NANOPHOTONICS WITH QUANTUM DOTS

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There is a growing market for cameras that detect infrared radiation with applications in night vision, space, surveillance, search and rescue and medical diagnosis. More stringent requirements for the cameras, such as higher operating temperature, create a demand for detectors that use more advanced materials. One interesting candidate is Quantum Dot Infrared Photodetectors (QDIPs)

1. Background and Motivation

Quantum dot infrared photodetectors (QDIPs) is a new class of nanophotonic devices with the potential to significantly increase the performance and reduce the cost of infra-red detectors.

Quantum dots are small islands of a semiconducting material, surrounded by another semiconducting material with a larger energy band gap. The quantum dot (Fig. 1 below) acts as a potential well, where electrons and holes are trapped. The size of the quantum dot is so small that the electrons and holes trapped inside can no longer move freely. The electronic structure of quantum dots is characterized by discrete energy levels, similar to atoms. The quantum dots are therefore sometimes refered to as artificial atoms.

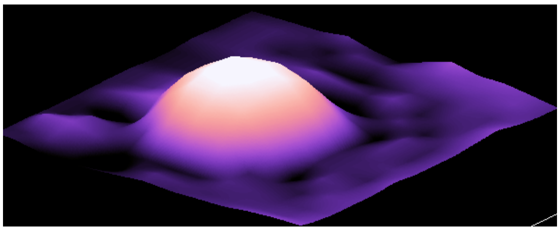


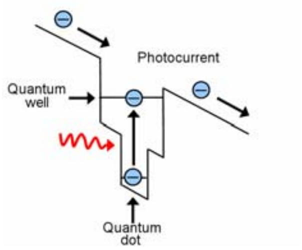
Fig. 1 AFM image of a 20nm wide and 3nm high quantum dot.

2. Basic device layout

The energy level separation in the quantum dots are designed to absorb IR radiation. Electrons situated in a lower energy state are, by absorption of the incident radiation, excited to a higher energy state. The electrons in the excited state are swept out of the quantum dot by an applied electric field and contribute to the photocurrent of the IR detector (see Fig. 2). The detection energy / wavelength can be tuned by adjusting the size of the quantum dot or the depth of the potential well.

For further tuning possibilities the dots can be inserted in a quantum well, a so called dots-in-a-well structure (DWELL). The detection wavelength is then partly determined by the dot and partly by the well and the long wavelength infrared region (LWIR, 8-12µm) can more easily be achieved.

Fig. 2 Energy level scheme and detection principle of quantum dots- in-a-well structure



The main advantage of a quantum dot based detector is the reduction in the dark current (current induced by thermal energy) of the component. Since the electrons are confined in all directions in the quantum dots, there are no intermediate energy levels between the discrete energy levels shown in the schematic energy diagram above. Consequently, higher activation energy is required in order to thermally excite electrons out of the dot, which results in a significantly lower dark current compared to conventional quantum well infrared photodetectors (QWIPs). A lower dark current permits higher operating temperatures, which reduces the cooling requirements of the detector and hence the cost. Another advantage of a quantum dot based detector is that radiation can be absorbed at all angles of incidence, since the electrons are confined in all directions. This simplifies the design of the light coupling of the detector.

3. Results

Acreo has been developing growth of quantum dot based material since 2003. Such materials have been grown for the production of photodetectors in a DWELL structure, with InAs quantum dots surrounded by InGaAs/GaAs quantum wells. The quantum dots are grown by a self assembly method, which enables a high dot density and consequently high absorption in the dot material. The density is around 1000 dots/µm^2, which means that a 25µm pixel with 10 layers of quantum dots consists of 6.25 million quantum dots! The top left hand image (Fig. 3) below shows a 1µm x 1µm AFM image of uncapped InAs quantum dots.

QDIP single pixel components have been fabricated at

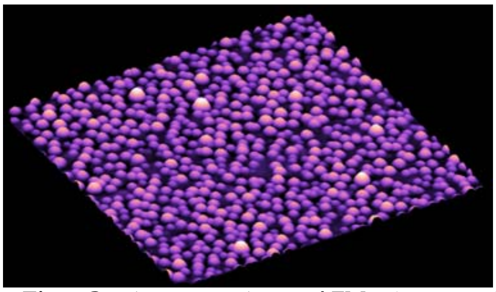


Fig. 3 1µm x 1µm AFM image of InAs/InGaAs/GaAs quantum dots

Acreo. The peak responsivity has been measured as 60mA/W at an applied bias of 2.25V and the peak wavelength is situated at 8.3µm (Fig. 4). The corresponding dark current is 2E-2A/m^2 at 77K, which is as predicted lower than for the conventional QWIP operated at 65K.

QDIPs are still in their infancy, but recent results have shown that their performance has already almost reached the performance of conventional QWIPs. Further material and structure optimisation are expected

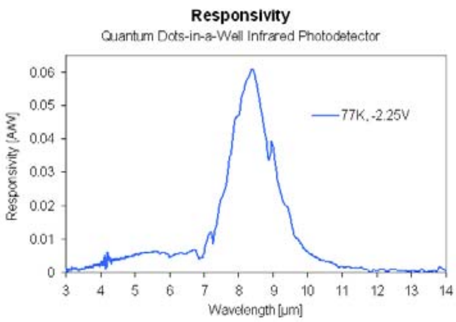


Fig. 4 Responsivity of a quantum dots-in-a well infrared photodetector at 77K and an applied bias of 2.25V

to significantly boost the performance of QDIPs. Finally, it is expected that the commercialisation time of QDIPs will be relatively short since they utilize well-established GaAs process technology. This will encourage a larger deployment of high-performance IR cameras in the coming years.

Partners and Status

Acreo

Linköping University

Halmstad University

FLIR Systems

Publications

[1]*Bias and temperature dependence of the escape processes in quantum dots-in-a-well infrared photodetectors*
L. Höglund, P.O. Holtz, H. Pettersson, C. Asplund, Q. Wang, S. Almqvist, S. Smuk, E. Petrini and J.Y. Andersson
Appl. Phys. Lett. **93**, 103501 (2008)

[2]*Bias mediated tuning of the detection wavelength in asymmetrical quantum dots- in-a- well infrared photodetectors*
L. Höglund, P.O. Holtz, C. Asplund, Q. Wang, S. Almqvist, E. Petrini, H. Malm, H. Pettersson, J.Y. Andersson.
Appl. Phys. Lett. **93**, 203512 (2008)

[3]*Optical pumping as artificial doping in quantum dots-in-a-well infrared photodetectors*
L. Höglund, PO Holtz, H Pettersson, C. Asplund, Q. Wang, S. Almqvist, E. Petrini, H. Malm, and J.Y. Andersson
Appl. Phys. Lett. **94**, 053503 (2009)