QCDs versus QWIPs

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Abstract— **Quantum Cascade Detector (QCD) have been introduced recently as an alternative photovoltaïc version of QWIPs. The objective of the paper is to understand how the specific requirements of the application of thermal imaging can influence the optimization of an infrared detector. In the light of these considerations, the conditions where QCDs could be preferred to QWIPs will be established.**

Index Terms— **quantum cascade, photodetection, mid-infrared, quantum wells structures.**

Quantum cascade detectors (QCD) have been introduced recently as a photovoltaic alternative to QWIPs [1,2]. Such a structure is composed of typically 7 or 8 coupled quantum wells, which are repeated typically 20 or 40 times. Figure 1 presents an example of one period of the device. The widths of the quantum wells are adjusted to create a cascade of energy levels : under illumination, electrons localized on the lowest energy level are excited to higher subbands E7 and E8. They are then transferred to the next period through successive electronic relaxations in the cascade.

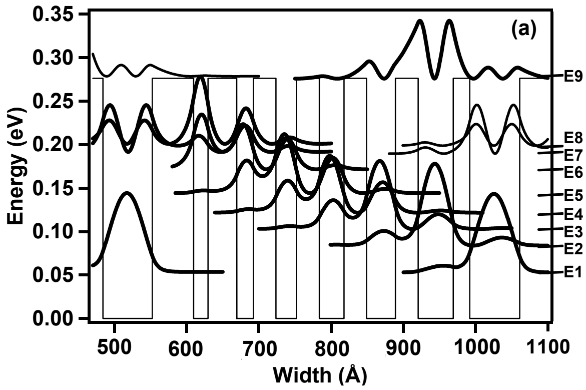

Fig 1. : Structure of one QCD period

A noticeable difference between QCDs and QWIPs is the possibility of modelling of the performances of QCDs, without any adjustable parameter except the band diagram, the effective masses and the doping concentration. Indeed, the transport in QCDs involves only electronic transitions between "2D" wavefonctions, which can be calculated with standard matrix elements. In QWIPs, "3D" states in the continuum lead to the introduction of additionnal parameters such as capture and escape probabilities, difficult to evaluate. In the case of QCDs, it will be shown how the optimisation of the structure can be performed completely numerically. This is the first time that such a route for the optimisation of an infrared detector can be followed.

For example, at reasonnably high temperature electronic transfers between the quantum levels are governed by electron/optical phonon hamiltonian only. All possible transitions between the different energy subbands from one cascade to another one can be taken into account and the different transitions rates can be calculated using ref [4]. Under low applied voltage, the dark current is evaluated with the transitions rates calculated at equilibrium in a perturbative approach. The R_0A (the product of the resistance by the area of a pixel) deduced from the current-voltage relation can be finally written in a very simple form, which can be interpreted as an Einstein relation adapted to the case of quantum well heterostructures. This relation traduces the fact that the electronic transport is described as a diffusion through all subbands. Excellent agreements between experimental results and this simple modeling, on more than 5 orders of magnitude as a function of temperature, without any adjustable parameter (except the doping density), validates this perturbative approach.

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The ultimate purpose of our study is the comparison of the performances of QCDs versus QWIPs. The first step is the choice of a clear factor of merit, which is very difficult in the case of infrared thermal imaging, since the performance of a detector depends on the scene (and therefore on the application). In the specific application of thermal imaging, the choice of a spectral band, a working distance, an integration time, and a pixel size, governs the requirements in terms of quantum efficiency on the one hand, size of the capacity which stores the electrons behind each pixel, on the other hand. These parameters give constraints for the choice of a doping level, which is directly responsible for a high dark current in QWIPs, which finally determinates the working temperature of the QWIP. This impacts the choice of the cooling system, its consommation, life time and cost. It will be shown, indeed, that the doping level in QWIPs is NOT determined by an optimisation of the detectivity, which is the good factor of merit for low signal detection in a zero background, but certainly not for thermal imaging. A specific need for a high quantum efficiency (due for instance to a very long working distance, a short integration time, or band II imaging) requires an increase of the doping of the QWIP, which can be increased up to the point where the dark current becomes prohibitive considering the capacity size and the working temperature.

This analysis of the impact of the doping level on quantum efficiency, electron storage and integration time, will lead to the conclusion that QWIPs and QCDs have different optimum doping levels. In the light of these considerations, the conditions where QCDs could be preferred to QWIPs will be established.

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