Tuning Quantum-Cascade Lasers by Postgrowth Rapid Thermal Processing

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We report on postgrowth heat treatment of quantum-cascade lasers. Intermixing of the atoms at the barrier-well interfaces in the temperature range between 850 and 875 °C shifts the energy levels and thus the gain of the structure. The achieved emission wavelength shift is from 10.3 to 11.9 µm.

The QCLs described here were grown by solid source molecular beam epitaxy on doped n^+ GaAs (100) substrates with a doping concentration of $n_{Si} = 2 \times 10^{18}$ cm^{-3}. $Al_{0.45}Ga_{0.55}As$ was used for the barriers and GaAs for the wells. We performed rapid thermal processing (RTP) on the structure shown in Fig. 1. The lasing is based on a bound-to-continuum transition similar to a sample described elsewhere [1]. The lasing transition takes place between levels 2 and 1. Temperature-induced diffusion of atoms grades the bandstructure. An effect similar to diffusion may be achieved by growing a digitally graded structure. Such a structure has been calculated with the aim of maximizing the gain. [2]

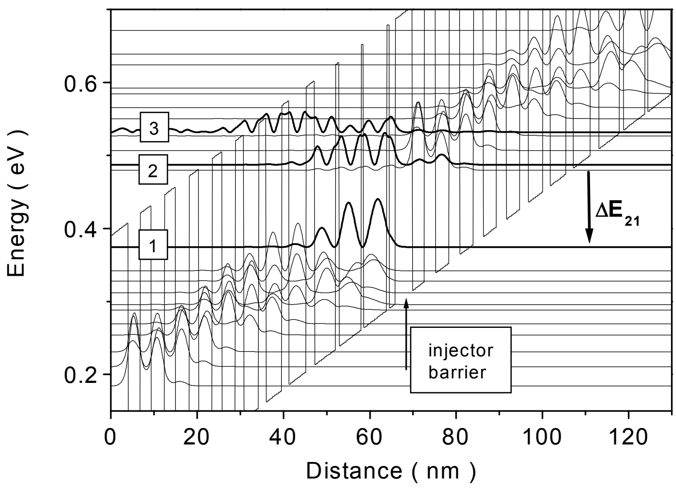

Fig. 1: Calculated conduction band structure of an active cell embedded between two injectors for an external field of 45 kV/cm at room temperature.

The heat treatment parameters were 60 s at 850, 860, 870 and 875 °C for four different pieces covered with SiO. After removing of the SiO with hydrofluoric acid, the samples were processed into ridge waveguides with as-cleaved facets. The length of the ridges was approximately 1.9 mm. Their widths were 20 and 10 µm. The QCLs were mounted into a cryostat cooled with liquid nitrogen. The lasing spectra were measured by driving the device with a pulse length and repetition rate of 100 ns and 5 kHz, respectively, at a current density just above the threshold. Spontaneous emission was measured with a pulse length and repetition rate of 300 ns and 67 kHz, respectively, at less than half of the threshold. The optical signals were detected by a mercury cadmium telluride detector. The spectra were obtained by a Fourier transform infrared spectrometer.

Figure 2 shows that both spontaneous and lasing emission shift to longer wavelengths as the RTP temperature is increased. Apparently, the intermixing of the interface atoms causes the bandstructure to round such that the energy level spacing is smaller, and hence the gain is shifted to lower energies. We may compare this to a result on MOVPE-grown QCLs. In contrast to MBE-grown samples, which have relatively abrupt interfaces, the interfaces of MOVPE-grown devices are always graded because of finite switching times. J. S. Roberts et al. [3] find that the emission wavelength of their MOVPE-grown QCLs is consistent with a grading of two monolayers at each interface.

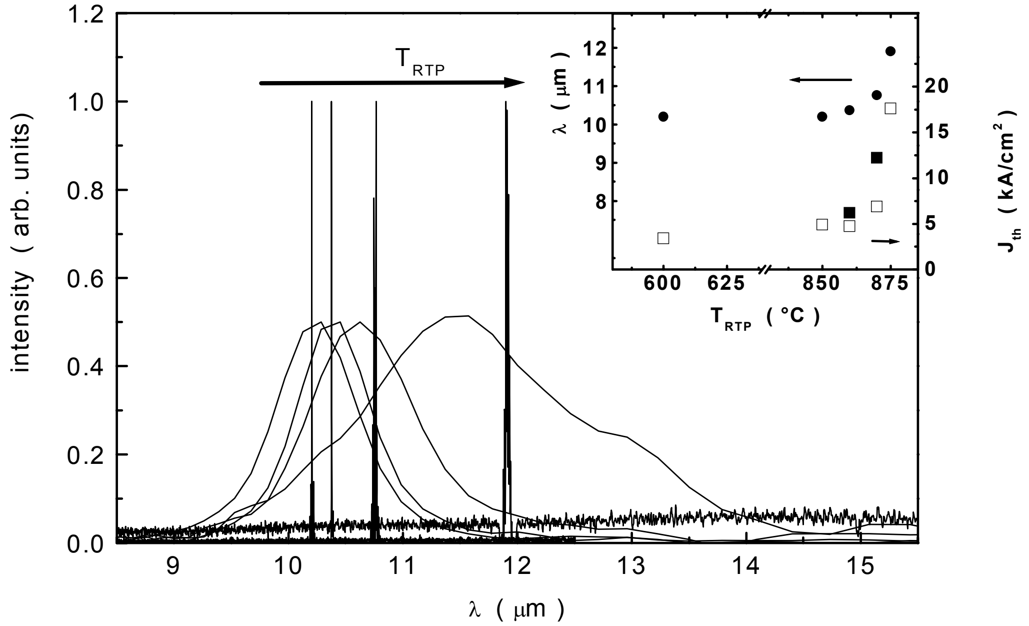

Fig. 2: Spontaneous emission (normalized to 0.5) and lasing (normalized to 1). Samples were heat treated for 1 min at 850, 860, 870 and 875 °C (from left to right). Inset, circles: Shift of the lasing signal with increasing RTP temperature. All data are from 20 μm wide ridges. Inset, squares: Shift of the threshold with increasing RTP temperature. Open symbols: laser width is 20 μm; closed symbols: 10 μm. In the inset, the data for the sample that was not heat treated are shown at 600 °C, which is a typical growth temperature for QCLs.

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References

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