Multi-Gb/s free-space communication with energy-efficient room-temperature quantum cascade laser emitting at 8.1 μm

Olivier Spitz
LTCI Télécom Paris
Institut Polytechnique de Paris
19 place Marguerite Perey, Palaiseau, France
olivier.spitz@telecom-paris.fr

Ke Yang
Key Lab of Semiconductor Materials Science
Chinese Academy of Sciences
Beijing 100083, China
yangke17@semi.ac.cn

Alice Guillaume-Manca
LTCI Télécom Paris
Institut Polytechnique de Paris
19 place Marguerite Perey, Palaiseau, France
amanca@telecom-paris.fr

Pierre Didier
LTCI Télécom Paris
Institut Polytechnique de Paris
19 place Marguerite Perey, Palaiseau, France
pierre.didier@telecom-paris.fr

Junqi Liu
Key Lab of Semiconductor Materials Science
Chinese Academy of Sciences
Beijing 100083, China
jqliu@semi.ac.cn

Frédéric Grillot
LTCI Télécom Paris
Institut Polytechnique de Paris
19 place Marguerite Perey, Palaiseau, France
frederic.grillot@telecom-paris.fr

Abstract

We demonstrate a free-space transmission with a direct electrical modulation in a quantum cascade laser emitting in one of the transparency windows of the atmosphere, near 8.1 μm. The advantages of the presented work are a room-temperature setup, real-time high-speed operation and low-power consumption.

Index Terms

Quantum cascade laser, mid-infrared photonics, free-space communication

2021 IEEE Photonics Conference (IPC) | 978-1-6654-1601-6/21/$31.00 ©2021 IEEE | DOI: 10.1109/IPC48725.2021.9592899

I. Introduction

Room temperature communication with quantum cascade lasers (QCLs) has recently emerged as a challenger of choice in the race to new free-space data transmissions for next-generation networks such as 6G [1]. QCLs used to be sources requiring large electrical power but recent insights showed that efficient QCLs with less than 1 Watt of power consumption [2] are envisioned and this means that those mid-infrared lasers can now be implemented in compact and portable communication systems. So far, transmission rates up to 4 Gb/s were demonstrated for an emission wavelength of 4.6 μm [1]. However, these results were obtained with complex pre- and post-processing which hinder any real-time application. Another previous work showed a QCL transmission at 8.1 μm and 2.5 Gb/s with a subsequent direct video broadcasting [3], but this feat required both the QCL and the detector to be cooled down at cryogenic temperatures, which again hindered the large scale deployment of QCL-based communication systems. In our experimental effort, we demonstrate a 2.0 Gb/s communication with a room-temperature QCL requiring less than 2 Watts of electrical power. Furthermore, our result is obtained without any pre- or post-processing and a real-time error rate of less than 1×10^{-2} is derived. This result paves the way towards free-space communication in the long-wave infrared (LWIR) domain that is known for its high transparency and resistance to atmospheric perturbation [4], which overall make our solution very relevant in comparison with existing near-infrared systems very dependent on link availability [5].

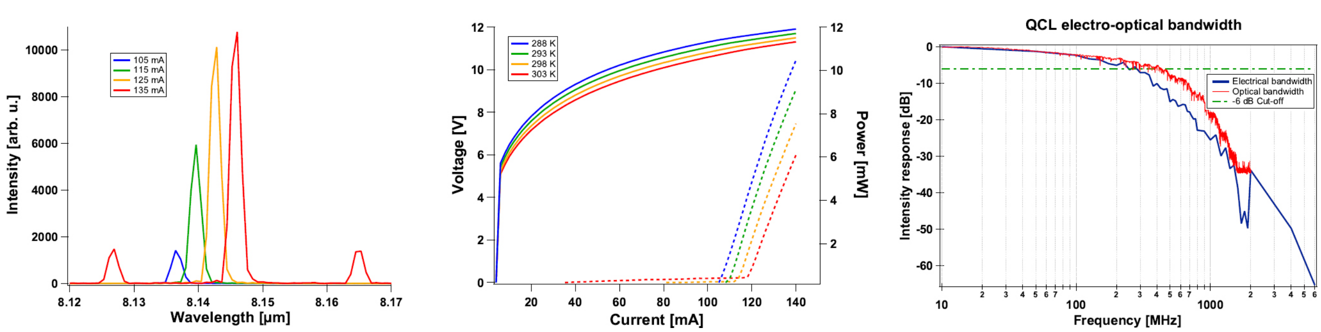

Fig. 1: Characteristics of the QCL under study. Left: optical spectrum for four bias currents at 288 K. Center: light-intensity-voltage (LIV) for various room-temperature conditions, the solid lines correspond to the voltage versus current while the dashed lines correspond to the optical power versus current. Right: modulation bandwidth of the QCL under study, the red curve corresponds to the optical rectification, the blue curve corresponds to the electrical rectification and the dash-dotted line represents the -6 dB cut-off.

