Quantum Cascade Microlasers with Two-Dimensional Photonic Crystal Reflectors

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Abstract—**Edge-emitting GaAs/$Al_{0.45}Ga_{0.55}As$ quantum cascade micro-lasers with two-dimensional photonic crystal reflectors have been fabricated. The resonator length of 100 µm leads to a large free spectral range of the longitudinal resonator modes. Owing to this large free spectral range, single-mode operation with a side mode suppression ratio of 20 dB at 80 K has been achieved. This micro-laser can be operated up to 220 K. 275 µm long devices can be operated up to 280 K.**

I. Introduction

The comparatively long emission wavelength of quantum cascade lasers (QCLs) makes the combination of QCL gain material with photonic crystal (PhC) structures very attractive. Two-dimensional PhCs were first employed for surface-emitting QCLs [1] and consecutively also used to realize highly reflective mirrors for edge-emitting QCLs [2], [3]. Recently an improvement of threshold current density by the usage of PhCs has been reported [4]. Decreasing the cavity length provides the opportunity of single-mode operation due to the increasing Fabry-Perot mode spacing of the laser resonator. However, highly reflective mirrors are required for such short laser resonators to manage the mirror losses. In this paper, we report on microlasers as short as 100 µm with two-dimensional PhC mirrors at both ends of the laser resonator.

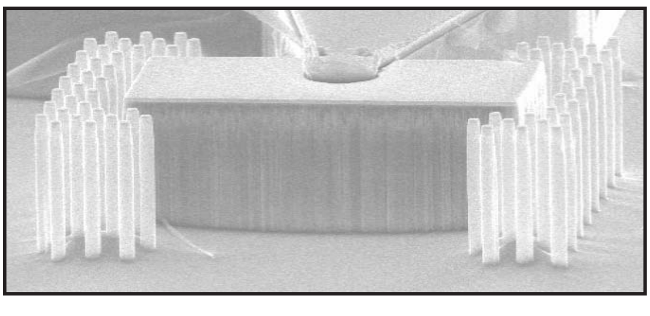

Fig. 1. Scanning electron microscopy picture of a microlaser with two-dimensional photonic crystals mirrors at both ends of the laser resonator.

II. Device Layout and Fabrication

The layout of our PhCs is based on a triangular geometry which is suitable to achieve broad stop bands for TM-polarized radiation. Finite differenc time domain simulations predict broad photonic stop bands (765 to 1175 cm^{-1}) for our design parameters (lattice constant 3.5 µm, 1.75 µm diameter of the pillars). Hence, the emission wavelength of our gain material (953 cm^{-1}, obtained from a 1mm ridge wave guide structure without PhCs) lies in the mid of the stop band. The used triangular geometry of the PhCs guarantees high reflectivity (R>0.9) and broad stop bands regardless of the orientation (ΓM / ΓK) of the PhCs relative to the laser facette. Gain material consisting of 50 periods of a bound-to-continuum design ([5], structure 1) was grown by solid-source molecular beam epitaxy using an Eiko EV100 MBE system. The active region is embedded in a plasmon enhanced waveguide. Laser ridges with two-dimensional photonic crystal mirrors are defined by a combination of optical and electron beam lithography and subsequent dry etching. Fig. 1 shows a scanning electron microscopy (SEM) image of a microlaser. The etch depths of the pillars are about 14 µm and they are of high structural quality, with smooth and vertical sidewalls.

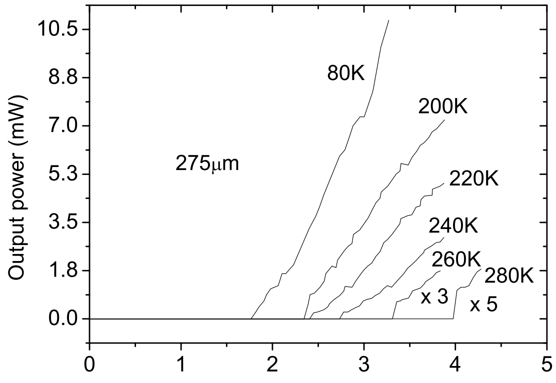

Fig. 2. Light output characteristics of a 275 µm long microlaser. The P-I-curves at 260 and 280 K are re-scaled for better clarity.

III. Results

Light output characteristics of a 275 µm and a 100 µm long microlaser are shown in figure 2 and the inset of figure 4, respectively. At 80 K threshold currents amount to 1.75 A and 1.47 A and typical output powers of several mW are observed. The relatively low output power can be attributed to the high

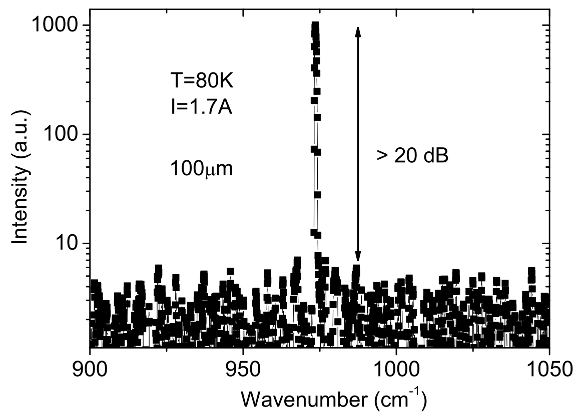

Fig. 3. High resolution singlemode spectrum of a 100 µm long microlaser at 80 K.

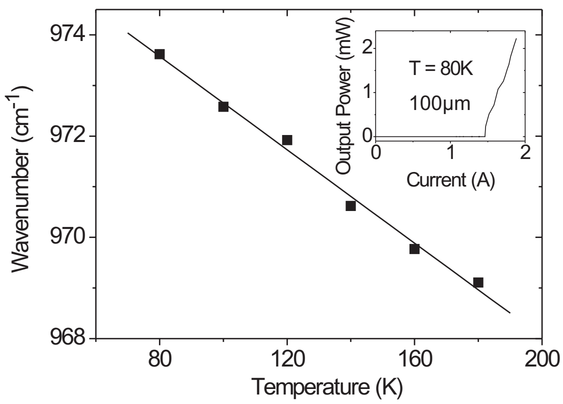

Fig. 4. Tuning behaviour of the emission wavelength of the 100 µm long device with temperature. The inset shows a P-I-curve at 80 K.

reflectivity of the PhC mirrors. Owing to the large free spectral range of approximately 15 cm^{-1} for the 100 µm long device, single mode operation with a high side-mode supression of 20 dB is achieved for a heat sink temperature of 80 K and a driving current of 1.7 A. A high resolution single-mode spectrum is shown in figure 2. Between 100 K and 180 K still a sidemode supression of 10 dB is obtained. From the spectra recorded between 80 K and 180 K one can extract a tuning of the emission wavelength with temperature of -0.046 cm^{-1} / K (figure 4), which reflects the shift of the Fabry-Perot mode comb. The maximum operation temperature of the 100 µm long device is limited to 220 K. The 275 µm long device, however, can be operated up to 280 K, which is easily accessible by a peltier cooler.

IV. Conclusion

In conclusion, we have fabricated microlasers with high quality two-dimensional PhC mirrors. The 100 µm long device allows single-mode operation with a side-mode supression of 20 dB at 80 K, which is enabled by the large free spectral range of the microlaser. Typical output powers of several mW are observed, which are mainly given by the high reflectivity of the PhC mirrors. This provides the possibility to adjust the output power of the device by engineering the reflectivity of the PhCs.

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