Experimental and theoretical investigation of the spectral Stark shift in quantum dots-in-a-well infrared photodetectors

P. Aivaliotis[1*], N. Vukmirović[2#], E. A. Zibik[1], D. Indjin[2], J. W. Cockburn[1], P. Harrison[2], C. Groves[3], J. P. R. David[3], M. Hopkinson[3], and L. R. Wilson[1†]

1 Department of Physics and Astronomy, University of Sheffield, Sheffield, S3 7RH, UK,
2 School of Electronic and Electrical Engineering, University of Leeds, Leeds, LS2 9JT, UK,
3 Department of Electronic and Electrical Engineering, EPSRC National Centre for III-V Technology, The University of Sheffield, S1 3JD, UK

*p.aivaliotis@sheffield.ac.uk, †luke.wilson@sheffield.ac.uk #eennv@leeds.ac.uk

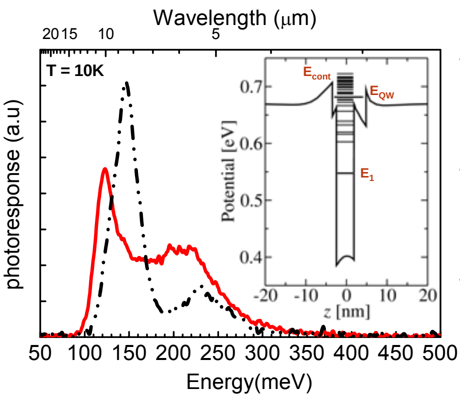
Introduction

Developing QDIPs with a detection wavelength which can be Stark-shifted with an external bias, offer benefits such as the ability to tune the peak wavelength of the photoresponse within one infrared (IR) atmospheric window or between two IR atmospheric windows.

DWELL QDIPs are ideal for studying the Stark shift due to the enhanced asymmetry compared to InAs/GaAs QDs [1], which produces shifts comparable to QWIPs [2]

We present bias-dependent spectral shifts of 15% of the transition energy of the photoresponse in InAs/InxGa1-xAs quantum-dots-in-a-well (DWELL) structures, and use 8 band *k•p* theory to model this Stark shift and fit the experimental results.

Bias dependent photoresponse



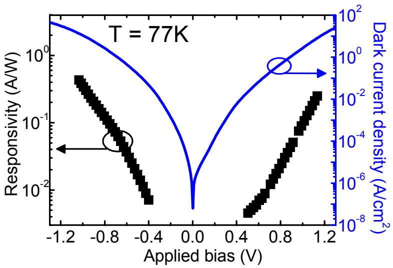
- Strong *p*-polarized photoresponse due to confinement in the growth direction (5x *s*-pol)
- Red-shift (15%) between +1V (solid line) and -1V (dashed line) due to DWELL asymmetry
- Higher intensity for negative -1V, E_{QW} closer to the band edge

Two photocurrent peaks at ~130meV (~9μm) and ~230meV (~5μm) corresponding to transitions from the QD ground state to states in the QW ($E_1 \rightarrow E_{QW}$) and GaAs continuum ($E_1 \rightarrow E_{cont}$), respectively

Current characteristics

Peak responsivity for DWELL detector for $E_1 \rightarrow E_{QW}$ peak.
Close to zero applied field the low tunnelling probability from the QW suppresses the $E_1 \rightarrow E_{QW}$ photocurrent peak

Asymmetry in Peak responsivity and dark current IV correlate well with spectral results



[1] P. Aivaliotis et al, *J. Phys. D: Appl. Phys.* 40 (2007) 5537-5540
[2] J. Li et al, *Appl. Phys. Lett.* **86** (2005) 211114

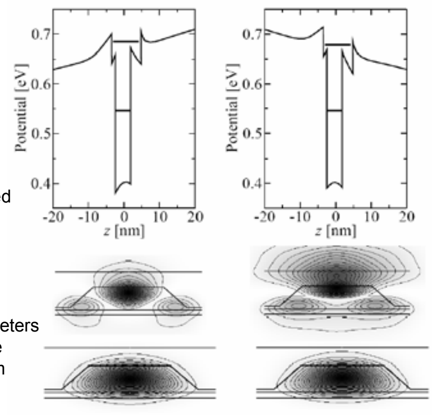
Modelling the Stark shift with 8 band *k•p* theory

8 band *k•p* method theoretical model with the effects of strain and electric field taken into account.

E_1 wavefunction weakly influenced by the electric field.
Wavefunction of higher energy quasi-bound states which mostly contribute to the absorption are strongly influenced by the electric field.

Calculation assumed truncated QDs with base diameter *D*, height if the dot were not truncated *H*, actual height *h*, and indium content in the dot *x*. Parameters were varied in a range according to the maximum in the experimental spectrum

Negative bias shifts the wavefunction towards the region of low potential and decreases the distance between the centroids and the dipole moment of the transition.



Wavefunctions of the E_1 and E_{QW} to which the absorption is maximal when the bias is equal to -0.6V and +0.6V(bottom), and on-axis potential profile with the energies of the states that mostly contribute to the absorption (top).

Stark shift - experiment and theory

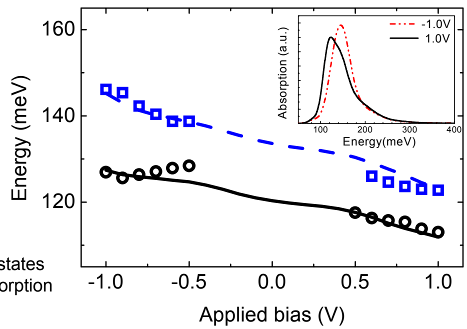
Best fit for experimentally observed dependence of $E_1 \rightarrow E_{QW}$ on bias obtained when *h*=4nm, x=0.7, *D*=17nm (blue dashed line)

Reduction of peak energy and reduced Stark shift (11%) for sample (S2) containing dots with less InAs during growth (black dots). Best fit -*h*=6nm, *x*=0.66, *D*=17nm (black line)

Indication of S2 having smaller separation between centroids of E_1 and E_{QW}

Both samples in good agreement with theory

Non-quadratic behaviour of the Stark shift due to the quasi-continuum nature of the density of states in the QW whereby complex changes in the density of states determine the maximum of the absorption spectrum



Experimental observation of the Stark shift in DWELL QDIPs in good agreement with 8 band k•p theory

See: Journal of Physics D: Applied Physics, **P. Aivaliotis et al, J. Phys. D: Appl. Phys. 40 (2007) 5537-5540**