Electrically Pumped Quantum Cascade Ring Lasers

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Introduction

Circular cavities from a quantum cascade material have been investigated by several groups [1] – [3]. It is generally believed that light propagates as a whispering gallery mode in microcylinder or microdisk [4], [5] cavities. This implies that almost all of the light is at the periphery of the device and the centre of such a device should have little or no influence on the light field. Nevertheless, current will also flow through the centre region and provide gain, which is wasted due to the almost complete absence of a relevant light field. This was a motivation to remove the centre portion of microcylinders and thereby obtain a ring shaped laser cavity (as shown in Fig.1). It was expected that the threshold current required to achieve lasing would drop due to the decreased area of the device.

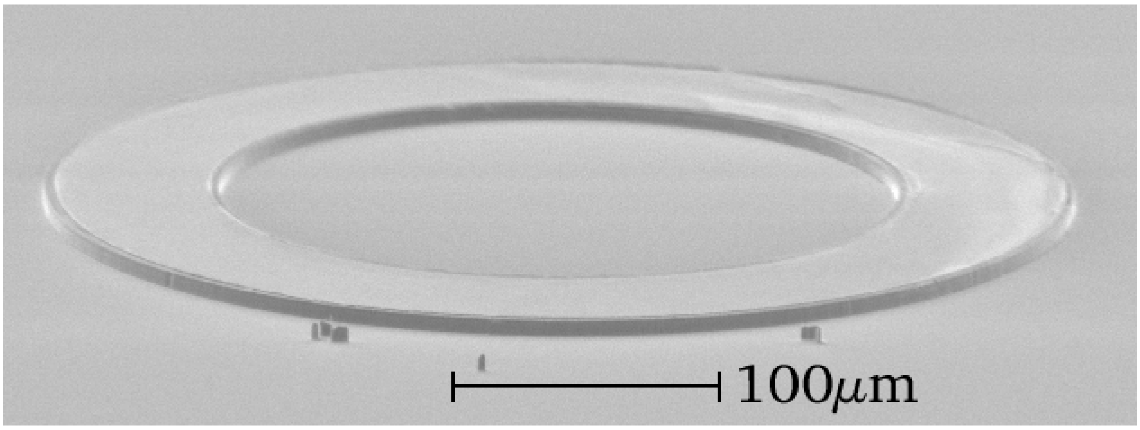

Fig. 1: Ring laser; the height of the laser is approximately 10 µm.

Experimental

The material from which the ring lasers were processed was grown by solid source molecular beam epitaxy. It is based on a three-well design quantum cascade structure. When processed as a standard ridge waveguide, this material functioned at least up to room temperature [6]. An x-ray-rocking curve (shown in Fig. 2) indicates that the actual period of the chosen material is about four percent less than the designed one, but also reveals the accurate periodicity. The deviation between the grown and the simulated period is only 1.8 percent. It thereby denotes the high quality of the material with regard to the cascaded structure and reproducible interfaces.

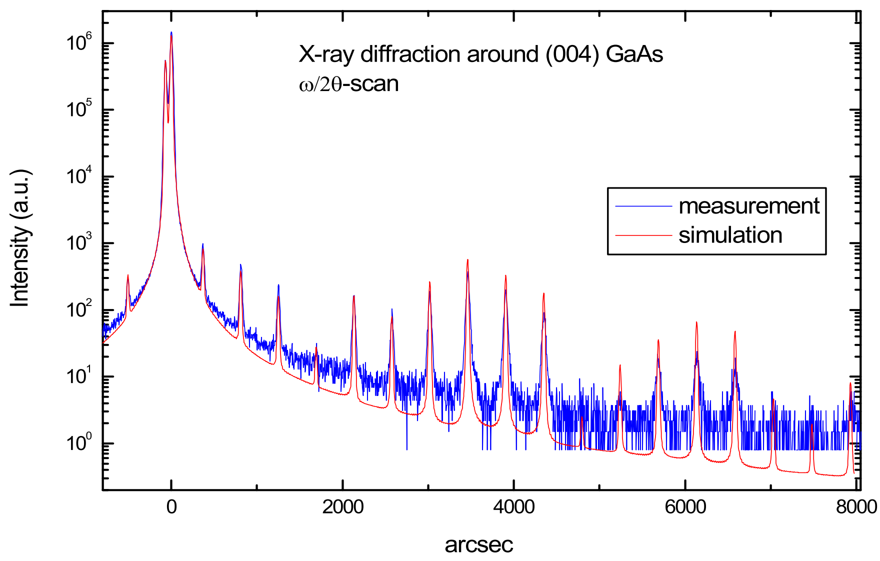

Fig. 2: X-ray-rocking curve.

The rings were processed using standard photolithography and reactive ion etching to achieve smooth and perpendicular sidewalls. These are considered critical for device operation, as deviations from a vertical sidewall will lead to deviations in the length of the optical path. Even small deviations suffice to degrade device performance. This would represent an additional loss mechanism in addition to standard wave-guide losses. Circular cavities that work above room temperature have already been demonstrated [7].

