A 231 GHz Generation in High-Power Long-Wavelength Quantum Cascade laser Operating at Room Temperature

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Terahertz quantum cascade laser sources (THz nonlinear QCLs) based on nonlinear optical difference frequency generation (DFG) in the mid-infrared QCL are currently the only monolithic semiconductor laser sources that can operate at room temperature, covering the sub-THz to 6 THz range. Recently, the performance of THz nonlinear QCLs has been significantly improved by optimizing active regions and waveguide structures. Our group has demonstrated room-temperature operation at a frequency of ~0.42 THz by employing anti-crossed dual-upper-state (DAU) design in the active region of THz nonlinear QCL source to achieve a watt-class MIR pump power with long wavelength (λ~14 μm) [1].

In this paper, we report on the extension of the operating range on the low-frequency side down to <300 GHz in a terahertz nonlinear quantum cascade laser source adopting a long-wavelength and high-power DAU active region. All epilayers of the device were grown on semi-insulating InP substrates by metal-organic chemical vapor deposition (MOCVD). Figure 1 shows a schematic of the device structure. For the optical confinement of the mid-infrared pumps, dielectric waveguides were formed. Additionally, the front facet of the semi-insulating InP substrate was polished at an angle of about 10 degrees to extract the DFG emitted by the Cherenkov radiation. Two-section distributed feedback gratings (DFB) were set to produce the difference frequency ($\omega_{THz}=\omega_{DFB1}-\omega_{DFB2}$) of each pump light is 7.7 cm-1 (~231 GHz) and fabricated in the laser cavity. Figure 2 and its inset show the THz and MIR current-optical output characteristics and spectral measurements for a device with a ridge width of 14 μm and a cavity length of 3 mm during pulsed operation. THz spectra were measured by Fourier transform infrared (FTIR) using a Si bolometer as a detector. The THz spectrum of the device matched the difference frequency of the MIR spectrum, indicating single-mode operation at about 231 GHz. This is the lowest operating frequency for a semiconductor laser source operating at room temperature with current injection.

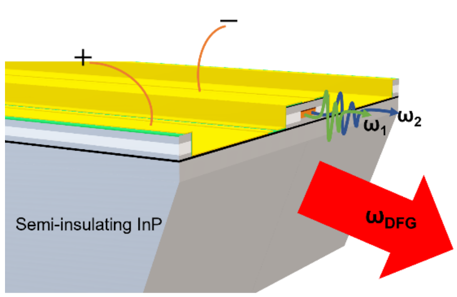

Figure 1 The schematic image of the nonlinear QCL source.

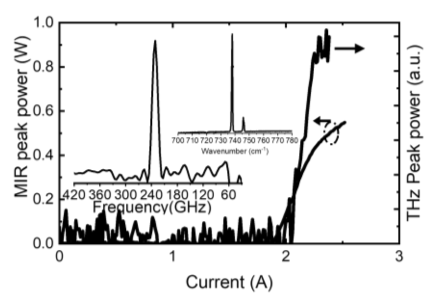

Figure 2 The current-voltage-light output characteristics of the device for THz and MIR peak power. The inset shows the MIR and THz emission spectra of the device.

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Supplementary Pages

Figure S1(a) displays the current-voltage-MIR output (I-V-L) characteristic of a 14 μm wide and 3 mm cavity length of the device without the grating operating in pulsed mode (pulse width 200 ns; duty cycle 1 %). The emission spectra at various currents are shown in Figure S1(b). This Febri-Perot device produces a threshold current density of 3.5 kA/cm^2 at 293 K and a maximum power of 1.1W (from a single facet) with a slope efficiency is 0.95 W/A, which is one of the highest peak powers in long wavelength (> 13 μm) QCLs reported to date.

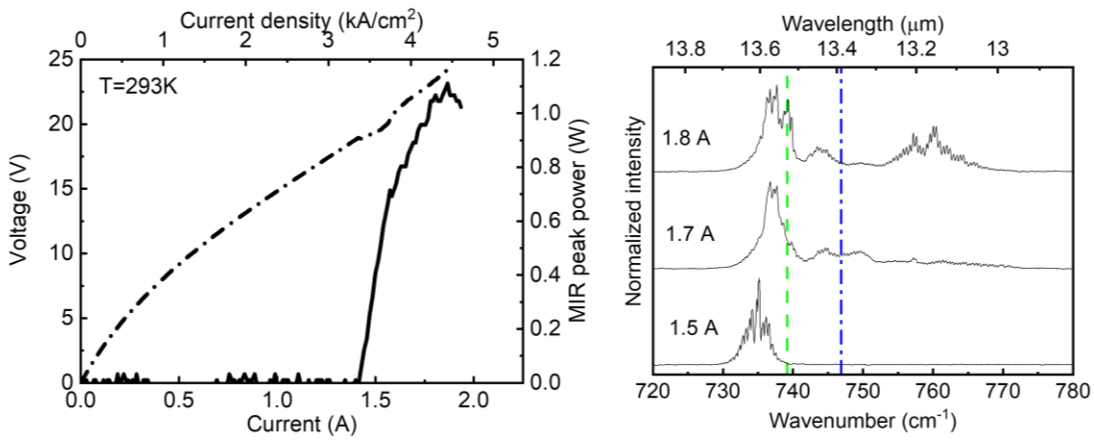

Figure S1 (a)The current-voltage-light output characteristics of the Fabre-Perot device for MIR peak power. (b) MIR emission spectra of the device