Silicon Nitride based high contrast grating for heterogeneously integrated tunable VCSELs.

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We propose a novel design for a dielectric subwavelength grating for the integration of a GaAs Vertical Cavity Surface Emitting Laser (VCSEL) operating in the near-infrared (λ=700-1000nm). The design uses a Si3N4/Air high-contrast grating (HCG), that can be fabricated using standard CMOS technology to replace the conventional DBR as bottom mirror. The optimized mirror reflects strongly (>99%) over a fractional optical bandwidth Δλ/λ of about 9% with a strong polarization selectivity and reasonable tolerance on the grating dimensions. A continuous wavelength tuning can be achieved by implementing these single-layer free standing HCGs as the VCSEL bottom mirror when it is electrostatically actuated.

Introduction

Silicon nitride (SiN) is a promising platform for integrated photonics applications in the visible and near IR spectrum due to its transparency in the near-infrared and visible spectrum and full compatibility with the standard complementary metal-oxide semiconductor (CMOS) technology, which can significantly lower costs of the devices in high volume manufacturing [1]. The realization of CMOS compatible light sources is considered to be the biggest challenge of silicon photonics. Hybrid integration approaches, which can keep the advantages of III-V devices grown in a homoepitaxial process before the film is transferred on silicon, is considered to be an attractive route in the development of silicon lasers because of its potential for high efficiency [2]. Such sources integrated on the silicon platform have important applications in datalinks and in spectroscopy. GaAs-based VCSELs are close to being the “perfect” laser: they are very compact, have very low power consumption, single mode behaviour, are very cheap and are realized with very mature production technology. These lasers are the perfect choice for laser emission in the visible-Near IR (covering 0.65–1.3 μm) range [3]. Recently a high-reflectivity broadband mirror using a high-index-contrast subwavelength grating (HCG) has been proposed to replace the traditional DBR structure in VCSELs [4,5]. These HCG mirrors can provide several advantages over DBRs such as a reflectivity equivalent to many pairs of DBR resulting in substantial thickness reduction of the device, high polarization sensitivity, large fabrication tolerance and the suppression of higher order transverse modes [4,5]. Here, we propose a CMOS-compatible SiN HCG mirror which can be integrated with a half GaAs VCSEL using adhesive wafer bonding technology.

HCG design

The HCG design has been optimized by the Rigorous Coupled-Wave Analysis (RCWA) software RODIS for the Air/SiN grating as shown in figure 1 (a). Parameters for optimization of this structure are the period of the grating (ʌ), the duty cycle (DC) and the thickness of the nitride layer. We optimize these parameters of the grating to get a broadband high reflection with high fabrication tolerance. Our optimized grating structure consists of 300nm thick Silicon nitride on Silicon substrate using Silicon dioxide as sacrificial layer in order to achieve a free standing HCG. With a grating period of 800nm and a duty cycle of 40% the HCG shows a reflection bandwidth of 75 nm with reflection coefficient >0.99 centered at 850nm, hence giving a fractional optical bandwidth Δλ/λ of about 9%. The high reflection band arising in our grating design is supported by the presence of two leaky modes shown as two transmission dips inside the high reflection band in figure 1(b). These transmission dips correspond to a guided mode resonance at which transmittance approaches zero [6].

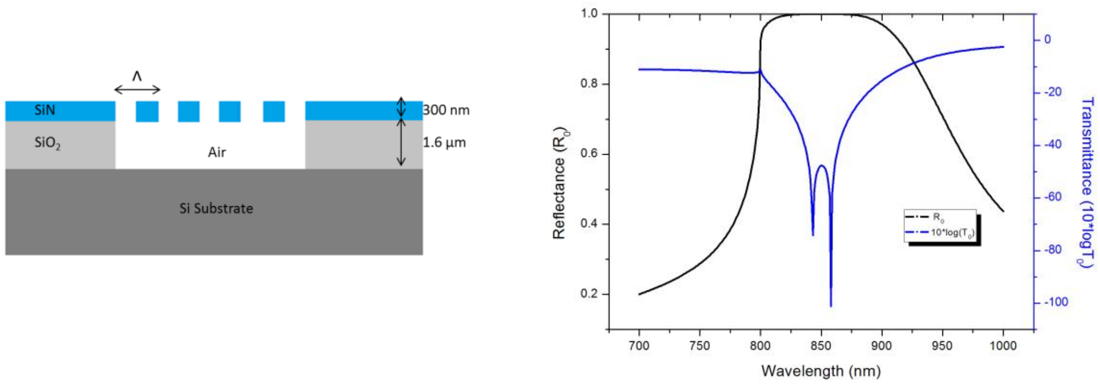

Figure 1: (a) Schematic drawing of the SiN HCG structure, (b) Reflectivity (black curve) and transmission on a logarithmic (blue curve) scale as a function of wavelength for the following grating parameters: Period 800nm, DC=40%, SiN thickness 300nm

The fabrication tolerance for this grating parameter also has been calculated using the RCWA method by varying two parameters at a time while fixing other parameters.

