WIDE-BAND MID-INFRARED QUANTUM DEVICES BASED ON INTERSUBBAND TRANSITIONS

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Abstract

The infrared region is the cradle of many vital applications in spectroscopy, medicine and communication. In the Mid-Infrared (MIR) region, innovations and significant improvements of the existing technologies call for advanced technologies such as frequency comb laser and high-speed photodetectors with high photoresponse at room temperature. Conventional systems are facing significant challenges due to their intrinsic high-speed limitations and the complexity to reach this domain. The development of quantum devices based on Intersubband Transitions (ISBT) has revealed significant advantages in the MIR reviving intense research in these fields. They allow excellent efficiency in the MIR region, and due to their intersubband transitions based on quantum well, they permit an easy tunability of the operation wavelength. In comparison to conventional devices, ISBT exhibits a very short carrier lifetime which makes them suitable for high-speed applications.

The objective of this thesis is to develop and study the high-speed behaviour of quantum devices based on intersubband transitions for emission and detection of coherent light in the MIR region. Additionally, thanks to their wide-band properties, passive and active mode-locking Quantum Cascade Laser (QCL) will be investigated as well.

In this thesis, we first present an overview of standard characterisations of QCL devices and then investigate their high-speed behaviour using rectification methods. High-speed photodetectors are also developed in this project. We study the comb formation in QCLs owing to the coexistence of low-dispersion region and non-linear effects favouring the comb formation. The low-dispersive area in simulations is in good agreement with experimental data showing a constant Free-Spectral Range (FSR) over this region. Moreover, the detection of a small beatnote at the round-trip of the cavity is a clear evidence of passive mode-locking of a part of the spectrum. Next, we investigate the evolution of the spectra using active mode-locked

methods based on Radio-Frequency (RF) injections at the round trip of the cavity. Furthermore, high-resolution spectra recorded under RF injection provide interesting information regarding the dispersion and the variation of the FSR.

Secondly, we developed a Quantum Well Infrared Photodetector (QWIP) based on air-bridge contacts to promote the high-speed modulation. Optical characterisation of the devices has been realised to deeply understand the dependence of the responsivity and photoconductive gain with the temperature and high electric field. Finally, we tested its wide-band operation by detecting the high-frequency modulation of the QCLs previously characterised. The development of both high-speed emitter and receiver at the same wavelength allow a powerful pair for many applications in the MIR region.