Long-Wavelength BTJ-VCSEL with High-Contrast Grating

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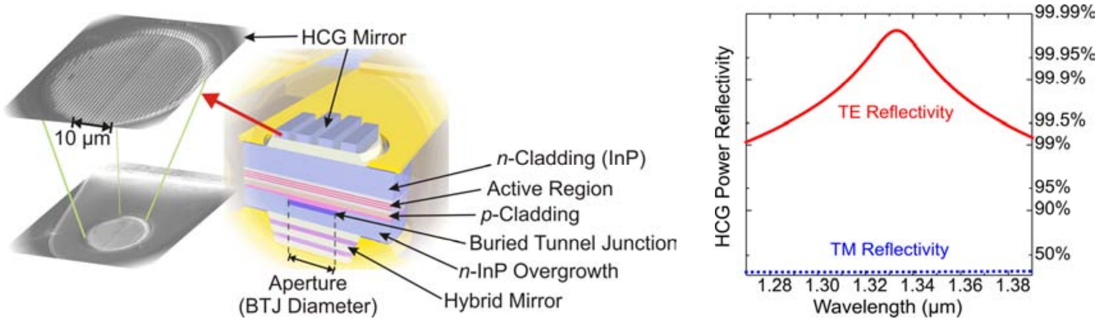
Abstract: InP-based, long-wavelength buried tunnel junction (BTJ) VCSELs, emitting at 1.32 µm with a high-contrast grating (HCG) are demonstrated. This is the first HCG VCSEL presented emitting at long wavelengths. CW operation is demonstrated up to 18°C. The device with an aperture of 11 µm is highly single-mode. No second polarization mode can be identified in the spectrum.

OCIS codes: (140.7260, 250.7260) VCSELs; (050.6624) Subwavelength structures; (310.6628) Nanostructures

1. Introduction

Vertical-cavity surface-emitting lasers (VCSELs) are preferred in many applications because of their low cost and small packaging capability, single longitudinal mode operation with narrow circular beam for direct fiber coupling, lithographically defined arrays, high-speed modulation and low power consumption. Devices in the long-wavelength regime around 1.3 and 1.55 µm with satisfying performance were demonstrated only in the past decade [1-2]. For many applications, polarization stability has been a challenge for VCSELs, as the structure does not have an intrinsic polarization preference. Recently, we reported a novel subwavelength high contrast grating (HCG) and its incorporation into a 850-nm VCSEL [3]. However, electrically pumped, long-wavelength HCG VCSELs have not been realized so far. Here, we present the first long-wavelength HCG VCSEL.



(a) (b)

Fig. 1. (a) Schematic figure of the cross section of the investigated HCG long-wavelength VCSEL. A scanning electron microscope (SEM) image of the processed device as inset. (b) Simulated HCG reflectivity as deployed on the VCSEL structure. The reflectivity for TE-polarized light is very high over a wide range, whereas the other polarization mode is strongly suppressed.

2. HCG VCSEL Design

The HCG long-wavelength VCSEL presented here is based on the latest high-speed long-wavelength VCSEL structure with short cavity and record modulation bandwidth [4]. A buried tunnel-junction (BTJ), whose dimensions are precisely controlled by lithography, serves as current aperture. The active region was tailored to emit at 1320 nm, an interesting wavelength for the 10G Ethernet long-range IEEE standard.

For the previous design [5] with an epitaxially grown distributed Bragg-reflector the polarization mode stability is not guaranteed by design, and higher order transverse modes appear at relatively small apertures of 5~7 µm diameter. An HCG long-wavelength VCSEL was fabricated with a SiO_2 spacer and an HCG consisting of amorphous Si written by e-beam lithography. The Si/SiO_2 HCG was previously reported to exhibit high reflectivity over broad bandwidth [6].

