Numerical Analysis on V-shape Gratings for III-V/Silicon Hybrid Lasers

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Abstract

We propose and numerically analyze a novel sub-wavelength grating for the purpose of III-V/silicon integration. The design is based on different shapes of gratings in order to increase the lateral (or sideway) coupling. By using COMSOL® as the platform, the reverse V-grating design can have doubled percentage of optical field into the silicon grating region when compared to reference. However, the threshold gain of this design is still high and further optimization is needed.

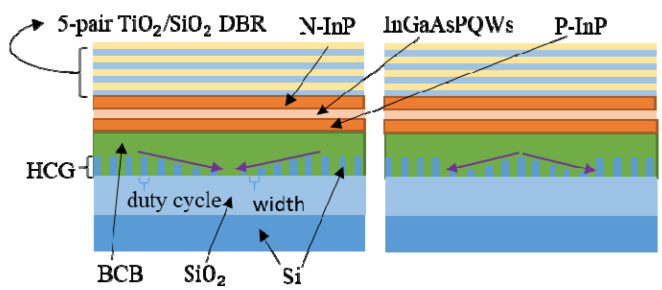
I. INTRODUCTION

Over the past few years, the heterogeneous integration of III–V material on silicon-on-insulator (SOI) wafers has appeared as a promising solution for the integration of active optical devices on complementary metal oxide semiconductor (CMOS) substrates[1]. One of the important designs is to use benzocyclobutene to attach the III–V epitaxial layers onto silicon substrate[2]. By using sub-wavelength grating, people have demonstrated vertical cavity surface emitting lasers in the past[3]. However, to make the emitted photons useful, we need not only normal direction but also side way emission into the silicon waveguide. In this work, we try to design a laser with such function by alternating grating thickness. In the following detailed numerical analysis will be demonstrated.

II. Device structure

Three designs are considered: first is the reference sample with rectangular gratings similar to other device[4]. The second one is named "V-grating" VCSEL, and the third is called "reverse V-grating" device. All three devices have a 10-pair TiO_2/SiO_2 DBR, an InP/InGaAsP active layer, a benzocyclobutene (BCB) layer. The BCB layer acts as an adhesion layer between the active layer and the HCG, and its thickness is 300nm. Our SiO_2 thickness is 3000nm, and the thickness of HCG is 250nm. . The active layer contains nine 6-nm-thick InGaAsP quantum wells (QWs) separated by 9-nm-thick InGaAsP barriers and spacers. The thickness of P-InP layer is 80nm, and N-InP layer is 306nm.

As can be seen in Fig. 1. (a) and (b), the grating designs of V-grating and reverse V-grating are quite different. In the V-grating, the silicon slab is tall at the center of the grating structure and linearly reduce silicon slab height to the side. In the reverse V-grating design, the variation is reversed: lowest at the center and tallest at the edge of the grating structure. What we try to achieve here is to obtain the best side-way coupling while maintain the laser action.



(a) (b)

Fig. 1. (a) Schematic view of V-grating VCSEL (b) Schematic view of reverse V-grating VCSEL

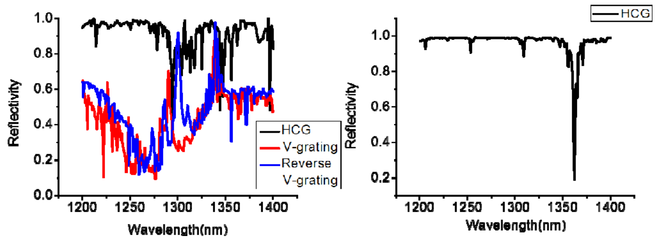
III. SIMULATION METHOD

We use COMSOL® Multiphysics software to calculate our simulation. Electromagnetic Waves, Frequency Domain(emw) module is used to compute transmission and reflection coefficients for the refraction, specular reflection, and diffraction. We calculate DBR and three kind of grating reflectivity spectrum respectively shown in Fig. 2(a).

In Fig. 2(b), the whole structures are calculated to find their resonant wavelength and integral their optical field to find optical confinement factor. Finally, we use Eq. 1 to obtain the threshold gain and determine whether the threshold gain is reasonable.[5]

$$\Gamma g_{th} = \langle \alpha_i \rangle + \frac{1}{L_{total}} \ln\left[\frac{1}{r_d r_g}\right] \quad (1)$$

where Γ is the optical confinement factor and $\langle \alpha_i \rangle$ is the internal loss. L_{totel} is cavity length, r_d is the reflectivity of DBR and r_g is the reflectivity of HCG.



