Surface Emitting Quantum Cascade Laser

M. Austerer, C. Pflügl, W. Schrenk, T. Roch and G. Strasser
Institute of Solid State Electronics, TU Vienna, Austria

We present high power surface-emitting single mode GaAs-based quantum cascade lasers (QCLs) in the mid infrared. By using an air-AlGaAs waveguide combined with second-order distributed feedback processing, we obtained optical output via the surface above 3W. Surface-normal dual-lobe light emission exceeds the emission from one as-cleaved facet by a factor of six.

Quantum cascade lasers are based on intersubband transitions [1]. Selection rules for transitions in quantum wells allow gain only for TM polarized electromagnetic waves. Therefore conventional vertical cavity surface emitting laser design is not suitable for QCLs. If one wants to exploit the advantages of surface normal emission an other approach must be taken. We have chosen a distributed feedback design where the feedback is given through a second-order Bragg grating etched into the surface of the laser ridge. Such surface emitting QCLs have been realized both in the InGaAs/InAlAs/InP [2] and also in the GaAs/AlGaAs material system [3]. Appropriate etch depths, a low loss top air cladding, and metallization of the grating peaks only, lead to high power surface emission. The far field of such lasers exhibits an asymmetric dual lobe pattern, because the near field close to the emitting surface also includes interference terms. An in-detail investigation shows that the relative position of the grating and the end mirrors determines the ratio of the two lobe intensities [4]. The single mode emission wavelength is continuously tuneable by the heat sink temperature.

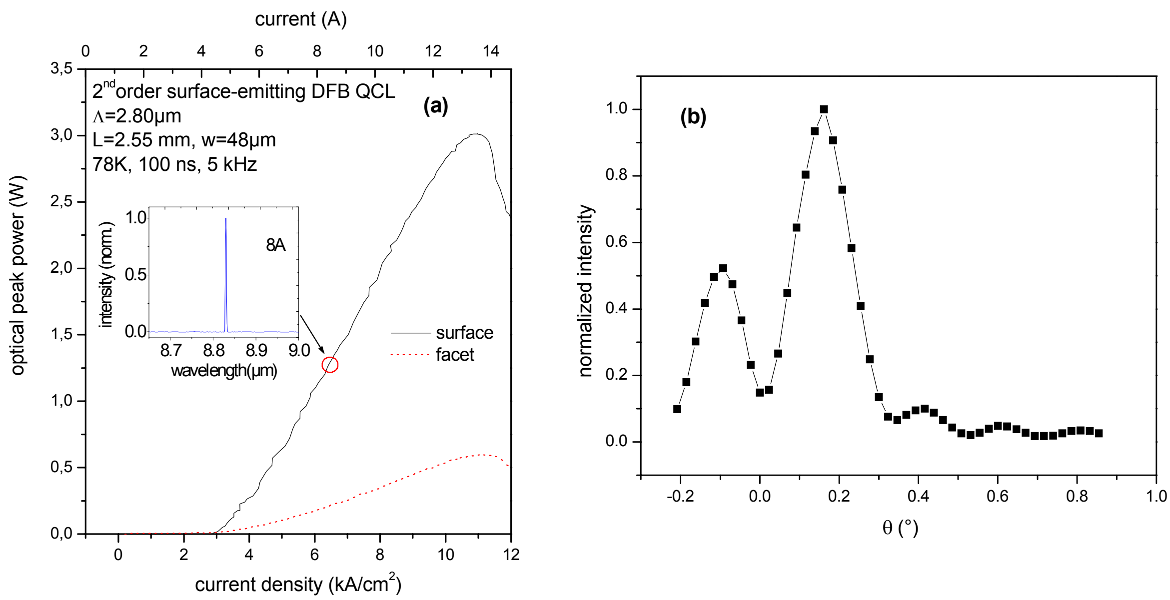

Fig. 1: (a) Emission spectrum and light-intensity curves for surface and facet emission. The emission wavelength is the same in both cases.
(b) Angular dependence of the far-field 124 cm away from the laser chip. An asymmetric dual lobe pattern is observed.

A three-well GaAs/$Al_{0.45}Ga_{0.55}As$ quantum cascade active region [5] was grown by means of molecular beam epitaxy on a <100> GaAs substrate. For waveguiding an air/AlGaAs cladding was used in order to reduce absorption losses. Our calculations yield a waveguide loss coefficient of α = 3.8 cm^{-1}, whereas another structure with the same active region at the same wavelength, but a double-plasmon waveguide has α-values of 12cm^{-1}. Taking the waveguide structure and the desired wavelength of 8.9 µm into account, a suitable grating period, duty cycle and grating depth were calculated. The MBE grown material was processed into DFB laser ridges by means of optical lithography and reactive ion etching (RIE). The laser ridges were cleaved to different lengths in order to investigate the critical DFB coupling length. Lasers that are shorter than 1.4 mm, thus having a product of DFB coupling coefficient κ = 7 cm^{-1} and length (cm) smaller than one, do not experience sufficient feedback from the surface grating and are showing typical Fabry-Perot modes. The samples were mounted substrate-down on a turnable cold finger and operated under pulsed bias (100 ns, 5 kHz) at 78 K. By turning the cold finger we could observe both edge and surface emission.

In Fig. 1 (a) absolute light output power versus bias current density for a 2.55 mm long laser is plotted. Single mode emission is observed for all bias currents above threshold. Light power was measured using a calibrated thermopile detector. In the case of edge emission an f/1 AR-coated ZnSe lens was used to collect the light from the highly divergent beam. In both cases the light power was focused onto the thermopile detector by means of a gold coated off-axis parabola. The ratio between surface emission and single-facet emission is determined to be 6 for this device.

The far field distribution (Fig. 1 (b)) of the laser emission was measured using a 1 mm x 1 mm sensitive area liquid-nitrogen cooled HgCdTe detector at a distance of 124 cm away from the laser chip. Lateral resolution of 1 mm results in an angular resolution of 0.046°. The two beam lobes are separated by 0.25° and have an FWHM beam divergence of 0.2° in laser ridge parallel direction. Beam divergence in ridge normal direction is determined by the ridge width, here FWHM beam divergences are in the range of 10° to 20°.

We have shown the high-power capabilities of surface emitting DFB quantum cascade lasers. Single lobe emission surface emission of second order DFB QCLs is proposed by introducing a phase shift into the surface grating. Such low divergence emission pattern would further improve practical usability. In contrary to facet emitters, for many applications no collimating lens would be necessary.

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