. Liou, C. C. Wu, J. H. He, and H. C. Kuo, Appl. Phys. Lett. **109**, 24 (2016).
3. Md. Jarez, K. V. Kalosha, P. Dieter, J. Pohl, and M. Weyers, Opt. Express. **24**, 26 (2016).
4. W. Zhen-fu, N. Yong-qiang, Z. Yan, S. Jingjing, Z. Xing, Z. Lisen, W. Wei, L. Di, H. Yongsheng, C. Haibing, L. Qin, L. Yun, and W. Lijun, Opt. Express. **18**, 23 (2010).
5. W. Xiao-fa, W. Zheng-mao, and X. Guang-qiong, Acta Physica Sinica. **65**, 2 (2016).
6. L. Shuo, G. Bao-lu, S. Guo-zhu, and G. Xia, Acta Phys. Sin. **61**, 18 (2012).
7. Z. Tong, J. Zhiwei, W. Anbang, H. Yanhua, W. Longsheng, G. Yuanyuan, and W. Yuncai, IEEE Photonics Technol. Lett. **33**, 7 (2021).
8. Z. Xiang-wei, N. Yong-qiang, Q. Li, L. Yun, and W. Lijun, Chinese Journal of Luminescence **34**, 11 (2013).
9. M. C. Y. Huang, Y. Zhou, and C. J. Chang-Hasnain, Nature Photon. **1**, 119 (2007).
10. C. Chevallier, N. Fressengeas, F. Genty, and J. Jacquet, J. Opt. **13**, 125502 (2011).
11. W. Huang-ming, M. Wen-qin, H. Jin, G. Ding-shan, H. Ran, J. Hong, G. Rui-min, W. Wen-hua, and Z. Zhiping, J. Opt. **12**, 045703 (2010).
12. Y. Laaroussi, C. Chevallier, F. Genty, L. Cerutti, T. Taliercio, O. Gauthier-Lafaye, P. F. Calmon, B. Reig, and J. Jacquet, Opt. Mater. Express **3**, 10 (2013).
13. R. Yi, Y. Weijian, C. Chase, M. C. Y. Huang, D. P. Worland, S. Khaleghi, M. R. Chitgarha, M. Ziyadi, A. E. Willner, and C. J. Chang-Hasnain, IEEE J. Sel. Top. Quantum Electron. **19**, 4 (2013).