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Mid-infrared detectors with on-chip light collection

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1. Introduction

Mid-infrared (MIR) intersubband detectors are of major interest for many applications, which led to extensive research on that topic in the past years. Applications, such as chemical sensing, mid-infrared imaging and spectroscopy, rely on high performance detectors in that spectral region. The applicability of these detectors for integrated and portable devices is highly dependent on their temperature performance and monolithic integration. Room temperature operation with a reasonable performance is still a challenging topic. Novel device concepts are required to increase the responsivity and detectivity as well as to lower the noise equivalent temperature difference. We demonstrate a MIR detector combining a quantum cascade detector and a plasmonic lens structure, integrated on the same substrate to increase the performance and noise characteristics (Figure 1).

2. Quantum Cascade Detector

The operation wavelength of Quantum Cascade Detectors (QCDs) can be designed within a wide spectrum ranging from the THz region to the near-infrared. QCDs consist of a periodic repetition of an active well and an extraction region. Electrons are excited by MIR radiation from the ground state to an excited state within the active well. The excited electrons are extracted trough resonant tunneling and scatter down to the next active well. The active zone of a typical QCD device consists of 20 up to 50 periods. The built-in electric field extracts the electrons without the need of an external bias voltage. This photovoltaic operation mode is advantageous in terms of noise performance, as dark current and therefore shot noise are negligible. Due to this fact, QCDs exhibit significantly higher operation temperatures than quantum well infrared detectors [1].

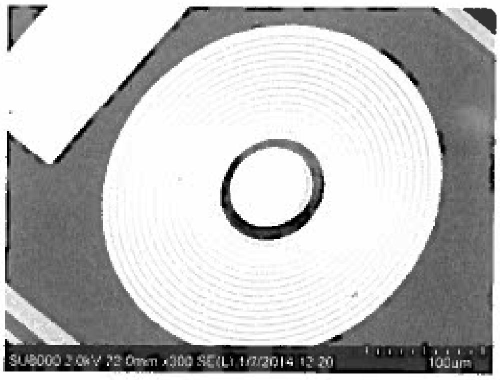

Fig. 1. Scanning electron microscopy image of plasmonic lens QCD.

3. Plasmonic lens Quantum Cascade Detector

As a major drawback of intersubband detectors such as quantum well infrared detectors (QWIP) and QCDs, these devices are only sensitive to light polarized in growth direction of the heterostructure. Thus special techniques are required to obtain sensitivity to the normal incident light. The lens consists of a 2^{nd} order grating which couples the light impinging the device to a surface plasmon wave. The surface plasmon wave is then guided to the detector facet and coupled to the active zone. To increase the coupling efficiency at the detector facet, the detector active zone is embedded in a dielectric waveguide. Our numeric simulations show a maximum external quantum efficiency of 24%.

The combination of a QCD and a plasmonic lens has two major advantages. First, the MIR radiation impinging perpendicular to the device plane can be coupled to the detector while the intersubband selection rule is fulfilled. Second, the lens, respectively plasmonic structure, surrounding the detector mesa, extends the area of light coupling from free space radiation. As the noise of the detector is proportional to the mesa size the signal to noise ration can be increased by a small detector mesa surrounded by a plasmonic lens [2].

We fabricated three different device shapes to investigate different plasmonic structures. The first one is a line shape grating, which does not focus the coupled radiation. The second, a star shape design was fabricated around a standard size square mesa to compare the detector performance to a 45° polished facet device. The third, a lens shape design (Figure 1) is the most advanced and provides an additional focusing effect. We achieved room temperature operation for these plasmonic lens detector devices. Figure 2 shows a comparison between two of our designs in comparison to a 90° facet detector illuminated QCD processed from the same material. With this work, we envision an improved room temperature compared to standard mesa devices.

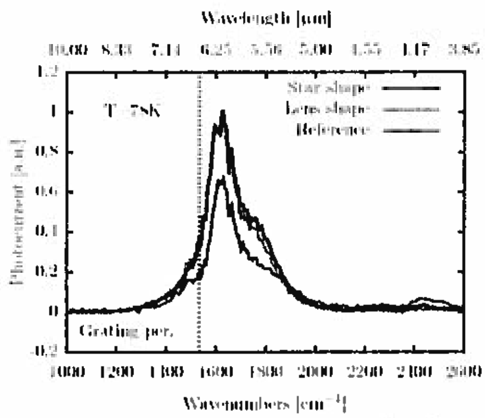

Fig. 2. Photocurrent response of plasmonic lens quantum cascade detectors with various shapes in comparison to a 90° facet illuminated reference detector fabricated from the same material [3].

4. References

[1] F. Giorgetta et al. "Quantum Cacade Detectors" IEEE Journal of Quantum Electronics V 45, NO. 8 (2009).
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[3] B. Schwarz et al. "A bi-functional quantum cascade device for same-frequency lasing and detection," Appl. Phys. Lett. **101, 191109 (2012)**.