(a) (b)

Fig. 2. (a) The reflectivity curves of the HCG, V-grating and Reverse V-grating(b) Reflectivity spectra of HCG-VCSEL

IV. RESULTS AND DISCUSSION

The first thing to be evaluated is the cavity resonance and the corresponding reflectivity of the gratings. Then Eq. 1 can be used to obtain the threshold gain necessary for the lasers. Table 1 lists all three cases, and unfortunately, both reverse and non-reverse V-grating designs show much greater g_{th} than that of HCG design. A careful selection of active material will be crucial to have these design working. After properly constructing the numerical model, Fig. 3. (a) and Fig. 3. (b) show the cross-sectional view of the calculated optical field intensity at cavity resonance. From the field pattern, we can further estimate how many photons, which are generated in III–V Quantum well, can be guided into grating/Silicon region. In TABLE 1, we summarize the percentage of lateral coupling for each design, and the reverse-V-grating is a clear winner.

TABLE 1 The lateral coupling and threshold gain

	HCG	reverse V-grating	V-grating
Sideway coupling	5.4%	10.35%	5.5%
g_{th} (cm^{-1})	2820	23701	15445

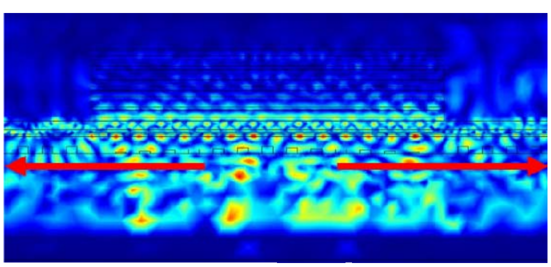


Fig. 3. (a) The optical field of the reverse V-grating VCSEL

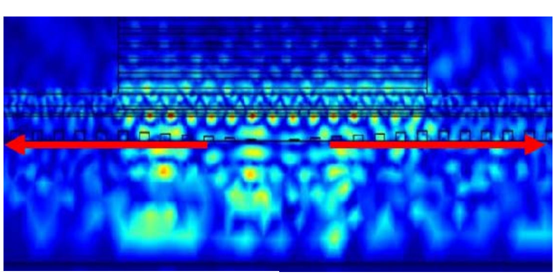


Fig. 3. (b) The optical field of the V-grating VCSEL

V. CONCLUSION

In conclusion, we demonstrated two different grating designs for the possible integration of III-V chips on silicon substrate. The lateral coupling of the reverse V-grating shows promising result with almost doubled output when compared to the reference and the other case. Although the threshold gain is high due to less reflectance in the grating, some adjustment can be done to improve this drawback. We believe this demonstration can be useful for the future design of such hybrid devices.

ACKNOWLEDGMENT

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REFERENCES

[1] Tiphaine Dupont, Laurent Grenouillet, Alexei Chelnokov, and Pierre Viktorovitch, "Contradirectional Coupling Between III–V Stacks and Silicon-On-Insulator Corrugated Waveguides for Laser Emission by Distributed Feedback Effect, "IEEE Photonics Technology Letters, VOL. 22, NO. 19, pp. 1413 - 1415, 2010.

[2] G. Roelkens, D. Van Thourhout and R. Baets " Ultra-thin benzocyclobutene bonding of III–V dies onto SOI substrate, " Electronics Letters, VOL 41, Issue 9, pp. 561 – 562(2005)

[3] Michael C.Y. Huang, Y. Zhou and Connie J. Chang-Hasnain, "A surface-emitting laser incorporating a high-index-contrast subwavelength grating, "Nature Photonics, vol. 1, pp. 119 - 122, 2007.

[4] Yoshihiro Tsunemi, Nobuhide Yokota, Shota Majima, Kazuhiro Ikeda, Takeo Katayama, and Hitoshi Kawaguchi, "1.55-μm VCSEL with polarization-independent HCG mirror on SOI, " Optics Express, vol. 21, Issue 23, pp. 28685-28692, 2013.

[5] Yi Rao, Student Member, Weijian Yang, Student Member, Christopher Chase, Michael C. Y. Huang,D. Philip Worland, Salman Khaleghi, Mohammad Reza Chitgarha, Morteza Ziyadi, Alan E. Willner, Fellow, and Connie J. Chang-Hasnain, "Long-Wavelength VCSEL Using High-Contrast Grating " IEEE Journal of Quantum Electronics , vol. 19, No. 4, 1701311, 2013.