Design of an intra-cavity SiN grating for integrated 850nm VCSELs

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A weakly etched grating placed inside a vertical cavity surface emitting laser (VCSEL) cavity between the top and bottom DBR can couple out light into a waveguide connected to it. In this paper, the design of such an intra-cavity Silicon Nitride (SiN) grating for hybrid 850nm VCSELs integrated on a SiN waveguide platform will be presented. This design enables the integration of polarization stable, single mode and energy efficient VCSELs on a SiN photonic integrated circuits (PIC).

1. Introduction

Silicon nitride (SiN) exhibits transparency from the visible to the near-infrared with fairly high refractive index (~2.0), making it suitable for various photonic applications such as short-wavelength optical interconnect and life sciences [1]. Due to the dielectric properties of SiN, this platform is limited to passive devices. So, there is a need for active devices such as laser sources and photodetectors in this platform. A heterogeneously integrated III-V semiconductor light source on a SiN-based photonic integrated circuit (PIC) can be one possible solution. Availability of light sources which operate efficiently with low threshold current is an important criterion for such a platform. In this case, GaAs-based VCSEL can be the ideal candidate for laser emission in the visible-near IR range (covering 0.65–1.3 µm). But one of the major challenges is to couple the out-of-plane emission from the VCSEL efficiently into a SiN waveguide.

In our previous work we demonstrated a hybrid-cavity VCSEL (HC-VCSEL), where a GaAs based 'half-VCSEL' was bonded to a dielectric distributed Bragg reflector (DBR) consisting of 20 pairs of Ta_2O_5/SiO_2 on a Si substrate [2,3]. This integrated VCSEL had an out-of-plane light output which is not suitable for planar light wave circuits. In this paper, we discuss the design of a weakly etched grating which allows coupling the light from such a hybrid cavity VCSEL in a SiN waveguide connected to it.

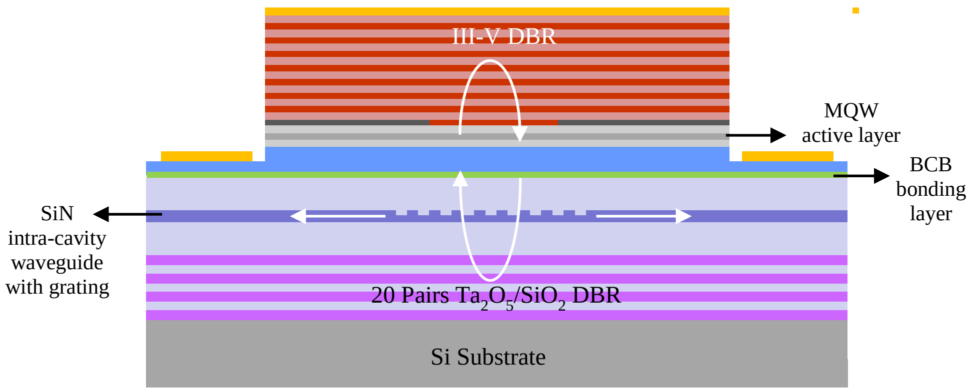

Fig. 1: Schematic cross-section of hybrid vertical cavity laser with in-plane outcoupling.

Fig. 1, shows the schematic cross-section of the HC-VCSEL. The structure is divided in two parts. The top half of the device consists of a GaAs half-VCSEL (a III-V distributed Bragg reflector (DBR), a III-V active layer, and a current spreading layer). The bottom half of the device consists of a grating/dielectric DBR combination (weak diffraction grating etched in a SiN waveguide on top of 20 pairs of Ta2O5/SiO2 DBR, and a SiN waveguide connected to the grating). As shown in Fig. 1, light resonates vertically between the III-V DBR and the grating /dielectric DBR combination, and is coupled out of the VCSEL cavity through the SiN waveguide.

2. Intra-cavity grating design

A weakly etched grating on SiN waveguide is designed to be placed inside the VCSEL cavity as demonstrated in [2, 3]. For this purpose, the bottom half of the VCSEL cavity was designed. Fig. 2 shows the schematic of the simulation setup. The intracavity design was optimized by using commercial FDTD software [4]. Size of the Gaussian beam ($1/e^2$ power radius) incident on the intracavity grating is dependent on oxide aperture of the GaAs VCSEL. Hence, a Gaussian beam with $1/e^2$ power radius (w) of 2.7 µm was incident on the structure translating to a GaAs VCSEL with 6 um aperture. As the grating is placed inside the VCSEL cavity, only a small fraction of light should couple to the waveguide, otherwise it will compromise the laser action. The objective of this simulation was to design a weak grating coupler operating at 850 nm which couples only a small fraction of light with TE polarization into the in-plane waveguide mode efficiently while maintaining stronger TM coupling. This result in higher reflectivity for the grating / DBR combination for the TE mode compared to the TM mode, hence setting the polarization of the device to the transverse electric polarization.

