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Chaos synchronization in mid-infrared quantum cascade lasers for private free-space communication

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***Abstract*—We report on the first experimental chaos synchronization in mid-infrared quantum cascade lasers and subsequently perform private free-space transmission at a bit-rate of 0.5 Mbits/s. The quality of the privacy is assessed with eye diagrams, both at the legitimate receiver side and illegitimate receiver side.**

***Index Terms*—Quantum cascade laser, chaos synchronization, free-space communication, mid-infrared photonics**

I. Introduction

As soon as the 60ies [1], mid-infrared lasers draw attention for free-space communication because of the reduced attenuation, scintillation and scattering in the long-wave domain. The CO_2 lasers were replaced by intersubband technology in the late 90ies [2] but the development of free-space solutions, either with CO_2 lasers or with quantum cascade lasers (QCLs), was hindered because of complex implementation and limited capabilities for these two optical sources. Recently, there has been a renewed interest for free-space transmission with QCLs due to the rapid evolution of essential building blocks, such as high-speed modulators [3] and room-temperature detectors [4]. In parallel, methods were developed to increase the privacy of fibered transmissions that nowadays span the globe. One of them relies on the temporal chaos that can be generated in semiconductor lasers under external optical feedback. In such configuration, the message to be transmitted is concealed within the chaotic output of a master laser, then recovered after long-haul transmission thanks to a slave laser [5]. The latter synchronizes with the chaos of the master laser but only if they share the same characteristics. The privacy is thus dependant on the physical parameters of the optical source.

We combine the advantages of mid-infrared wavelength with the non-linear dynamics of QCLs under feedback [6] to achieve the first ever private free-space communication based on QCL's chaos synchronization with mid-infrared semiconductor lasers. The privacy of the communication is evaluated with eye diagrams and shows that, even with extensive filtering, an eavesdropper (Eve) has no chance to decipher the hidden message. On the legitimate receiver side, the error rate is compatible with the latest achievements in terms of forward error correction (FEC) [7].

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II. Experiment

The setup, described in Fig. 1, that we used for the synchronization of chaos is composed of a distributed feedback (DFB) master laser driven chaotic by external optical feedback (produced by a mirror) and a DFB slave laser. The message to be transmitted is injected in the bias current of the master laser and subsequently conforms the chaotic wave generated by the master QCL. One of the key condition is that the message has a very small amplitude compared to the subsequent optical

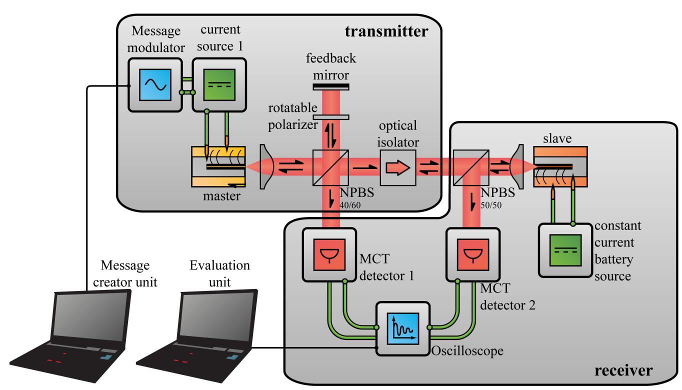

Fig. 1. Setup for chaotic secure communications with QCLs. The apparatus is split into two parts: one (with the master QCL) is dedicated to chaos masking and transmission whereas the other (with the slave QCL) is dedicated to synchronization and recovery. NPBS: non-polarizing beam-splitter, MCT: Mercury-Cadmium-Telluride.

chaos, so that it remains unnoticed for a potential eavesdropper. The output of the master is sent towards the slave laser through an optical isolator to avoid back-reflections, and the signal of the master and the slave are detected with a Mercury-Cadmium-Telluride (MCT) detector. The signal from the MCT detectors are analyzed with a fast oscilloscope.

III. Results and discussions

Figure 2 shows the temporal waveforms that are obtained from the MCT detectors after filtering, for the master's output (red) and the slave's output (blue). The latter reproduces the chaotic part of the master, and this is called chaos synchronization, but does not reproduce the concealed message. Consequently, the small message can be deduced by substracting the master's signal with the slave's signal and can be compared with the initial message. This corresponds to the purple signal and the orange signal in Fig. 2, respectively. The orange signal shows a return-to-zero (RZ) format, which is commonly used in private transmission schemes because it eases the recovery process [5]. The purple dash-dotted line represents the decision threshold to determine if a difference bit must be considered as '0' or '1'. A comparison with the orange signal shows that the sixteen '0' are all correctly recovered, while among the nine '1', there is a single mistake (third '1' from the left).