Rings with outer diameters of 200, 300 and 400 µm and various inner diameters were fabricated. Several measurements were conducted, including a temperature dependence of the emitted spectra of the rings (as shown in Fig. 3). It can clearly be seen that the emission wavelength shifts to lower wave numbers and thereby to lower energy as temperature is increased. The frequency shift per Kelvin is somewhat higher than for a Fabry-Perot laser made from the same material where it is in agreement with the temperature dependence of the index of refraction. Presumably, the relatively large shift in emission wavelength indicates an additional loss mechanism in the ring laser. Since the emission wavelengths at higher temperatures approach that of a Fabry-Perot laser from the same material, but shift to smaller wavelengths at lower temperatures, we infer that the additional loss mechanism is less dominant at higher temperatures. But not only the energy of the emitted light changes, but also the number of modes. We note that the number of lasing modes decreases as the temperature increases. This can be attributed to the fact that the lasing threshold increases with temperature and so the same current is not as far above the lasing threshold at different temperatures.

Figure 4 depicts spectra of several rings with a constant outer diameter and different inner diameters. The outer diameter is 400 µm and the inner diameters are varied between 240 and 320 µm in steps of 10 micrometers, with the exception that there is no ring with an inner diameter of 290 µm. The spectra have all been measured at the same temperature of 77 K. The modes are not regularly spaced as would be expected for whispering gallery modes of lowest order. Interestingly, the diameter of the hole influences the emission wavelengths of the lasers, such that the emitted light has a shorter wavelength with decreasing thickness of the ring.

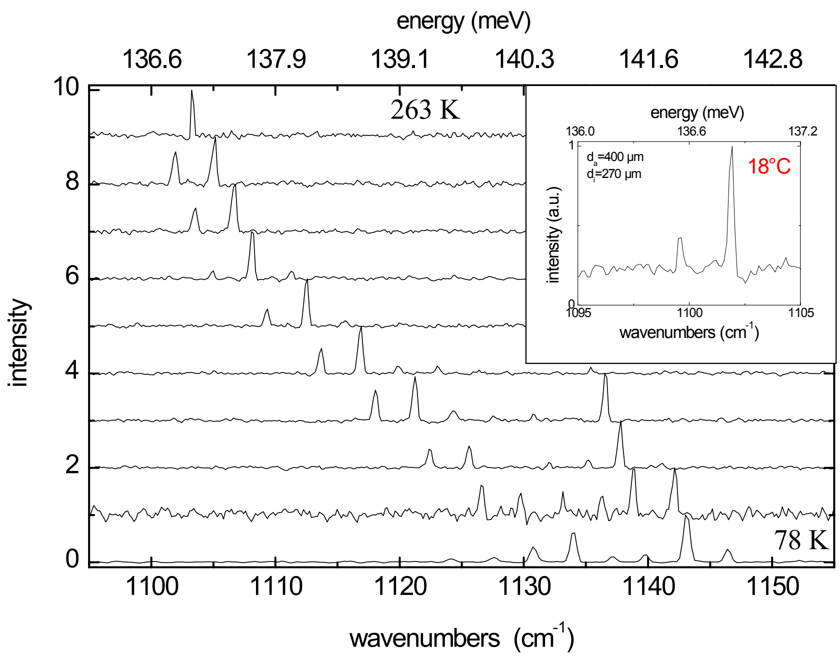

Fig. 3: Temperature dependence of emitted spectra. Temperatures are 78, 98, 118, 138, 158, 178, 198, 218, 238, and 263 K.

This is in contrast to previous assumptions that the light field should not enter the central region of the device and therefore should not be influenced by any changes in the centre section. Considering these facts, it seems necessary to reconsider the idea of whispering gallery modes within these devices.

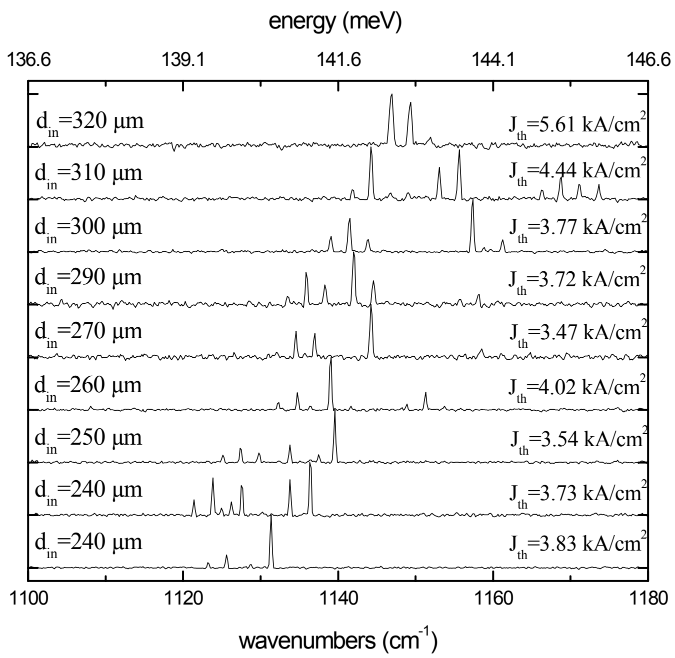

Fig. 4: Spectra of rings of different widths. The outer diameter was 400 µm; the inner diameters are as indicated.

Threshold current densities for the individual lasers are also indicated in Fig. 4. They show a tendency to increase as the inner diameter of the ring increases. We note that the shift in emission wavelength is not caused by a shift in threshold. The threshold current density scatters considerably more than the emission wavelength. Further, we checked that the envelopes of the spectra do not depend on the bias.

Conclusion

We manufactured electrically pumped quantum cascade ring lasers and characterised their optical properties. The emission wavelength was found to be sensitive to changes in the centre section of the device, which is in contrast to the general assumption that circular cavities dominantly support whispering gallery modes. Together with the observation of irregular mode spacing our results suggest that a different mode structure is preferred.

Acknowledgements

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