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Ultrafast terahertz detectors based on 3D meta-atoms

B. Paulillo[1], S. Pirotta[1], H. Nong[2], P.Crozat[1], S. Guilet[1], G. Xu[1,3], L. Li[4], E.H. Linfield[4], G.A. Davies[4], S. Dhillon[2] and R. Colombelli[1]

[1]*Centre for Nanoscience and Nanotechnology (C2N Orsay), CNRS, Univ. Paris Sud, 91405 Orsay, France*

[2]*Laboratoire Pierre Aigrain, Ecole Normale Supérieure, UMR 8551 CNRS, Paris, France*

[3]*Key Laboratory of Infrared Imaging Materials and Detectors, Shanghai Institute of Technical Physics, Chinese Academy of Sciences, Shanghai 200083, China*

[4]*School of Electronic and Electrical Engineering, University of Leeds Leeds, United Kingdom*

Terahertz (THz) and sub-THz frequency emitter-detector technology is receiving increasing attention because of key applications in several fields. In particular, ultrafast THz receivers are desired for compact, ultrafast spectroscopy and communication systems. While most of the available THz detectors (thermal, FET …) are currently limited in response time by slow thermal processes and/or by the read-out electronics, quantum well infrared photodetectors (QWIP) are excellent candidates given their intrinsic ps-range response [1]. The key to true ultrafast response is an aggressive reduction in device size, well below the typical diffraction-limited optical cavities [2].

In this contribution, we demonstrate ultrafast sub-wavelength (λ/10) THz QWIP detectors based on a 3D split-ring geometry recently developed in our team [3]. The key idea is to exploit a miniaturized loop RF antenna as a coupler element to efficiently feed THz radiation (λ=100-200 µm) into an ultra-sub-wavelength (λ/25) QWIP active core (active volume ~20 μm^3, as depicted in Fig. 1(a). The LC resonance of the device has been set by carefully selecting both the capacitor and inductor sizes in order to match the GaAs/AlGaAs QWIP response band (detection peak at ~3 THz) [4].

Several arrays and even single "meta-atom" detectors equipped with individual electrical contacts have been implemented and fully characterized optically and electrically. Photocurrent spectra show a clear response around 3 THz at 4.5 K, as reported in Figure 1(b). The measured dark currents are very low due to the sub-wavelength active volume: less than 2 nA and 20 nA for single device and array configuration, respectively, for the typical operational bias. The background-limited infrared performance temperature (T_{blip}) is ≈8 K for both configurations, similarly to what is found when the same material is processed in a standard mesa geometry.

We have explored the operational electrical bandwidth of these devices: the effect of the extremely small size on the device speed is dramatic. Experimentally measured electrical S-parameters place the cut-off frequency - for both single object and array configurations – at above 20 GHz. In order to perform a direct optical response analysis, we have illuminated the detector with a 3 THz QCL, operating in continuous wave, that was intensity-modulated using an RF synthesizer. The output of the detector was amplified and fed to a spectrum analyzer. Figure 1(c) shows the spectrum obtained when the QCL is modulated at 1.5 GHz (solid red line) while the solid blue line is the noise reference with the QCL operated under threshold. Our latest results, which will be thoroughly discussed during the talk, prove a clear optical response up to 2.5 GHz for the array geometry, currently limited only by the experimental setup (current laser modulation speed).

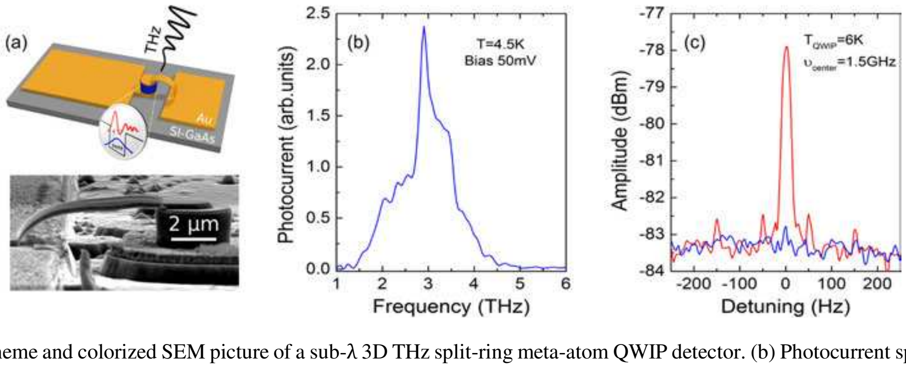

Fig. 1 (a) Scheme and colorized SEM picture of a sub-λ 3D THz split-ring meta-atom QWIP detector. (b) Photocurrent spectrum for a meta-atom array with 50 mV applied bias. (c) RF spectrum from a meta-atom array when a 1.5-GHz-modulated THz QCL is focused on it (solid red line). The blue solid line is the noise reference when the QCL is under threshold (DC+RF).

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