Optics in 2022

High-Speed Stark-Effect Modulators for Mid-Infrared Communications

RESEARCHERS

Hamza Dely, **Thomas Bonazzi**, **Etienne Rodriguez**, **Djamal Gacemi**, **Angela Vasanelli** and **Carlo Sirtori** (carlo.sirtori@ens.fr), Ecole Normale Supérieure, Université PSL, CNRS, Sorbonne Université, Université Paris Cité, Paris, France

Pierre Didier, **Olivier Spitz** and **Frédéric Grillot** (frederic.grillot@telecom-paris.fr), LTCI, Télécom Paris, Institut Polytechnique de Paris, Palaiseau, France

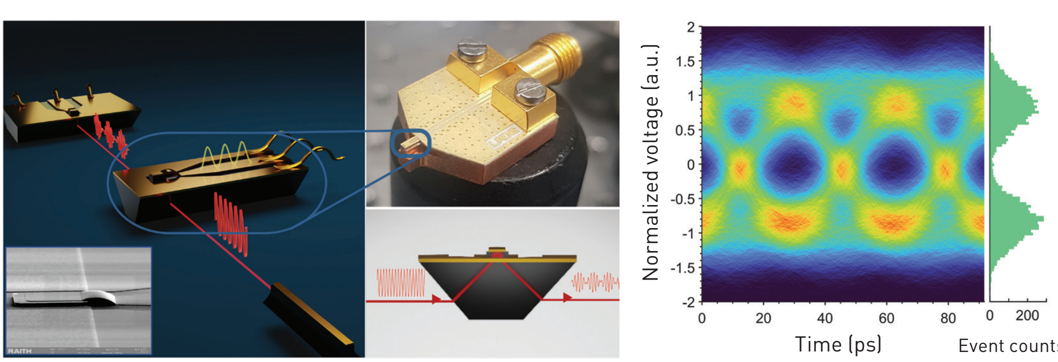
High-power quantum cascade lasers and detectors with large responsivity are now mature semiconductor devices operating in the mid-infrared range (4 µm < λ < 14 µm) at room temperature. These unipolar quantum optoelectronic devices are of paramount interest for implementing high-speed free-space communication systems.[1] Yet fast modulation of light in this wavelength domain remains a critical bottleneck, hindering large deployment of telecom systems at wavelengths longer than 1.55 µm. In our work this year, we demonstrated a potential resolution to this bottleneck—a Stark-effect modulator operating at room temperature at 9 µm that, on a 31-m free-space link, reached a transfer speed of 30 Gbits/s.

One promising solution that has been proposed for extending the telecom wavelength range is based on frequency up- and down-conversion between telecom wavelengths and the chosen mid-infrared wavelength. In such a case, the signal is modulated and detected at 1.55 µm, while the transmission occurs in the mid-infrared. However, at the emitter side, this technique requires multiwatt near-infrared pump lasers to generate a mid-infrared beam of a few mW and is consequently bulky and inefficient.[2]

Another proposed option is to take advantage of the ultrashort photocarrier lifetime of graphene to perform all-optical modulation with a subwavelength-thick graphene–metal hybrid metasurface. Even if the response time with this type of 2D material is predicted in the picosecond range, state-of-the-art experiments are restricted to sub-GHz demonstrations so far.[3] Furthermore, these two methods have not yet been able to reach the 8-to-12-µm wavelength range, which is the most relevant spectral domain for free-space applications due to the combination of low atmospheric attenuation, low scattering and background stealth.

Based on recent progress in the concept of unipolar quantum optoelectronics, we developed external Stark-effect modulators operating at 9-µm wavelength.[4] These modulators combine a multi-GHz bandwidth with a large modulation depth, and are thus compatible with high-speed communications in the mid-infrared. By using unipolar devices, we have realized a system made of a single-mode quantum cascade laser, the aforementioned Stark-effect modulator and a fast quantum-well infrared photodetector, and demonstrated an unprecedented indoor free-space communication at 30 Gbits/s over a distance of 31 m.[5]

This breakthrough, in our view, provides a path toward a new paradigm in high-speed atmospheric data-transmission at mid-infrared wavelengths. It could also lead to transformative advantages in lidar, precision remote-sensing and ultrafast molecular spectroscopy, as many molecular fingerprints are in the mid-infrared domain. OPN



Left and top center: Unipolar quantum-device communication system in which light is emitted by a quantum cascade laser (bottom right corner of left-hand image), then modulated with a high-speed Stark modulator (center of left-hand image and inset in bottom left corner) and finally detected by a quantum-well infrared photodetector (top left corner of left-hand image). Bottom center: Cross-section of modulator operation. Right: Eye diagram and histogram showing the quality of 31-m on-off-keying transmission at a data rate of 30 Gbits/s.

REFERENCES

1. L. Flannigan et al. J. Opt. **24**, 043003 (2022).
2. Q. Hao et al. Appl. Opt. **56**, 2260 (2017).
3. A. Basiri et al. Light Sci. Appl. **11**, 102 (2022).
4. H. Dely et al. Laser Photon. Rev. **16**, 2100414 (2022).
5. P. Didier et al. CLEO: Science and Innovations, JTh6A.5, postdeadline paper (2022).