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Room-temperature operation of a quantum well mid-infrared detector embedded in nano-antennae array at critical optical coupling

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We present the first room temperature photodection of hundreds on nanowatts using a quantum well mid-infrared detector at 9µm, with a background-limited temperature of 82K and a corresponding background-limited specific detectivity of 1.4×10^{10} cmHz$^{1/2}$/W. The photonic architecture consists of an array of double metal nano-antennae and allows to reduce the dark current and increase the absorbed electromagnetic field inside the active region, so to prove a high temperature photoresponse.

THE mid-infrared range (few micron wavelengths) of the electromagnetic spectrum is interesting to study because of the two atmospheric windows (3-5µm and 8-10µm) which allow spectroscopy and thermal imaging applications.[1] Several quantum detectors have been proposed for this spectra region, in particular interband detectors, like photodiodes and HgCdTe detectors and intersubband detectors.

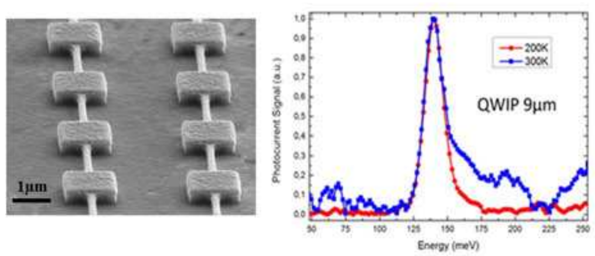

Fig.1. (left) Antenna array with size = 1 3µm and distance between each patch-antenna a=2µm. (right) Photocurrent spectra measured with a 1000 C blackbody

Quantum Well Infrared Photodetectors (QWIPs) represent a valid solution to the demand of fast and high sensitive mid detection in the infrared and far-infrared spectral region (5µm < λ < 200µm)[2]: these devices use intersubband (ISB) transitions in a semiconductor quantum well (QW) superlattice (mainly n-type doped GaAs/AlGaAs) to generate photocurrent. The main issue related to QWIP is the high dark current which obliges to work at liquid nitrogen temperature. Recently, we demonstrated an antenna-coupled microcavity geometry for QWIPs operating at mid-infrared[3] and terahertz[4] frequencies, which enables an improved light coupling, a reduced dark current and a higher temperature performance. The benefit of such plasmonic architecture on the detector performance relies on the ability to collect photons from an area much larger than device itself. We have designed the patch-antennae array and optically characterized so to achieve the condition of *critical coupling*[5], i.e. all the incident photons are absorbed by the device array. We have characterized the detector performances comparing it with a device made using the same quantum well absorbing region, but processed into a standard 45° polished facet mesa[2]. The antenna-coupled microcavity IR detector shows an enhancement of the background-limited temperature of more than 10K and responsivity values up to 1A/W, measured with a calibrated blackbody at 1000°C. Figure 1 (left) shows the antennae array realized by electron-beam lithography, the fabrication procedure includes an astuce to have an ohmic contact under each microcavity and a schottky contact within the 140nm-thin metallic wires, so to suppress parasitic dark current. Figure 1 (right) shows the 200K and 300K photocurrent spectra of the device. The remarkable room temperature operation is clear in the background-limited detectivity: at 300K we achieve a signal–to-noise ratio comparable at the 150K operation of the same detector structure but processed without our antenna concept. This result is important because with simple electro-cooling the antenna-coupled device can have a competitive sensitivity for a broad range of applications like fast laser characterization, infrared spectroscopy and heterodyne techniques.

Fig.2. Background-limited specific detectivity with 180 FOV: the enhancement of the antenna-coupled device is evident in the background limited temperature (from 69K to 82K) and in the high temperature operation, where the reduction of the QWIP dark current has an impact of 1 order of magnitude

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