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High sensitivity 9µm metamaterial Infrared QC detectors at 300K

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***Abstract*—Quantum Cascade Detectors are promising devices for high-temperature mid-infrared detection. The responsivity, related to its photovoltaic working principle, still suffers from lower responsivity respect to a photoconductive device such as QWIP. Here, we demonstrate that inserting a QCD detector in a photonic metamaterial made of patch-antenna microcavities, we can boost light-matter interaction reaching responsivity value in the order of 50mA/W at room temperature, the highest value reported in the literature**

I. INTRODUCTION

We have recently investigated a new photonic concept for mid-infrared and THz quantum well photodetectors [1] [2]. The resulting structure is a metamaterial that has several advantages over the present detector technologies and will have an impact on the future realization of fast, high sensitivity and room temperature operating thermal sensors.

Our metamaterial is an array of double metal resonator where the top contact of each individual element acts as an antenna that gather photons on a collection area, A_{coll}, much bigger than the electrical area of the detector. As the photocurrent is proportional to A_{coll}, while the dark current is proportional to the electrical area, we can substantially increase the signal to noise ratio of the device. Using these metamaterials in conjunction with Quantum Well Infrared Photodetectors (QWIPs) we have achieved high responsivities, (~1A/W at 78K), ultra-fast response and have increased their operation up to room temperature [1].

In this work, we present a new generation of antenna coupled devices based on quantum cascade detectors. The use of a photovoltaic structure has some net advantage, particularly for the performances at high temperature of operation. Quantum cascade detectors have been demonstrated in the 3-5µm range with performances higher than QWIP devices and operating up to room temperature [3]. At 8-9 µm a detector with a diagonal transition design has shown a peak responsivity of 16.9 mA/W [4]. The photoconductive operation and the high temperature performances make QCD devices very competitive in the field of mid-infrared detection.

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II. RESULTS

The device used in this study is a GaAs/AlGaAs QCD containing Nqw = 5 quantum wells absorbing at a wavelength of 8.9 µm at room temperature (140 meV) for a total of 8 periods. The first QW of each period is Si-doped $n_{3D} = 5.0 \times 10^{11}$ cm^{-2}. The structure has been designed to fit in an array of double-metal patch resonators, which provide sub-wavelength electric field confinement and act as antennas. In particular, the doping density has been chosen to limit the thermally activated dark current at 300K. The resonant wavelength is defined by the lateral patch size s according to $\lambda = 2sn_{eff}$, where $n_{eff} = 3.3$ is the effective index [2]. In our case it occurs for structures with s = 1.4 µm.

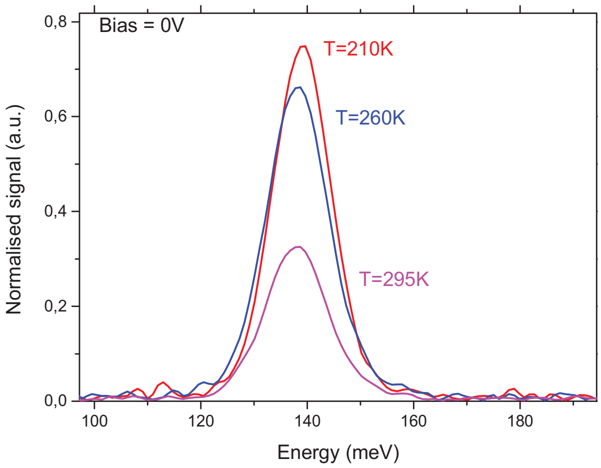

Figure 1 Photocurrent spectra at 210K, 260K, 295K.

Photocurrent spectra are shown in figure 1. Spectra are taken at 0 bias and for temperatures of 210K, 260K and 295K. We can notice that the signal degrades only of a factor 2, as we expect for a photovoltaic structure having a reduced dark current noise. An improvement of 1.5 respect to the bare active region is found for low temperatures. At high temperatures, the effect of the metamaterial is even more impressive: thanks to an improved light-matter interaction, the peak responsivity stays constant at a value of 50 mA/W up to 295K, that is a factor of 2-3 greater than the state of the art for this wavelength [4]. These results let dream of a high temperature detector technology operating in a thermoelectric cooler and integrable in a compact mid-infrared heterodyne set-ups for high-frequency and low noise MIR detection.

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