2.5 D photonic crystal quantum cascade detector

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Abstract: Quantum cascade detectors are intersubband photodetectors that offer a vast design freedom. By combining it with a novel photonic crystal cavitiy, a significant improvement of the detectors performance could be achieved.

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1. Introduction

An upcoming class of mid-infrared intersubband photodetectors is the quantum cascade detector (QCD) [1]. Compared to quantum well infrared photodetectors (QWIP), QCDs offer a vast design freedom for the electronic band structure. However, to fully exploit that feature, a novel cavity is required.

We present a QCD that is fabricated as photonic crystal slab (PCS) [2]. The PCS is built as purely dielectric structure that utilizes an artificially induced periodic variation of the refractive index. By employing this specifically designed resonant cavity, the QCD is improved in three distinct ways. The PCS makes the device sensitive to surface normal incident light, the photon lifetime at the designed resonance frequencies is increased significantly and with typical hole radii, the device resistance is increased by 50% to 100% [2, 3].

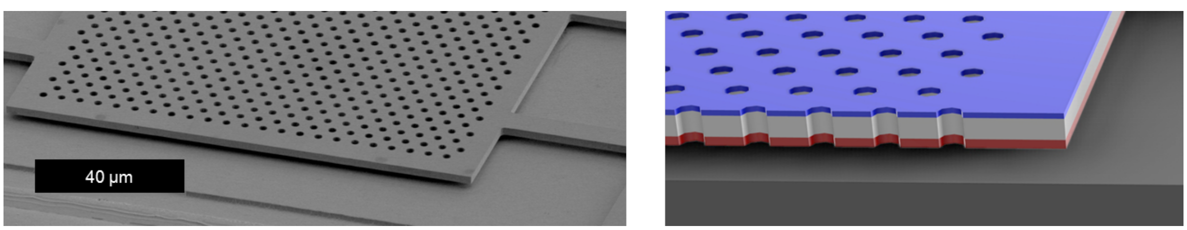

Fig. 1. Scanning electron microscopy image of a fabricated PCS-QCD and a schematic illustration of the crosssection of the PCS. Contact layers are red (bot) and blue (top), the active region is white.

2. Processing

The QCD is grown by molecular beam epitaxy from the $GaAs/Al_{0.34}Ga_{0.66}As$ material system. With the same detector material, a standard mesa and several PCS-QCDs are fabricated to compare the spectral responses and analyze the benefits of the PCS on the QCD. Processing of a PCS-QCD starts with the definition of the PC and the slab outline by anisotropic reactive ion etching through the grown structure into the substrate. Then, in a separate etching step, the contact spaces are defined by etching into the contact layer. A SiN insulation and contacts are deposited. As last step, the sacrificial layer is removed with 1:1 diluted HCl. The PCS parameters are lattice constant a = 4.5 μm and slab thickness d = 1.91 μm. Several devices with different normalized hole radii, around r = 0.28, were processed. The slab dimensions are 115 x 115 μm. As the PC provides polarization conversion of the electric field, the photodetector is illuminated with surface normal incident light from a broadband Globar light source. The spectral response is measured with a Fourier transform infrared spectrometer.

3. Experimental Results

A QCD is a photodetector that is based on a photon induced intersubband transition between two distinct states. An excited electron escapes from the upper state into an extractor, eventually reaching the ground level of the next cascade and contributing to the photocurrent. The spectral response of such a detector exhibits one strong absorption peak. Photons with higher or lower frequency do not contribute to the photocurrent. The PCS is designed such that the chosen mode coincides with the absorption spectrum of the QCD. Figure 2(a) shows the photonic bandstructure of the fabricated PCS versus the spectral response of the PCS-QCD. The large open circle indicates the single PCS-resonance that is visible in the measured photocurrent spectrum. Figure 2(b) shows the photocurrent response of a standard QCD

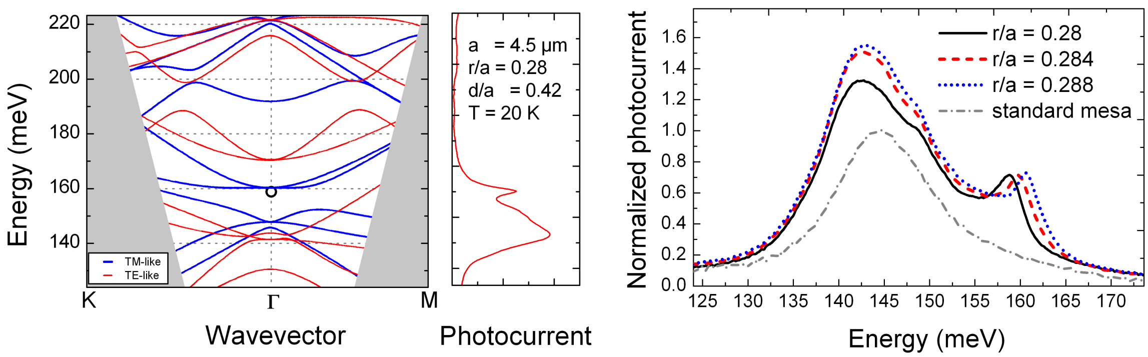

Fig. 2. (a) The photonic bandstructure of the fabricated PCS versus the spectral response of the PCS-QCD. The large open circle indicates the PCS-resonance that is visible in the measured photocurrent spectrum. (b) The photocurrent spectrum of a standard QCD and three PCS-QCDs devices, measured at liquid nitrogen temperature. At the PCS resonance frequency, the photocurrent of the PCS devices is 4 times larger than standard mesa devices.

and three PCS-QCDs devices at liquid nitrogen temperature. All devices show the broad absorption peak of the QCD at 143 meV. The PCS devices exhibit another peak at 160 meV, that shifts to higher energies for larger hole radii. In accordance with the results from the revised plane wave expansion method simulations, that peak could be identified at PCS resonances. At the PC resonance frequency, the photocurrent is enhanced by a factor of four.

4. Conclusion

In conclusion, we presented a quantum cascade detector that is fabricated as photonic crystal slab. The PCS cavity is a perfect match for QCDs, since both offer large design freedom. A significant improvement of the device performance, exhibiting a photocurrent enhancement of up to an factor of 4, has been achieved. We demonstrated that the PCS resonances are only visible within the responsivity spectrum of the QCD. Thus, such devices are perfectly suited for applications that require sensing of distinct spectral lines, while suppressing detection of side-band radiation. We envision that by fully exploiting the design freedom of both the QCD and the PCS, mid-infrared photodetector can be pushed towards room temperature operation with reasonable performance.

References

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