Free-space optical data link using Peltier-cooled quantum cascade laser

S. Blaser, D. Hofstetter, M. Beck and J. Faist

The authors demonstrate a free-space optical data link over 350 m using a Peltier-cooled 9.3 µm quantum cascade laser operating at a duty cycle of almost 50%. On the emitter side, a Ge lens was used for beam collimation and a flat mirror for beam steering, while on the receiver side, a fast room-temperature HgCdTe detector in combination with a ϕ = 16 cm mirror telescope detected the incoming signal. Short pulses at a maximum repetition rate of 330 MHz were successfully transmitted. The signal-to-noise ratio of the measurement was limited by the power equivalent noise of the detector.

Introduction: Mid-infrared quantum cascade (QC) lasers have undergone a remarkable development in recent years [1, 2]. Today's state-of-the-art devices can be operated at high duty cycles above room temperature [3]. While most potential applications lie in the field of optical spectroscopy [4], other interesting applications exist. These include, for example, free-space optical data transmission [5]. In contrast to fibre optical telecommunications, this technique has the advantage of not requiring additional cables to be buried in the ground. In urban areas where large amounts of fibre optical connections already exist, fast free-space optical data links could be particularly convenient. QC lasers are very suitable for such applications because their emission wavelength can be chosen in the so-called atmospheric window regions, i.e. around 5 and 10 µm. In addition, the fast internal lifetimes of the devices should allow for reasonable modulation frequencies of up to 5–10 GHz. Recently, Martini *et al*. published results of an optical data link using a high-speed modulated, liquid nitrogen-cooled QC laser over a distance of 70 m and under laboratory conditions [6]. They also succeeded in transmitting a video image via a common TV channel frequency. Since this experiment was carried out within a building, one of the main benefits of using QC lasers, namely having an emission wavelength which is barely affected by atmospheric conditions such as rain or fog, was not demonstrated. In addition, the use of liquid nitrogen-cooled equipment on both sides makes the technique somewhat less attractive for applications in the field. To take full advantage of our existing QC laser technology, we present in this Letter an optical data link between two different buildings separated by ~350 m and using a Peltier-cooled QC laser as well as a room-temperature HgCdTe detector.

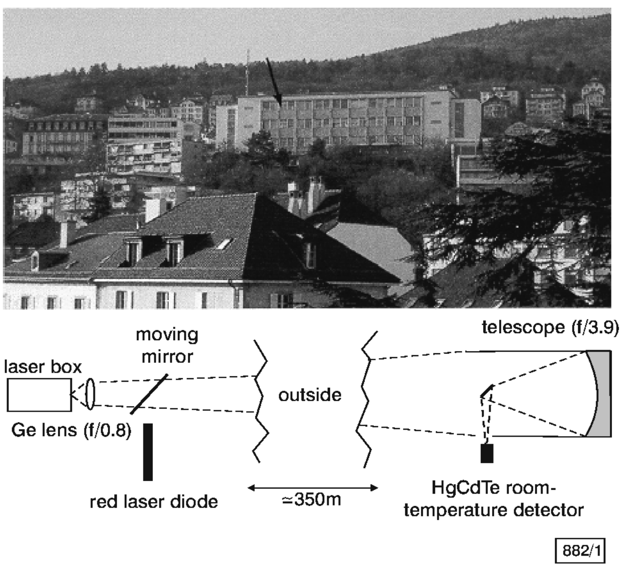

Fig. 1 *Photograph showing building with receiving electronics and systematic representation of optical data link using QC laser*

Experimental setup: On the emitter side, we used a 3 mm long 9.3 µm multimode QC laser mounted in a Peltier-cooled, temperature-stabilised aluminum box (Alpes Lasers SA) and an f/0.8 Ge lens 37.5 mm in diameter to collimate the laser beam. The device was maintained at a temperature of –15°C, operated at a duty cycle of almost 50%, and pulsed at different repetition frequencies. Using a bias-T, the laser was driven simultaneously at a constant current of 2 A (which corresponds to $0.72 \times I_{th}$) and a 10 W radio frequency signal of up to 350 MHz. On the receiver side, we employed a mirror telescope with a diameter of 16 cm and a focal distance of 62.5 cm, a fast room-temperature HgCdTe detector, and a 15 dB small-signal amplifier to detect the incoming signal. As schematically shown in Fig. 1, a 1 mW red semiconductor laser pointer was directed collinearly with the QC laser beam to facilitate alignment. The first stage involved aligning the two laser beams in the lab; then the two beams were bounced off a steering mirror and directed towards the other building, where the telescope was installed. The steering mirror could be tilted and rotated by manual micrometer screws. The angular accuracy of this kind of beam steering was about 3×10^{-5} rad. Taking into account the distance of the building with the telescope, this corresponded to roughly 1 cm.

