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Substrate-emitting ring quantum cascade laser array with distributed feedback metal gratings

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1. Introduction

Mid-infrared quantum cascade lasers (QCLs) operating in single-mode operation at room temperature are very attractive for a variety of applications in medical diagnostics, chemistry or material science. Distributed feedback (DFB) gratings etched into the surface of the laser ensures single-mode emission due to the refractive index contrast between air and the cap layer. In ring-shaped cavities a 2[nd]-order DFB grating enables mode-selection and partial out-coupling of the light in vertical direction [1]. By adjusting the grating duty-cycle, the ring QCL can be optimized for substrate or surface emission [2]. However, for continuous-wave operation a buried grating is beneficial as it introduces low waveguide losses when it is overgrown with e.g. insulating InP to improve the thermal management. But the close distance to the active region can cause an over-coupled feedback, leading to a reduced device performance. Another approach is to etch the DFB grating in the surface and fill the etched slits with a metal layer [3]. This configuration also improves the heat removal from the active region and furthermore the grating can be adjusted for specific wavelengths even after the full laser stack has been grown. On the other hand, the direct contact with the metal introduces optical losses.

We present an array of ring QCLs with a metal-covered 2[nd]-order DFB grating were we investigate the influence of the grating etch depth and the grating duty-cycle on the device performance. The coupling between the DFB modes and a surface plasmon mode is studied in 2D simulations.

2. Ring laser array

We processed an array of ring lasers with a waveguide width of 10µm and a length of ~1.2mm. The geometrical dimensions stay the same for all lasers, while two parameters of the 2[nd]-order DFB are changed. The grating duty-cycle is varied between 10 – 90%, which corresponds to the amount of Au deposited in the etched grating slits. Furthermore, different grating etch depths up to 800nm are realized on the same chip. A silicon nitride mask is used to transfer the grating via reactive ion etching into the surface of the cladding/contact layer (see Fig. 1). As there is no metal involved in the process so far, our fabrication is also suitable for an optional lateral regrowth with e.g. InP. After the rectangular grating has been etched a several micrometer thick gold layer is deposited.

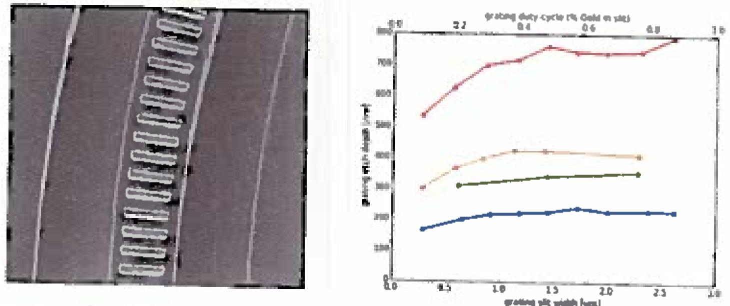

Fig. 1: SEM image (left) of a ring laser device (10µm waveguide width) with a surface 2[nd]-order DFB grating before gold metallization. Realized grating duty-cycles and etch depths are shown in the right plot.

3. Results

Due to the fact that the surface is covered with gold, the diffracted light is collected from the substrate. The electroluminescence spectrum below threshold was measured with a FTIR-spectrometer in step-scan mode at 77K. In Fig. 2 the measured spectrum of a substrate-emitting ring QCL with 2[nd]-order DFB metal-grating at a current of 76mA is shown. As the device is operated below the lasing threshold many whispering gallery modes are observable. From the peak-to-valley ratio the sub-threshold gain spectrum has been extracted by applying the Hakki-Paoli method. The inset in Fig. 2 shows the simulated magnetic field distribution for two DFB modes, where the grating is etched 250nm deep into the 8e18cm^{-3} doped InGaAs layer. As described in [4], the coupling mechanism is not only defined by the interplay of two waveguide modes, but also a surface-plasmon mode is involved. Moreover, it has been demonstrated [5,6] that a resonant coupling of the antisymmetric DFB mode to the surface plasmon leads to a strong absorption of this mode in the metal, which in turn favors the symmetric mode to lase. The transfer of this approach from a first-order to a second-order DFB metal grating seems to be very promising for high-performance mid-infrared QCLs.

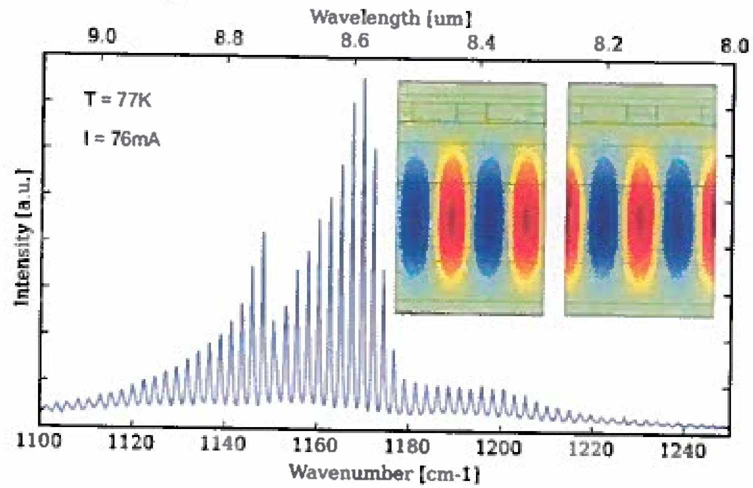

Fig. 2: Electroluminescence spectrum of a ring QCL with 60% grating duty-cycle. Below lasing threshold many whispering gallery modes coexist. The inset shows a simulation of the low- and high-frequency mode for a grating etch-depth of 250nm.

4. References

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