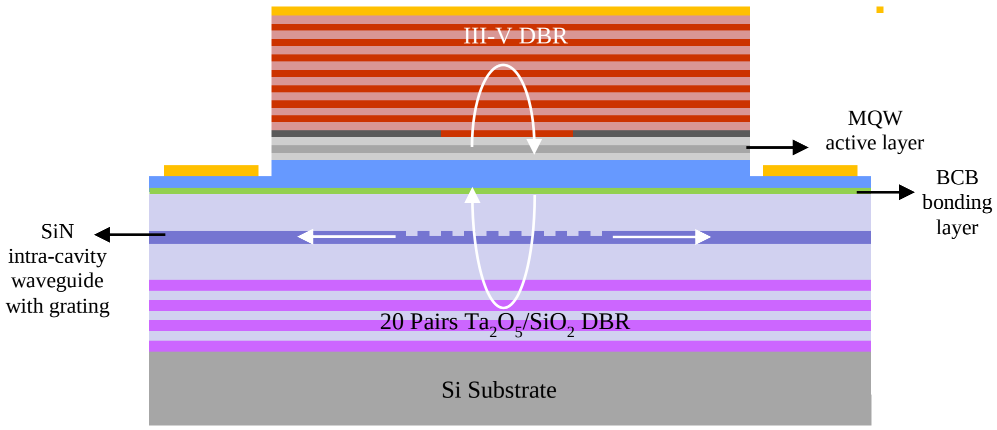

Fig. 2 Schematic cross-section of the simulation setup for the intra-cavity grating.

All the grating parameters (grating period, etch depth, thickness of oxide between grating and DBR ($TSiO_2$)) were first optimized by using an optimization algorithm. The figure of merit was defined in such a way that it maximizes the coupling efficiency for a given condition of Reflection (TE)>0.995 and (Reflection (TE) - Reflection(TM))>0 at 850nm. The SiN waveguide layer thickness was kept fixed at 300 nm and a 50% duty cycle of the grating was chosen for ease of fabrication. The optimal parameters provided by this algorithm for the intracavity grating are: a grating etch depth of 30 nm, a grating period of 530 nm, and a SiO_2 thickness between the SiN waveguide and dielectric DBR of 950nm.

Simulations for the final structure are shown in Fig. 3. Fig. 3(a) shows the reflection spectra for a TE and TM polarized Gaussian beam with a $1/e^2$ beam diameter of 5.4μm. The fraction of incident light coupled to the SiN waveguide (single-sided) for the two polarizations is plotted in Fig.3 (b).

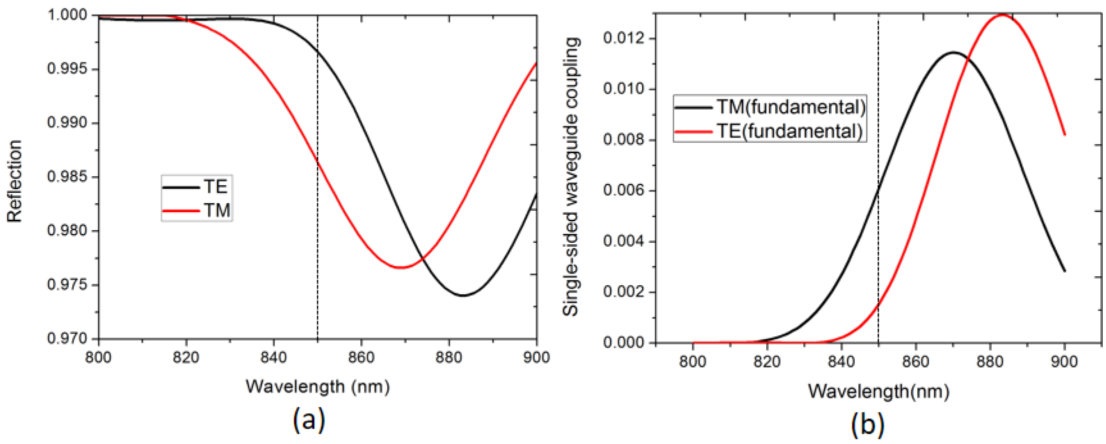

Fig. 3 (a) Reflection as function of wavelength for TE and TM polarization for a Gaussian beam with a 1/e2 power radius of 2.7μm (b) Single-sided waveguide coupling as a function of wavelength for TE and TM polarization.

The intracavity grating is designed to operate at 850 nm. The vertical dotted black line in Fig 3(a) and 3(b) indicates the reflection and coupling to single sided waveguide at 850nm respectively. As can be seen from Fig. 3(b) fraction of incident light coupled to the single side of waveguide is stronger for TM (0.006%) waveguide mode than TE (0.0015%) mode at 850nm. This results in lower reflection for the TM (98.6%) mode than for the TE mode (99.7%), which sets the polarization of the VCSEL to TE mode at wavelength 850nm. From the results reported in our previous work, [2,3] 1 mW output power coupled into the SiN waveguide at sub mA threshold current is expected. The output power of our previous devices was limited by the thermal impedance of the dielectric (Ta2O5/SiO2) DBR which can be improved further by using an a-Si/SiO2 DBR.

5. Conclusion

We presented the design of an intracavity grating which can efficiently couple output of a VCSEL to an in-plane waveguide. The unique quality of this design is its ability to suppress TM mode and selective VSCEL operation in TE mode. This design enables potential applications in short reach data com and optical spectroscopy in visible-near IR wavelength range.

Acknowledgments

This work was financially supported by FP7-ERC-InSpectra Advanced Grant, European Union's Horizon 2020 research and innovation program under grant agreement No. 688519 (PIX4life) and Swedish Foundation for Strategic Research (SSF).

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