Eye diagrams for each of the previous filtered timetraces are depicted in Fig. 3. The eye is a superposition diagram over one-bit period to assess the quality of the transmission [5]. On the one hand, the eye diagram corresponding to the master signal (red) is blurred because the large-amplitude chaos conceals the small amplitude message, that cannot be recovered. The same conclusion is true for the slave signal (blue) because it is a copy of the master chaos. On the other hand, the eye diagram of the initial message (orange)

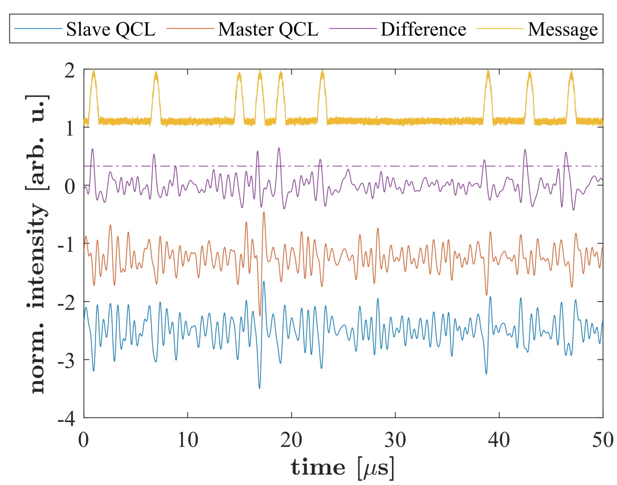

Fig. 2. Recovery process to decode the enciphered message. The blue curve is the filtered intensity of the slave QCL. The red curve is the filtered intensity of the master QCL. The violet curve represents the subtraction between the red curve and the blue curve and the dash-dotted line corresponds to the threshold used to detect a '1'-bit. The orange curve is the magnified initial message, subsequently hidden within the red curve.

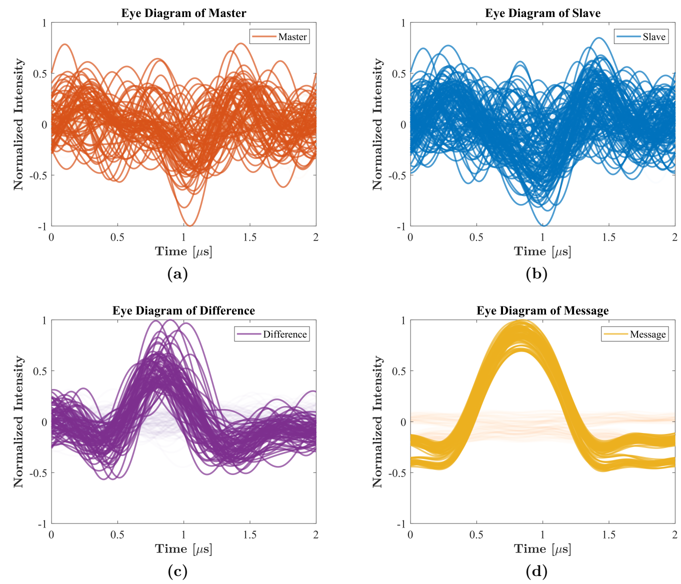

Fig. 3. Experimental eye diagrams for the 4 components of the previous figure. From these diagrams, one can see that it is impossible to recover the message only from the signal of the master QCL but it becomes possible for most of the bits from the difference signal. Bits deciphered as '0' are drawn with a light color while bits deciphered as '1' are drawn with a stressed color.

clearly shows the RZ structure of the signal, which is also recovered, though not perfectly, with the difference timetrace (purple). Eye diagram is a convenient tool to see that, even with appropriate filtering, Eve cannot retrieve any valuable information from the master's travelling wave. This figure also gives the data rate of the private transmission, which is 0.5 Mbits/s because the eye has a total length of 2 μs.

To summarize, we have experimentally demonstrated the first ever mid-infrared free-space communication based on QCL's chaos synchronization. The process allows recovering a hidden message at a transmission rate of 0.5 Mbits/s with a few percent error that could be corrected with regular FEC. Besides, Eve is left with no mean to decipher the message and the privacy of the transmission is ensured.

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