Light Field in Quantum Cascade Ring Lasers

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Several geometries of circular micro resonators have already been investigated in the past with micro disks, micro cylinders and rings among them. These devices showed appealing performance characteristics such as a low threshold and lasing up to room temperature [1]. Theory on the distribution of light within such devices predicted the concentration of the light at the periphery in lowest order whispering gallery modes [2], [3]. This assumption motivated the exploration of electrically pumped quantum cascade lasers with ring shaped cavities. Several devices with varying inner and outer diameters were manufactured in the course of this investigation. The measurements performed on these devices indicated that the light is not confined to extreme periphery of the device but also extended into the center region of the device. It is the aim of this report to explain the distribution of the light field within these devices.

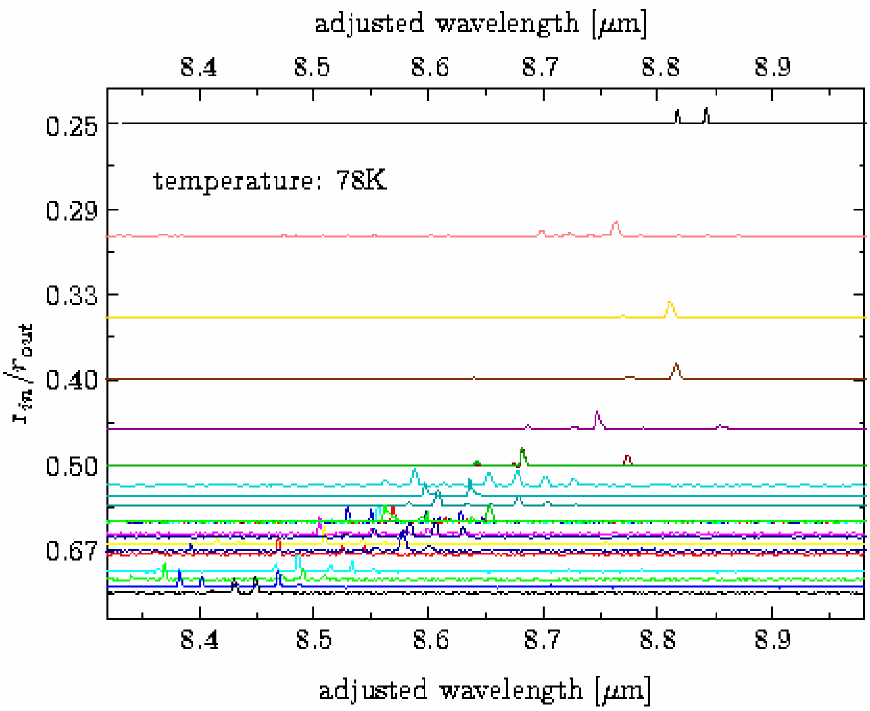

Fig. 1: The spectra begin to blue shift as the inner to outer diameter ratio exceeds the value of 0.4.

An important observation can be made by closely examining the emitted spectra. Since the emission wavelengths already shift with the change of the outer diameter at a constant ratio between inner and outer diameters, an adjustment of the emitted spectra is necessary to easily compare the different devices. Figure 1 shows these adjusted spectra. The spectra of the smallest devices (200 µm) were left unchanged, while the spectra of the larger devices (300 and 400 µm) were horizontally shifted by constant factors. The vertical position of the normalized spectrum is defined by the ratio of the inner to outer to diameters of the originating device. It can be seen that the emitted wavelength is constant up to a ratio of 0.4. Devices having a diameter ratio beyond this exhibit an increasing blue shift of the emitted wavelengths.

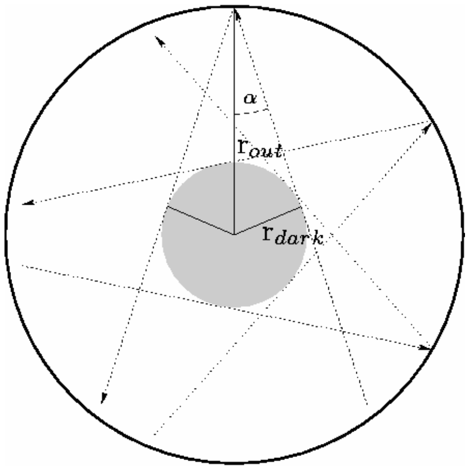

Fig. 2: The light reflected at the interface cannot enter the innermost region of the device.

A simple model based on ray optics can be used to explain this behavior. At the air-semiconductor interface total internal reflection occurs up to a certain critical angle. This critical angle depends on the refractive indices of the two adjoining media and in this case can be calculated at 18.4°. Light with a smaller angle of incidence than this critical angle is not reflected but will be refracted and leave the cavity. It thereby also limits the angle under which light is reflected back into the device. In this way it defines a central region that light, which is reflected at the border, cannot enter. This is shown in Fig. 2. The radius of the “dark zone” can be calculated as the sine of the angle of total internal reflection. As long as the inner diameter of a ring device is smaller than this “dark zone” the device’s operation remains undisturbed. As soon as the hole in the middle is bigger than the dark zone it pushes the light outward, resulting in the observed blue shift. The calculated value of inner to outer radius at which the spectra begin to shift is 0.32 and agrees reasonably well with the measured result. Simulations performed for ring shaped cavities [4] also agree with the assumption that the light field extends further into the central section of the device, than previously anticipated. This can be explained by the occurrence of higher order whispering gallery modes.

References

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