II. QCL characterization

The QCL under study is a distributed feedback laser designed to emit single mode around 8.1 μm when pumped with a continuous bias. Figure 1 (left chart) depicts the QCL's optical spectrum retrieved with a Fourier Transform InfraRed (FTIR) spectrometer and shows that the laser is initially mono-mode and turns to multi-mode when the bias current excesses 135 mA. However for communication experiments,

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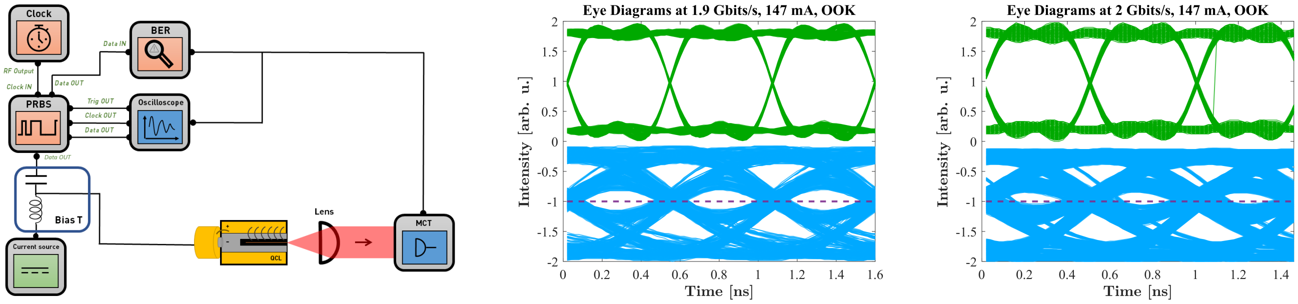

Fig. 2: Transmission experiment with energy-efficient QCL. Left: Experimental setup for the transmission of an electrical OOK signal with an optical LWIR channel and subsequent analysis of the quality of the communication. Center: eye diagrams of the transmission at 1.9 Gb/s, the green trace corresponds to the initial signal while the blue trace is the recovered signal after the MCT. Right: eye diagrams of the transmission at 2.0 Gb/s, the green trace corresponds to the initial signal while the blue trace is the recovered signal after the MCT. For both rates, the purple dashed line represents the decision threshold to access the error rate.

one has to focus on output power rather than mono-mode operation. Consequently, a bias current around 135 mA will be selected. Figure 1 (central chart) shows the LIV properties of the QCL and illustrates that even at 140 mA, the QCL under study requires less than 2 Watts of electrical power while emitting up to 10 mW of optical power. As we want to maximize this optical power, we carried out the experiments at 288 K. In order to determine the maximum transmission rate we can expect with this laser, we performed both an optical and an electrical rectification [6], as visualized in Fig. 1 (right chart). The optical and the electrical diagrams show a good agreement until 300 MHz, and the -6 dB cut-off is around 400 MHz in the QCL under study.

III. Experimental setup and results

The experimental setup is detailed in Fig. 2 (left chart). The on-off keying (OOK) signal is produced by a pulse pattern generator (Anritsu MP1763C) with pseudo-random binary sequences (PRBS) rates up 12.5 Gb/s and the sequence used is a 127-bit long (2^7-1). The data rate is set by the clock signal coming from a RF synthetizer (Marconi IFR 2032) able to output sine waves up to 5.4 GHz. The OOK electrical signal is sent towards the AC connector of a bias-tee and mixed with the DC bias generated by a low-noise current source (Wavelength Electronics QCL2000). The electrical signal received by the QCL is converted into a mid-infrared beam that is focused with a lens on the detector (Vigo UHSM-I-10.6) with 1 GHz bandwidth, which means that the transmission rate is limited by the aforementioned QCL's bandwidth. The electrical output of the Mercury-Cadmium-Telluride (MCT) detector is analyzed with a high-speed oscilloscope (Tektronix MSO72004C) with a maximum bandwidth of 20 GHz and a maximum sampling rate of 50 GS/s. In order to reduce high-frequency noise, the actual bandwidth of the oscilloscope is reduced to 3 GHz. The electrical output of the MCT is also compared with the initial OOK signal thanks to an error detector (Hewlett Packard 70004A). Figure 2 (central and right charts) show the resulting eye diagrams for a transmission rate of 1.9 Gb/s and 2.0 Gb/s, respectively. These two configurations correspond to a transition where the quality of the eye diagram of the transmitted signal start to degrade. Indeed, the error rate at 1.9 Gb/s is $2{\times}10^{-5}$ while the error rate at 2.0 Gb/s is $9{\times}10^{-3}$, but this value is low enough to achieve error-free transmission with forward-error correction (FEC) [7]. Further increase of the bit rate will further close the eye and lead to error rates above $2{\times}10^{-2}$ which cannot be corrected.

This work shows a 2.0 Gb/s transmission at room temperature with a QCL emitting near 8.1 μm and is very promising for future free-space communication links immune to degraded weather conditions. Further investigation will focus on real-time video broadcasting with serial digital interface (SDI) format that corresponds to a bit rate of 1.485 Gb/s for high-definition content. As we are still limited by the bandwidth of the laser, we will also study other structures [8] in order to improve the data rate and to widen the opportunities offered by our system.

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This work was supported by the National Natural Science Foundation of China under grant 61835011 and by the Key Program of the Chinese Academy of Sciences under grant XDB43000000, as well as by the Institut Mines Télécom through the DODECANESE project.