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10-W 4.6-μm quantum cascade lasers

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Abstract. **Ridge quantum-cascade lasers emitting near 4.6 μm are fabricated and their power and spectral characteristics are studied. Stable pulsed lasing with an output optical power exceeding 10 W (more than 5 W from one facet) at room temperature is demonstrated.**

Keywords: *quantum-cascade laser, heterostructure, high power.*

Quantum-cascade lasers (QCLs) are the most compact and efficient sources of mid-IR (3–20 μm) radiation [1–4]. Modern systems of gas analysis and industrial monitoring and safety need radiation sources with wavelengths corresponding to the absorption lines of various materials in the mid-IR region [5, 6]. At present, extensive studies are performed on the development of various QCLs for the spectral region near 4.6 μm [6–11], which includes, in particular, intense absorption lines of carbon monoxide and silane. It was shown that high output optical powers can be obtained both in the geometry with one broad stripe [7] and based on arrays of optically coupled narrow-ridge lasers [8] using, in particular, Y-couplers [9]. Investigations were also performed on the influence of temperature effects [10] and charge carrier transport [11] on the characteristics of QCLs.

The QCL structures were grown by molecular-beam epitaxy (MBE) on InP substrates at the Connector Optics LLC in a Riber 49 productiion system. The active region of the QCL contained 30 quantum cascades consisting of alternating strained quantum wells and barriers $In_{0.669}Ga_{0.331}As$/$In_{0.362}Al_{0.638}As$. The structure is described in detail in [12].

The post-growth processing of the QCL heterostructure by photolithography and chemical etching was performed to obtain ridges with widths from 20 to 50 μm by etching deep (to the lower waveguide cladding) trenches. The next step was the deposition of a dielectric and formation of the lower and upper contacts by metallisation. The length of the studied QCLs was 2–5 mm. The plane-parallel mirrors of the lasers were formed by cleaving and were neither high-reflection nor antireflection coated. The QCL crystals were mounted on a copper heat sink with the epitaxial surface down.

The QCLs were studied in a pulsed regime. The pump pulse duration was ~75 ns at a duty cycle of 0.3%. Figure 1 presents a typical light–current curve of a QCL measured from one facet. The power characteristics were measured using a calibrated Thorlabs PM100 power meter with an S401C thermoelectric head. The threshold current densities of the studied QCLs ranged from 1.5 to 2.5 kA cm^{-2}. The maximum peak output optical power at room temperature exceeded 10 W (more than 5 W from one facet). The obtained threshold current densities and maximum output optical power testify to high gain characteristics of the active region and to the structural perfection of the QCL heterostructure [12].

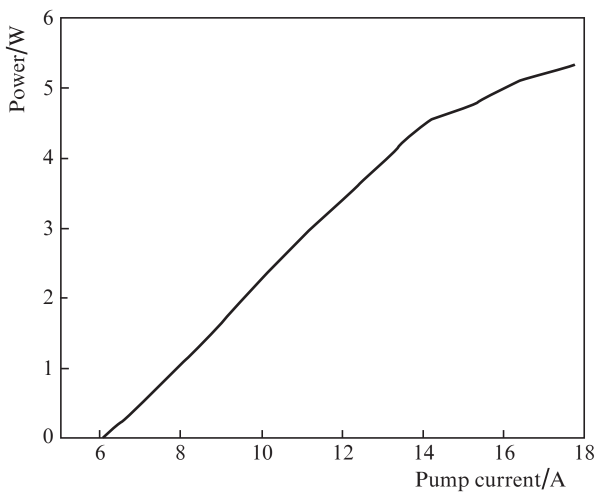

Figure 1. Typical light–current curve of a QCL with a ridge width of 50 μm and a cavity length of 5 mm at room temperature.

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The spectral characteristics of the lasers were measured using an MDR-23 monochromator with a 150-mm^{-1} diffraction grating. The spectra were recorded by a PVI-4TE-10.6 photodetector (Vigo Systems). The measurement method is described in more detail in [13, 14]. A typical spectrum of a QCL with a cavity length of 3 mm and a ridge width of 50 μm measured at room-temperature is shown in Fig. 2. The laser wavelength is close to the calculated maximum [12], and the spectral width exceeds 100 nm. The measured mode spacing of the QCL with a cavity length of 3 mm was 1.04 nm, which means that the effective refractive index of the QCL waveguide is 3.28.

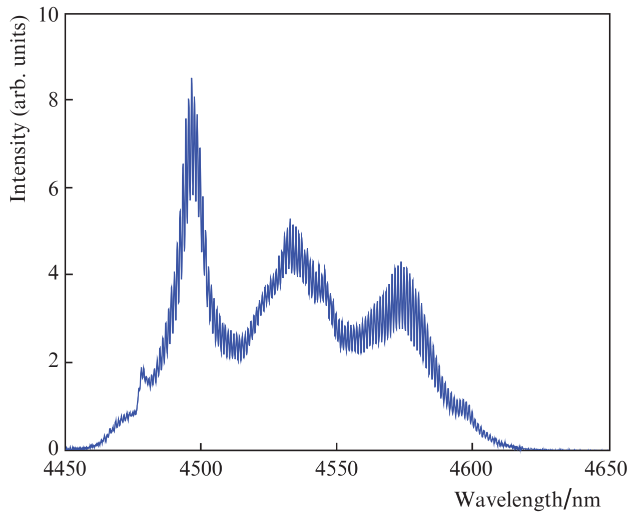

Figure 2. Typical spectrum of a QCL with a ridge width of 50 μm and a cavity length of 3 mm at room temperature.

Thus, we have presented the characteristics of QCLs emitting in the spectral region of 4.6 μm. The maximum output peak optical power of the laser at room-temperature exceeded 10 W (more the 5 W from one facet).

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