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Tuning the radiation frequency of a mid-IR quantum cascade laser

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The Fourier-transform spectroscopy method was used to measure the emission spectra of a pulsed quantum cascade laser in the 4.5 μm range and to demonstrate the tuning of the emission wavelength from 4.56 μm (2233.9 cm^{-1}) to 4.48 μm (2192.5 cm^{-1}) in a wide temperature range from 293 to 10 K.

Keywords: quantum cascade laser, mid-IR range, Fourier-transform spectroscopy, frequency tuning.

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1. Introduction

Mid-infrared (IR) compact quantum-cascade lasers (QCL) operating in the 3−5 and 8−12 μm atmospheric transparency windows are needed for many applications. Radiation frequency tuning capability is one of the critical properties of such lasers. Operating temperature variation is an easily available method for QCL radiation frequency tuning. Study [1] investigated the 7.7 μm QCL radiation frequency tuning in a wide temperature range from room temperature to 10 K. This study investigates the mid-IR QCL radiation wavelength tuning with a temperature variation. Regardless of the 30 year history of mid-IR QCL, there is just scarce information in the literature regarding the temperature dependences of radiation frequency of such devices (see, for example, [2–6]), and for commercially available lasers, such dependences are provided for a limited temperature range (see, for example, [7]).

2. Experiment procedure

The study investigated a mid-IR QCL processed from an elastically balanced heterostructure with $In_{0.67}Ga_{0.33}As/In_{0.36}Al_{0.64}As$ quantum wells (QW) on the InP(001) substrate identical to that described in [8]. Width of the laser ridge was 20 μm, length was 3 mm. Laser mirrors were formed by cleavage. Crystal was mounted onto an F-mount heat sink with its epitaxial surface downward. All studies were performed in a 100 ns pulse mode, the measurement procedure was identical to that described in [1]. The maximum output power of the studied QCL was equal to $\sim$ 1 W.

3. Results and discussion

Figure 1 shows the dependence of the QCL threshold current on temperature. It is shown that the threshold current decreases by the a factor of 2.5 as the temperature decreases to 100 K, which is associated with a decrease in phonon scattering, and remains unchanged further on.

Figure 2 shows laser radiation spectra at 293−10 K measured by the Fourier spectroscopy method [1], and Figure 3 shows the dependence of the spectral position of lines on temperature. It is shown that, as the temperature decreases, the QCL radiation spectrum generally shifts to a short-wavelength region with a „gap“ at 200 K, where the generation is observed at two spaced-apart frequencies of 2203 and 2222 cm^{-1}. The magnitude of tuning from 293 K to 10 K exceeds 40 cm^{-1}. „Blue“ shift (frequency rise) of the QCL generation as the temperature decreases is a general property of instruments made on the basis of an InGaAs/InAlAs heteropair and employing spatially vertical (rather than diagonal between two different QW) transitions [9]. Such frequency tuning was observed in the operation of the 8 μm [1–3], 5.7 μm [7], 3.8 μm [6] and 3.4 μm [5] QCL. The most detailed studies were performed in [6], however, they were limited by the temperature range of 80−298 K. Transition frequency variation mechanism was not discussed. As in [1], we suppose that it is associated with the growth of barrier height as the temperature decreases. Accurate calculations are complicated due to

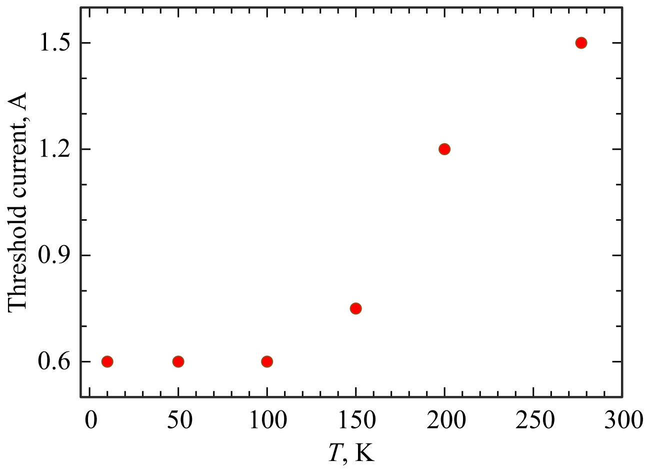

Figure 1. Dependence of the QCL threshold current on temperature.

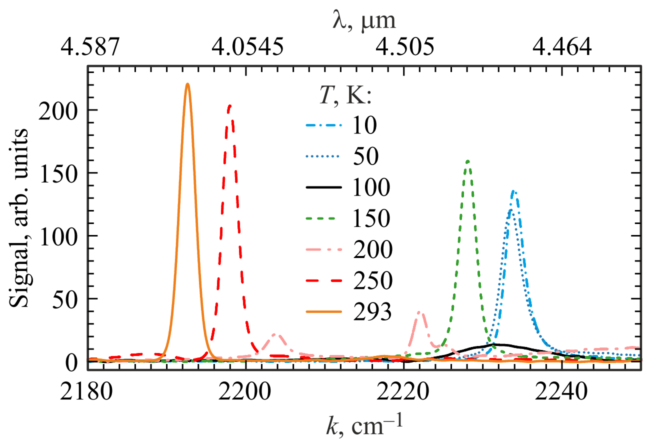

Figure 2. QCL radiation spectra at the pumping current of 2 A at various temperatures.

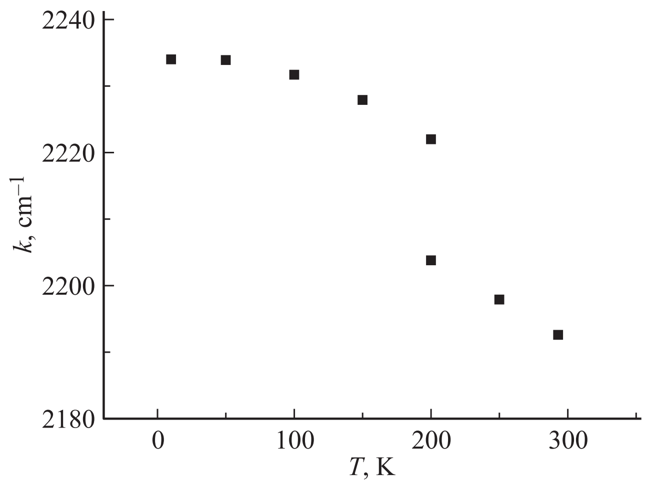

Figure 3. Dependence of the spectral position of QCL radiation line on temperature.

a large amount of multidirectional factors, in particular for strained and elastically balanced heterostructures. As for a QCL radiation frequency „jump" at $T = 200$ K, it is most likely associated with the proximity of the upper laser level in QW and a large amount of densely spaced levels in an injector superlattice (see Figure 1 in [8]), relative position of which obviously changes with temperature leading to two-frequency generation at some temperature.

4. Conclusion

Thus, the study demonstrates the capability of mid-range QCL radiation frequency tuning in the $3-5\,\mu$m atmospheric transparency window by $> 40\,\mathrm{cm}^{-1}$ due to the instrument's operating temperature variation from 293 K to 10 K.

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Conflict of interest

The authors declare that they have no conflict of interest.

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