Novel Surface Emitting Laser using High-Contrast Subwavelength Grating

The realization of VCSELs has been significantly limited by the choice of material available for making highly reflective distributed Bragg reflectors (DBRs). This remains to be one major bottleneck for blue-green, 1.3–1.55µm, and mid-wavelength infrared (MWIR) regimes. Furthermore, it is challenging to make wavelength tunable VCSELs, where the requirements on mirror bandwidth and reflectivity are stringent. CONSRT researchers led by Professor Chang-Hasnain have recently demonstrated, for the first time, a new class of surface emitting lasers utilizing a single-layer high-index-contrast subwavelength grating (HCG) as the top mirror of VCSEL, instead of conventional DBRs. Single transverse and polarization mode emission with low threshold current and 1mW output power was obtained at 850nm wavelength.

A high-contrast subwavelength grating was designed to have both broad bandwidth (∆λ/λ >30%) and high reflectivity (R >99%). The HCG consists of a single-layer 1D grating structure formed by periodic stripes of high-and low-index materials, sandwiched in-between two low-index cladding layers on the top and bottom. The simplicity of the design and versatility to adapt to various wavelengths make HCG an excellent reflector candidate to integrate with various surface-normal optoelectronic devices. Fig. 1 shows the device structure consisting of an active region with GaAs quantum wells in-between a HCG-based top mirror and 34 pairs of bottom DBR. The top mirror of the VCSEL comprises 4 pairs of DBR layers and a highly reflective HCG to provide optical feedback, where the grating (periodic stripes of AlGaAs and air) is freely suspended, with air as the low index cladding layers on the top and bottom. Since the HCG design contains 1D symmetry, it is naturally polarization sensitive – TM polarized light with electric field perpendicular to the grating lines sees higher reflectivity than the TE polarized light. The calculated reflectivity for the TM polarized light is >99.9% for 0.83-0.88µm wavelength ranges while that for TE polarized light is merely 95%, making the HCG an excellent component for 850nm VCSEL with excellent polarization control.

The HCG was defined on VCSEL mesa using electron-beam lithography on PMMA resist, which was then etched by reactive ion etching. A wet chemical based selective etching was used to remove the sacrificial material underneath the HCG and form the suspending grating structure. Fig. 2 shows a SEM image of the fabricated HCG integrated VCSEL and the inset shows the freely suspended HCG structure after etching. A novel “C”-shape trench surrounding the grating was used to eliminate buckling of the suspended gratings after the release process, which arises from the residual stress in the material accumulated during material growth.

With the HCG integrated as the top mirror, continuous wave (CW) operation of HCG-VCSEL was demonstrated for the first time at room temperature. Fig. 3 plots the HCG-VCSEL device characteristics for output power versus the input current (LI) and voltage versus input current (IV). The device exhibits low lasing threshold current < 0.5mA and excellent output power ~1mW. The low threshold current is a directly illustration of the extremely high reflectivity of HCG (exceeding 99.5%). Fig. 4 shows the emission spectra of the HCG-VCSEL at various injected current. The HCG-VCSEL emission shows side-mode suppression ratio ~45dB, which can be accounted by area-dependent of reflectivity of HCG that suppresses higher-order transverse modes. Due to thermal heating effects, current generation in HCG-VCSEL induces a larger wavelength dependence on input current. This can be alleviated with proper VCSEL design.

Not only does HCG provide high reflectivity, it can also be used to control the polarization of the emission (lithographically determined) with polarization suppression ratio of ~20dB. This intrinsic polarization selectivity nature can be utilized to control the polarization of VCSEL and hence minimize the polarization-dependent noises of the output VCSEL light. Our experimental results clearly demonstrated that HCG is an excellent reflector candidate to integrate with various optoelectronic devices in future applications.

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