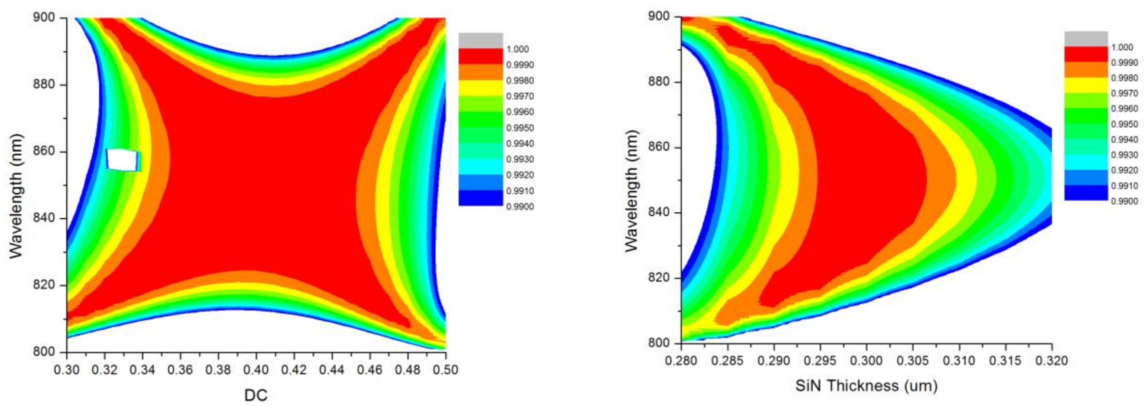

Fig 1(a) Reflectivity as function of DC and wavelength when the Silicon Nitride thickness and period of grating is 300 nm and 800 nm respectively.(b)Reflectivity as function of Silicon Nitride thickness and wavelength when the DC and period of grating is 40% nm and 800 nm respectively.

The contour plot in Figure 2(a) shows the reflectivity of the HCG as a function of the wavelength and duty cycle for a fixed grating thickness of 300nm. It shows that this grating has ±9% fabrication tolerance while keeping > 99% reflectivity. Other parameters like the thickness of the SiN layer also gives a tolerance of ±15nm for >99% reflectivity as shown in the contour plot in figure 2(b).

Integrated VCSEL design and fabrication

We can also take advantage of the SiN HCG as a highly reflecting broadband movable mirror. This mirror can be easily deflected by electrostatic actuation. By applying a voltage, between the grating and the VCSEL, the mirror will be displaced leading to a change in the cavity length resulting in a change in the emission wavelength. Hence continuous tuning can be achieved by electromechanical movement of these mirrors. Fig 3 shows the schematic of a GaAs VCSEL integrated with a SiN HCG mirror.

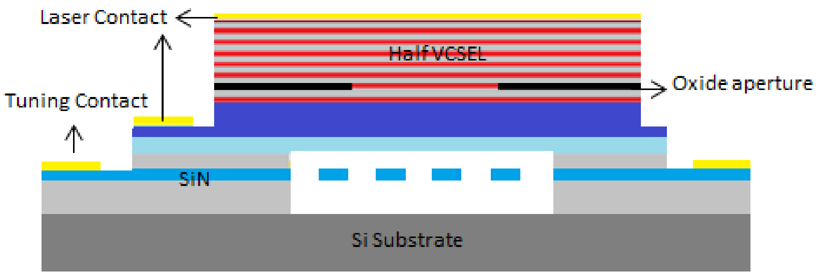

Figure 3: Schematic drawing of the integrated tunable GaAs VCSEL.

The free standing SiN HCG mirrors can be fabricated by selective wet etching by under etching the sacrificial oxide layer below the grating in a Buffered Hydrofluoric (BHF) solution. The half GaAs VCSEL die consist of a GaAs substrate, an AlAs etch stop layer, top DBRs, a multiple Quantum Well active region and a current spreading layer. The half VCSEL die can then be bonded to the free standing grating using ultra-thin adhesive polymer BCB (CycloteneTM) bonding. The GaAs substrate is then completely removed by mechanical grinding followed by a selective wet etching process. In this way we get a thin film of epitaxial III-V structure on the Si wafer. The oxide aperture can then be fabricated by lateral oxidation of the AlGaAs layer to achieve transverse optical and current confinement.

Conclusion

In conclusion, we propose a design for a broadband SiN HCG mirror to replace conventional DBRs. These mirrors can be integrated with GaAs half VCSELs to achieve a tunable laser structure in the near-IR.

References

[1] Sebastian Romero-García et al.," Silicon nitride CMOS-compatible platform for integrated photonics applications at visible wavelengths", Optics Express, Vol. 21, Issue 12, pp. 14036-14046 (2013)
[2] S. Keyvaninia, et al., "Ultra-thin DVS-BCB adhesive bonding of III-V wafers, dies and multiple dies to a patterned silicon-on-insulator substrate ",Optical Materials Express,Vol. 3, No. 1 ,2013
[3] Anders Larsson, "Advances in VCSELs for Communication and Sensing", IEEE Journal of Selected Topics in Quantum Electronics, Vol. 17, No. 6, 2011.
[4] Carlos FR. Mateus, Michael CY. Huang, Lu Chen, Yuri Suzuki, and Connie J. Chang-Hasnain ," Ultra broadband mirror using sub-wavelength grating", IEEE PHOTONICS TECHNOLOGY LETTERS, VOL. 16, NO. 2, FEBRUARY 2004.
[5] M. C. Y. Huang, Y. Zhou, and C. J. Chang-Hasnain, "A nanoelectromechanical tunable laser," Nat. Photonics, vol. 2, 180–184, 2008.
[6] Michael C. Y. Huang, Ye Zhou & Connie J. Chang-Hasnain, "A nanoelectromechanical tunable laser", Nature Photonics 2, 180 - 184 ,2008.
[7] Robert Magnusson and Mehrdad Shokooh-Saremi, "Physical basis for wideband resonant reflectors", Optics Express, Vol. 16, No. 5, 2008