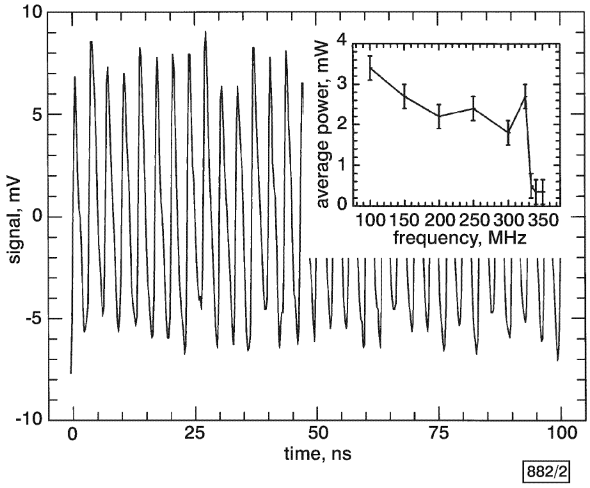

Fig. 2 *Stream of pulses after amplification at receiver at pulse repetition rate of 300 MHz and pulse duration of 1.5 ns*

Inset: Transmitted average against modulation frequency

Measurement results: At a temperature of 258 K and for a duty cycle of 50%, the threshold current of the QC laser used for the transmission experiment was 2.7 A (j_{th} = 3.0 kA/cm^2). For the maximum injection current of 3.2 A, we observed an average output power of 14 mW. When repeating the power measurement at the other end of the transmission line and at 300 MHz, we still obtained 1.9 mW average power for clear sky conditions; the measured peak power was thus of the order of 3.8 mW. In foggy conditions, the visibility range dropped to a value below 100 m. However, the average power signal decreased by barely 20%. Since the loss was thus of the order of 8 dB, these numbers show clearly the advantage of working at an emission wavelength in an atmospheric window region. As shown in Fig. 2, the typical transmitted signal consisted of a stream of almost sinusoidal pulses with a repetition frequency of up to 330 MHz and a pulse width of 1.5 ns. For 300 MHz, a noise level of roughly 0.25 mW (peak-to-peak value, before amplification) was observed; together with the transmitted peak power mentioned above, this corresponds to a signal-to-noise ratio of ~15. It should be noted, however, that the detector had a figure of merit of $D^* = 2.2 \times 10^7\sqrt{[\mathrm{cm^2 Hz}]}/\mathrm{W}$. From this value, we can calculate the noise equivalent power (NEP) using $D^* = \sqrt{[\Delta f \cdot A]}/NEP$. With $A = 0.625 \times 10^{-2}$ cm^2 being the detector area and Δf = 1 GHz the bandwidth of the detector system, we obtain an NEP (amplitude) value of 0.11 mW. The signal-to-noise ratio is therefore entirely limited by the detectivity of the detector.

In a second experiment, the result of which is shown in the inset in Fig. 2, we measured the transmitted average power as a function of the pulse repetition rate. It is clear from the Figure that the power has a resonance at 325 MHz, and then drops quickly to quite small values. A simple calculation shows that 325 MHz corresponds roughly to the electrical resonance frequency of the laser. The parasitic capacitance defined by the large contact pad area (3×0.5 mm) is ~150 pF; together with the resistance of the low-impedance line supplying the current to the laser (~4 Ω), we obtain an RC time constant of 600 ps. The maximum modulation frequency is thus ~250 MHz, in fair agreement with the experimental value.

In a different experimental configuration, we used the QC laser to optically transmit data between two computers. This data link was set up over a distance of 10 m between two optical tables and put together entirely within one laboratory building. On the emitter side, we used the serial port of a first PC and an RS232/TTL signal converter to produce a

TTL modulation signal at 115 kbit/s. This signal was used to electrically gate the continuous stream of laser pulses. At the receiver side, the signal was lowpass filtered, amplified and brought into rectangular shape again with a comparator. We then used a timer logic circuit triggered by the positive slopes of the single laser pulses to revert to the initial gate signal, and the final TTL/RS232 converter made the signal compatible with the serial port of a second computer. Using this technique, we were able to communicate optically between the two computers at the standard transmission speed of 9.6 kbit/s, and also at the highest possible speed of 115 kbit/s. When the laser power was decreased, the link still worked successfully down to a measured signal-to-noise ratio of 3.

Conclusions: We have demonstrated a free-space optical data link between two buildings separated by 350 m using a Peltier-cooled QC laser and a room-temperature HgCdTe detector. The shortest transmitted pulses measured 1.5 ns in duration and the highest transmitted modulation frequency was 330 MHz. A moderate signal loss of ~8 dB was seen for this distance. Under foggy conditions with a visibility range of below 100 m, the signal dropped to ~80% of its initial value, which proves that atmospheric transmission at a wavelength of 9.3 µm is not adversely affected by humidity. Using a similar setup, optical data transmission between two computers at a distance of 10 m and a data rate of 115 kbit/s was also achieved.

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S. Blaser, D. Hofstetter, M. Beck and J. Faist (*University of Neuchâtel, Institute of Physics, 1 A.-L. Breguet, CH-2000 Neuchâtel, Switzerland*)

E-mail: Daniel.Hofstetter@unine.ch

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