The device schematic is presented in Fig. 1 with a SEM-picture of the fabricated HCG. The HCG has the grating bars oriented along the [011]-axis of a (100)-InP-wafer. The grating thickness was measured to be 196 nm of silicon; the silica spacer was determined to be 1020 nm. We fabricated gratings with periodicities varying around 820 nm, with bar-widths around 200 nm, targeting high reflectivities for transverse electric (TE) polarized light, i.e. light with electric field components aligned along the grating bars. Due to the amorphous material, some slight

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roughness below 30 nm had to be tolerated without extensive optimization of the dry-etching process calibrated for crystalline silicon. Fig. 1(b) presents the simulated reflection spectra of the HCG used for the VCSEL described in this paper, including loss in the a-Si as measured by photo-thermal deflection ($\alpha = 10\ cm^{-1}$). We can clearly see that the TE-polarized light (solid red) is highly reflected, whereas TM-polarized light will suffer from large mirror losses. This can very efficiently break the polarization mode degeneracy in VCSELs and provide polarization stability by design. Although, from simulation, the top mirror may have such a high reflectivity that no power is coupled out; from experience, we expect a reasonable amount of power to be coupled out due to imperfections in the HCG from surface and etching roughness.

3. Device Performance

The continuous wave (CW) performance of the HCG VCSEL is presented in Fig. 2. Highly resolved single-mode spectra are depicted in (a) with no visible polarization modes. A tuning coefficient is 0.07 nm/K can be observed. The *LIV*-performance is shown in Fig.2(b) demonstrating CW-operation at room temperature and cooled CW-powers in excess of 0.5 mW.

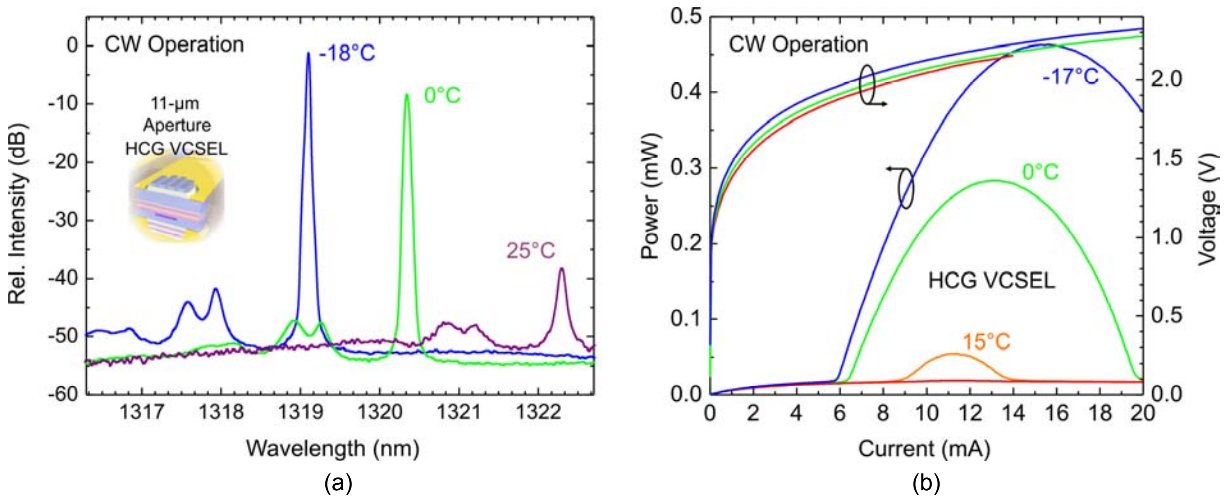

Fig. 2. CW performance of the HCG long-wavelength VCSEL. Highly resolved single-mode spectrua (a) with no visible polarization mode. Spectra are presented up to 25°C. The tuning coefficient is 0.07 nm/K. The *LIV*-performance (b) shows CW-operation at room temperature and cooled CW-powers in excess of 0.4 mW.

Here, we presented the first long-wavelength HCG VCSEL. The device emits at 1320 nm CW at room temperature and is designed for high-speed modulation. The out-coupling mirror is fabricated out of amorphous silicon on isolator material, with the HCG imprinted into the silicon layer, optimized for easy fabrication utilizing the vast know-how in silicon technology. No further DBR layer pairs are used for the mirror. As back-reflector, a hybrid mirror consisting of amorphous dielectrics and metal is deployed. This design is a very elegant solution of long-wavelength VCSELs solving the key challenges of high-power transverse single-mode emission and polarization stability.

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