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High speed mid-infrared Stark modulator for optical data transmission up to 10 Gbit.s^{-1}

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Abstract: Using the Stark effect in coupled InGas/AlInAs quantum wells, we demonstrate a mid-infrared broadband optoelectronic external modulator enabling 10 Gbit/s free space optical data-transmission in the second atmospheric window (9 µm) at room temperature. © 2022 The Author(s)

1. Introduction

Highly sensitive and ultrafast mid-infrared optoelectronic systems are required for free-space communications [1], light detection and ranging (LIDAR), high resolution spectroscopy and in observational astronomy.

In this work we present a high-speed room temperature InP-based external modulator at 9 µm [2]. The modulator is based on a system of *n*-doped asymmetric coupled GaInAs/AlInAs quantum wells grown by MOCVD on an InP substrate. When applying a bias on the device, the transition energy between states 1 and 2 (see left panel on Fig. 1) is submitted to a linear Stark shift. The transition energy can thus be put in and out of resonance with respect to a fixed laser frequency [3] (see left panel of Fig. 1). The absorption can be tuned over more than 40 meV with fields < 60kV/cm, allowing to switch between a transparent and an absorptive configuration (see right panel of Fig. 1) with a highly linear behaviour. This operation does not change the position of the charges in the system but only the absorption energy. The device is therefore characterized by an intrinsically large bandwidth and low electrical power consumption (~ few mW) with respect to direct laser modulation. In order to take advantage of this intrinsically ultrafast modulator, special care was taken to process this quantum structure into a RF-compatible device able to operate up to several GHz.

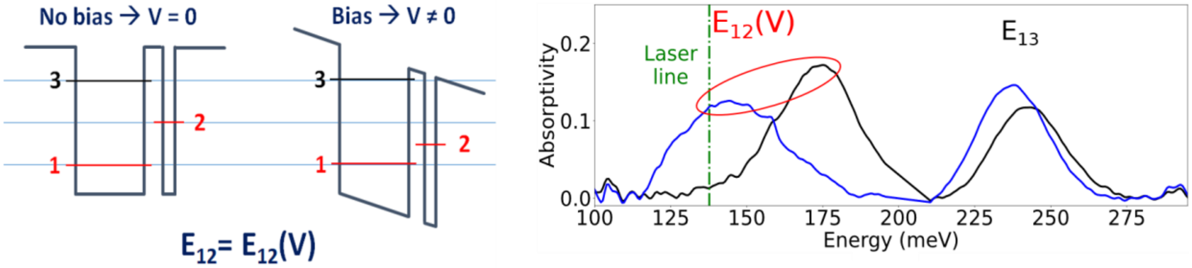


Fig. 1: Left: Conduction band sketch of the Stark-shift modulator, tunable with an external electric field. Right: Absorption spectra under bias at room temperature. The blue spectrum, with +4V positive bias, is resonant with the laser emission line while the black spectrum (-4V) showcases the transparent configuration under negative bias.

2. Experimental setup and results

In order to operate at high frequency, the detector and the modulator have been processed into mesa structures that are electrically connected to a 50 Ω coplanar waveguide through an air-bridge for a low-inductance top contact [2]. This is shown in the scanning electron microscope (SEM) image in Fig. 2(b). The device is then fixed on a custom-made holder and wire bonded onto an adapted PCB coplanar waveguide. Finally, in order to comply with the intersubband polarization selection rule and allow the device to operate in transmission, two symmetrical 60° facets were mechanically polished in the InP substrate (Fig 2(c)). The mounted modulator was then optically characterized using a commercial cw distributed feedback Quantum Cascade Laser (QCL) and a homemade Quantum Cascade Detector (QCD), as sketched in the set-up presented in Fig.2(a). We measured 47% modulation depth for our modulator, and electrical bandwidths of up to tens of GHz, depending on the size of the mesa.

