GaAs High-Contrast Gratings with InGaP Sacrificial Layer for Multi-Wavelength VCSEL Arrays

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Abstract: *We report on highly reflective suspended GaAs high-contrast gratings (HCGs) using an InGaP sacrificial layer. A high reflectivity approaching 100% was observed both in direct reflectivity measurement and by low threshold currents in fabricated multi-wavelength HCG-VCSEL arrays.*
Keywords: *High-contrast grating (HCG), sacrificial layer, InGaP, vertical-cavity surface-emitting laser (VCSEL).*

1. Introduction

Sub-wavelength high-contrast gratings (HCGs) can be designed to function as ultra-thin reflectors in vertical-cavity surface-emitting lasers (VCSELs) and integrated optics [1]. The device performance may be tailored by proper choice of the grating parameters (duty cycle, period, and thickness), enabling gratings with specific reflectivity, reflection phase, and angular reflection dependence [1,2].

We recently demonstrated a multi-wavelength HCG-VCSEL array by using HCGs with different period and duty cycle [3]. Such a monolithic integrated multi-wavelength source is highly sought after for wavelength-division multiplexing in optical interconnects. Many demonstrated HCG-VCSELs use hybrid top reflectors with a few DBR pairs and an HCG on top [1,2]. However, to obtain a large wavelength span in the array, the VCSEL cavity resonance must be sensitive to the phase of the HCG reflection. This requires HCGs with reflectivity approaching 100%, as the top mirror feedback must come from the HCG alone, with no support from additional DBR pairs. Here we go further into details of the HCG fabrication and properties, and HCG-VCSEL performance.

2. High-Contrast Gratings

The HCGs consist of a GaAs grating layer on top of a lattice matched InGaP sacrificial layer. While InAlP has been successfully used in a similar structure [4], InGaP was chosen to avoid oxidation of Al-containing material. The gratings were defined by electron-beam lithography in ZEP520A resist (Fig. 1a) and dry etched using anisotropic ICP-RIE with $SiCl_4$/Ar, resulting in vertical sidewalls (Fig. 1b). Highly selective and reproducible etching of the sacrificial InGaP layer was achieved using concentrated HCl. However, HCl does not etch InGaP in ⟨110⟩ crystal directions [5]. The grating lines were therefore oriented along ⟨100⟩, at 45° from the {110} cleavage planes, see Fig. 1c-d.

Reflectivity measurements (Fig. 2) were performed on HCGs fabricated in a 285 nm thick GaAs layer on top of 520 nm InGaP on a GaAs substrate. The HCG reflectivity was measured using a fiber-coupled superluminescent diode and a lens package which focused the incident light onto the HCG and collected the reflected light. The setup was calibrated against gold evaporated next to the HCG, assuming a 98% gold reflectivity throughout the wavelength range. Despite some disagreement between simulation and experiment at longer wavelengths, a reflectivity approaching 100% was measured around 1010 nm, with a large difference between TM and TE polarization.

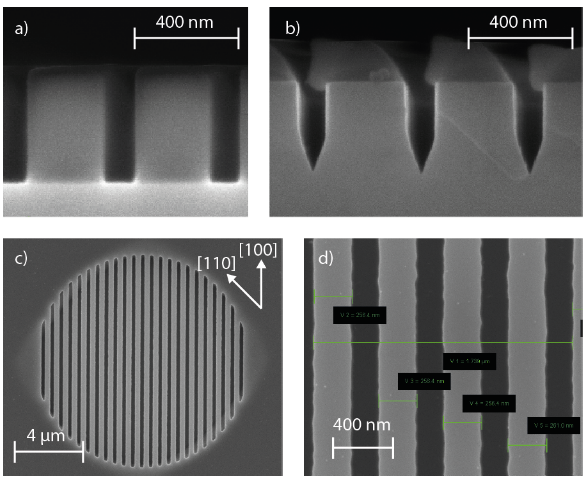

Fig. 1. SEM images from fabrication of HCGs. a) ZEP520A resist mask. b) After dry etching. The remaining resist has been distorted from the cleaving. c-d) Fabricated HCG.

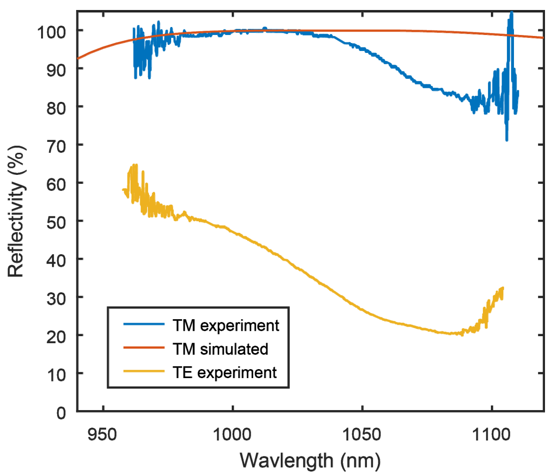

Fig. 2. Experimental and simulated reflectivity for a test HCG with 435 nm period and 63% duty cycle. The 520 nm air-gap and the underlying GaAs were taken into account in the simulations.

