2016
IQCLSW

International Quantum Cascade Lasers School and Workshop

Sunday 4 – Friday 9 September 2016
Cambridge, UK

High performance quantum cascade detector array for CO_2 detection

**A. Harrer[1], B. Schwarz[1], R. Szedlak[1], S. Schuler[3], P. Reininger[1], H. Detz[4], A.M. Andrews[1],
T. Zederbauer[1], D. MacFarland[1], W. Schrenk[1] and G. Strasser[1,2]**
1 Institute of Solid State Electronics, Technische Universität Wien, Floragasse 7/I, 1040 Wien, Austria
2 Center for Micro- and Nanostructures, Technische Universität Wien, Floragasse 7/I, 1040 Wien, Austria
3 Photonics Institute, Technische Universität Wien, Gußhausstrasse 27-29, 1040 Wien, Austria
4 Austrian Academy of Sciences, Dr. Ignaz-Seipel-Platz 2, 1010 Wien, Austria
andreas.harrer@tuwien.ac.at

1. Introduction

Mid-infrared two dimensional imaging arrays known as focal plane arrays (FPA) constantly attracted attention over the past years driven by several applications as search and rescue, military countermeasure systems, astronomy and remote gas detection. Efficient imaging systems require room temperature detection or thermo-electric cooled FPAs with high scalability and cost effectiveness. Large scale FPAs require sensor dimensions of several tens of mm with high uniformity. In addition to the well known advantages of quantum cascade detectors (QCD), such as low noise, photovoltaic operation, designable wavelength [1,2] and fast response time [3], they are compatible to stable growth technologies as MOCVD and MBE.

2. Quantum cascade detector array

We present a prototype quantum cascade detector array with 8 x 8 pixels wavelength matched to the CO_2 absorption around 4.3μm wavelength. The design is optimized for a high pixel resistance suitable for read out integrated circuits (ROIC). The substrate side illuminated array utilizes a diffraction grating fabricated into the top contact layer for light coupling to the active zone. The substrate backside is covered by a SiN anti-reflection coating to further enhance the light coupling efficiency. The array design is optimized for flip-chip bonding to a custom made CMOS ROIC and packaged into a TO-8 housing with a cold shield and Ge windows.

QCD simulation tools were developed for extraction efficiency, absorption, responsivity and resistance simulation and optimization. Extraction efficiencies of all involved levels were calculated to identify bottle-necks in the extraction scheme. A vertical optical transition design [4] is presented with a simulated extraction efficiency of ~80%. Thermal backfilling of the lower extractor levels was prevented by an increased transition energy to the next active well. The grating parameters were optimized by numerical simulations of the optical coupling to the active region.

3. Results

Standard mesa device characterizations and single pixel characterizations were conducted and compared prior to flip-chip bonding. The array has a pixel pitch of 225μm with a pixel size of 109μm x 109μm. It consist of a top pixel contact with a two dimensional diffraction grating and a separate bottom contact for every pixel. The active region is composed of 20 periods between a 800nm top contact and a 500nm bottom contact layer. The InGaAs/InAlAs QCD is grown lattice matched on semi-insulating InP. For a thermo-electric cooled operation temperature of 240K a differential pixel resistance of 13.9kΩ was achieved with a responsivity of 40mA/W and a specific detectivity of 4.5×10^8 $\mathrm{cmHz^{1/2}/W}$. At room temperature a responsivity of 32mA/W is demonstrated with a specific detectivity of 1×10^8 $\mathrm{cmHz^{1/2}/W}$. The sparse pixel design is due to the custom ROIC resistance requirements. The pixel size can be reduced for higher pixel counts and increased pixel resistance in future designs. The temperature dependent responsivity for the pixel device shows a lower performance drop than the 45° mesa device. This can be attributed to the more efficient grating coupling scheme. The simulated detector performance and wavelength matches well to the measurements.

QCDs suffer from low device resistances at elevated temperatures. We have shown a high resistance design to keep the detectivity at sufficient levels and enable for integrated pixel read out with CMOS technology. We have shown a 64 pixel high responsivity QCD array, wavelength matched to the CO_2 absorption band around 2350cm^{-1}. With our results we show progress towards room temperature mid-infrared imaging and envision applications in search and rescue devices.

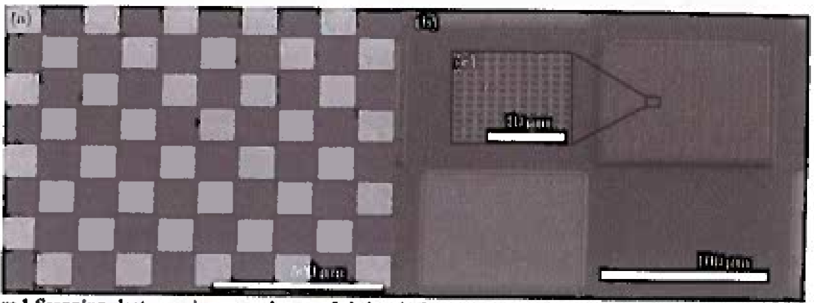

Figure 1 Scanning electron microscope image of a) the pixel array. All pixels are isolated from each other by an isolation trench surrounding the pixel b) and its bottom contact. Light coupling with a 2d diffraction grating c) was optimized by num. simulations.

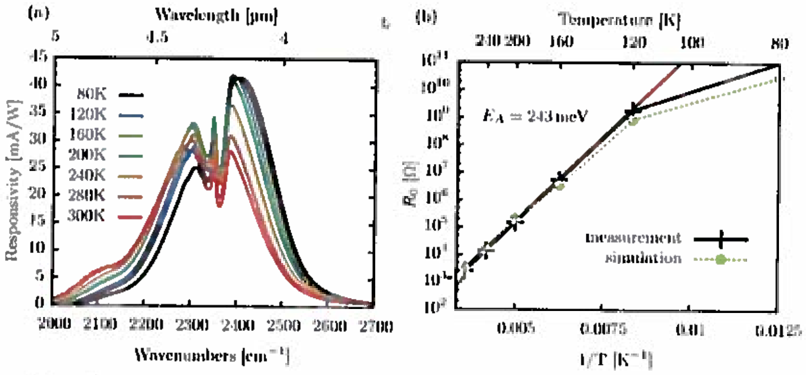

Figure 2 Single pixel temperature dependent responsivity a) and temperature dependence of the differential device resistance b) in comparison with the simulation. The two pronounced valleys in the responsivity spectrum are due to the strong CO_2 absorption around 2350cm^{-1}.

4. References

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