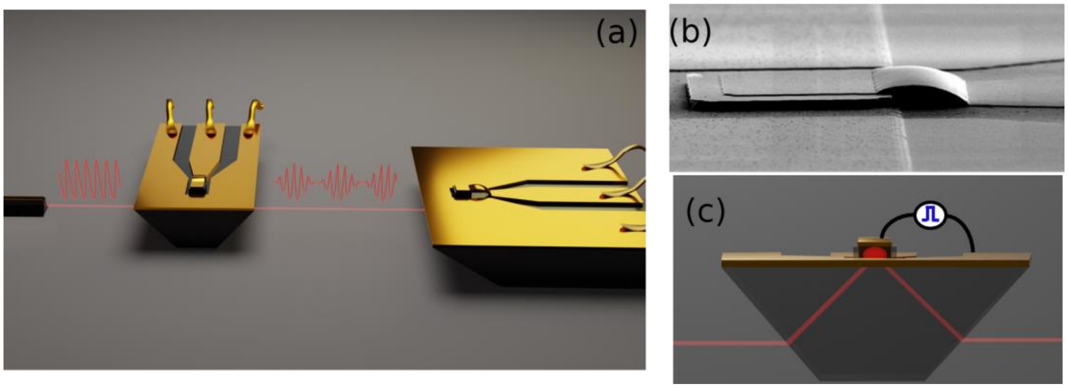
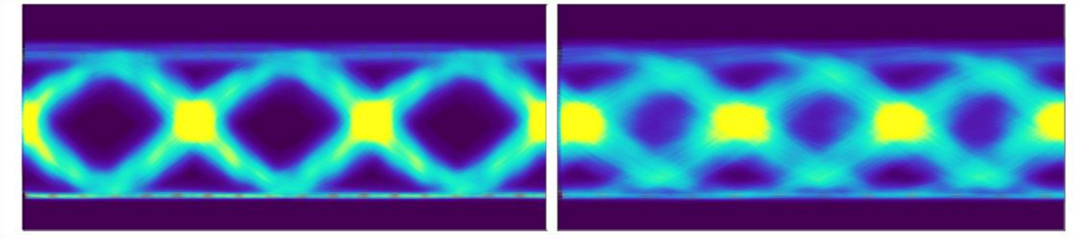


Fig. 2. (a) Sketch of our experiment comprising QC laser, Stark modulator and QC detector, all of them operating at room temperature and at the same wavelength, 9µm (138 meV). The laser is a commercial cw DFB QC laser (Thorlabs). The modulator and the detector have been designed, fabricated and mounted to operate at high frequency. (b) SEM image of the modulator connected via an air-bridge to the coplanar waveguide. (c) Sketch of the light coupling geometry of the Stark modulator, in order to comply with the polarization selection rule.

The same setup was used to showcase its capability as a FSO (Free Space Optics) link. We used an Arbitrary Waveform Generator as an input on the modulator and a simple On/Off Keying (OOK) scheme. Eye-diagrams and Bit Error Rate (BER) were measured for each frequency. Examples of such diagrams are displayed in Fig. 3. At 11 Gbit.s^{-1}, the BER eventually becomes greater than 4.10^{-3}, the criteria for an error free transmission assuming HC error correction codes [1].



7 Gbit.s^{-1} (OOK) 11 Gbit.s^{-1} (OOK)

Fig. 3: Eye diagram measured at 7 Gbit·s-1 and at 11 Gbit·s-1 without any equalization. On the left, no error were found. On the right the BER is just about 10^{-2}

3. Conclusion

We report here the fastest to date FSO link in the mid-infrared -here in the second atmospheric window-, enabled by a properly packaged external Stark shift high speed modulator. The limit in modulation speed appears to be eventually limited by the packaging of the device and not to the underlying physics, showing great potential of this concept for high bitrate data transmission. It also suggests room for further improvement with more advantageous geometries such as Patch Antenna Resonators [5].

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