3. HCG-VCSELs and Multi-Wavelength HCG-VCSEL Arrays

The fabrication of HCG-VCSELs with different HCG parameters enables wavelength setting in a post-epitaxial-growth process. The HCG-VCSEL employs an air-coupled cavity design, where the semiconductor-air interface is placed at a node of the optical field (Fig. 3). This makes the cavity resonance sensitive to the phase of the HCG reflection, enabling a wavelength span of 15 nm in a 4-channel VCSEL array, see Fig. 4c. However, this cavity design also leads to a low longitudinal optical confinement of 0.6%. As a consequence, an HCG reflectivity higher than that of the top DBR in a standard VCSEL with a typical confinement factor of 2-3% [6] is required. Further details on the design and fabrication can be found in [3]. Despite the challenging cavity configuration, low threshold current densities of 1-2 kA/cm^2 were observed (Fig. 4a), which is similar to our standard double-DBR VCSELs [6]. The low slope efficiency may be caused by low outcoupling through the HCG due to the high HCG reflectivity. Single-mode emission was observed for HCG-VCSELs with up to 7 μm oxide aperture (Fig. 4b), as expected from the large angular selectivity of the HCG [2].

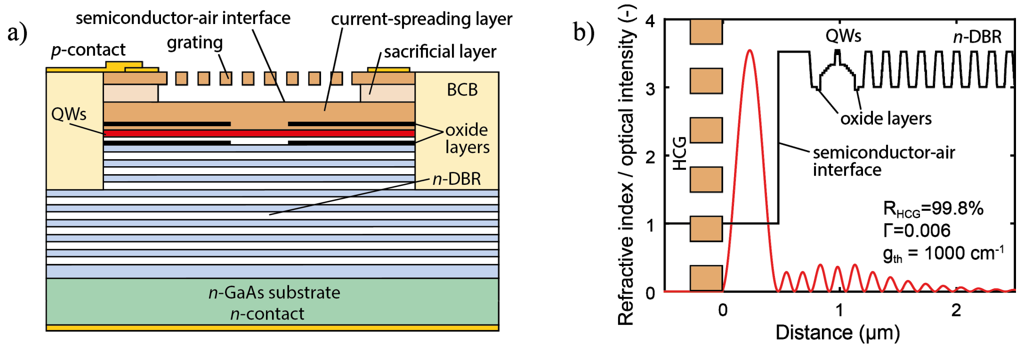

Fig. 3. a) Schematic cross-section of the HCG-VCSEL. b) Standing wave and refractive index profile of the HCG-VCSEL.

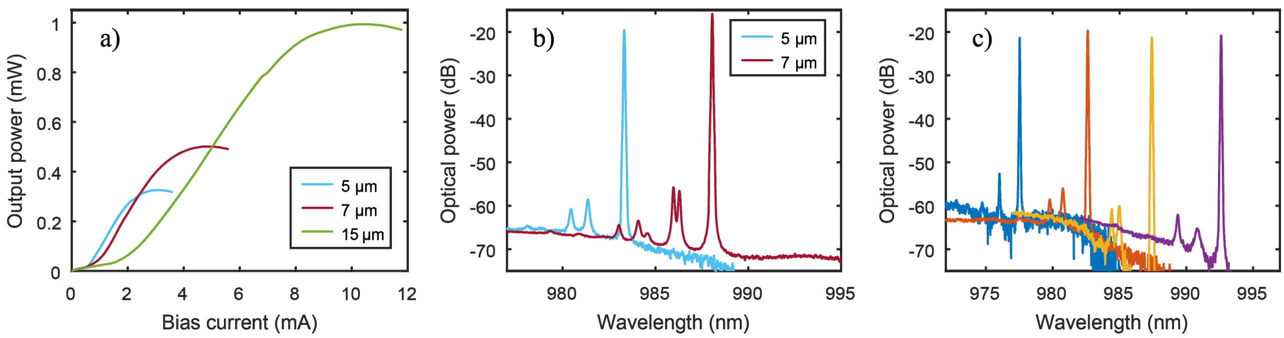

Fig. 4. a) Output power vs. bias current for HCG-VCSELs with different oxide aperture diameters. b) Optical spectra at roll-over for HCG-VCSELs with oxide aperture diameters of 5 and 7 μm. c) Multi-wavelength array of four HCG-VCSELs with different HCG period and duty cycle.

4. Conclusion

The use of an InGaP sacrificial layer enables simple and reproducible fabrication of HCGs with high reflectivity. Highly reflective HCGs enabled the realization of multi-wavelength VCSEL arrays by using HCGs with different period and duty cycle.

5. Acknowledgement

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