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Charged excitons in individual quantum dots: effects of vertical electric fields and optical pump power

B. Urbaszek[a,*] , E.J. McGhee[a], J.M. Smith[a], R.J. Warburton[a,b], K. Karrai[b], B.D. Gerardot[c], J.M. Garcia[d], P.M. Petroff[c]

[a] *Department of Physics, Heriot-Watt University, Edinburgh EH14 4AS, UK*
[b] *Center for NanoScience and Sektion Physik, Ludwig-Maximilians-Universität, Geschwister-Scholl-Platz 1, 80539 München, Germany*
[c] *Materials Department and QUEST, University of California, Santa Barbara, CA 93106, USA*
[d] *Instituto de Microelectrónica de Madrid, Isaac Newton 8, 28760 Tres Cantos, Madrid, Spain*

Abstract

We investigate the influence of optical pump power on a series of charging events of individual quantum dots embedded in a field effect structure. Increasing the optical pump powers moves all charging events towards more negative voltages and charged biexciton states in addition to single exciton states are observed. The linear shift in voltage with pump power is explained by the accumulation of photogenerated holes within the structure.

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1. Introduction

The InAs quantum dots studied are grown on GaAs in the Stranski–Krastanov mode. The dots are separated by a tunnel barrier of undoped GaAs from an n^+-type layer that serves as a back contact. An GaAs/AlAs superlattice blocking barrier (SBB), grown on top of the GaAs covering the dots, ensures that the coupling between the dots and a metal gate electrode on the sample surface is purely capacitive. The InAs quantum dots are filled with electrons by applying an electric field between the back contact and the gate and by using confocal microscopy we are able to investigate charging events of individual dots. For large negative gate voltages V_G the PL emission of the neutral exciton X^0 is quenched as the electrons tunnel out of the dot before radiative recombination can occur. Changing V_G from -1.0 to $+1.0$ V the PL emission of single dots reveals discrete jumps in energy as electrons are added one by one to the dot, see Fig. 1a and b. The size of the jumps and the occurring spin splitting of excitons charged with one (X^{1-}), two (X^{2-}) or three (X^{3-}) excess electrons contain rich information about the confinement potentials and carrier interactions [1].

2. Experimental results

The PL emission at 4 K of an individual InAs dot has been measured for V_G ranging from -1.0

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* Corresponding author. Tel.: +44-131-451-3048; fax: +44-131-451-3136.

E-mail address: b.urbaszek@hw.ac.uk (B. Urbaszek).

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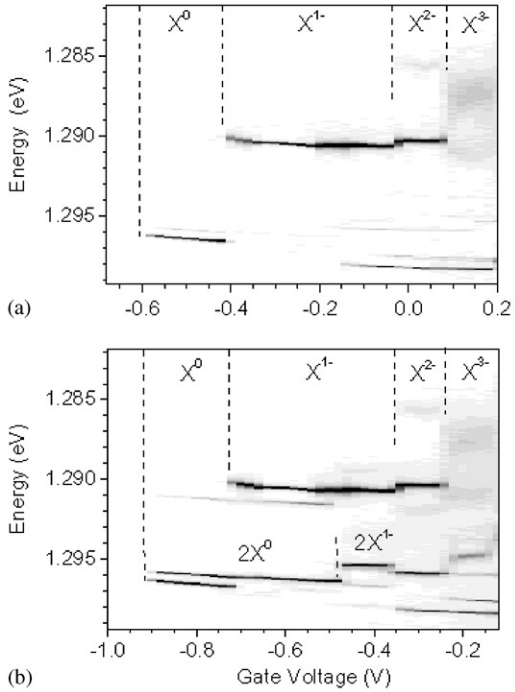

Fig. 1. Gray-scale plot of photoluminescence versus gate voltage at 4.2 K for excitation power 1 μW at 850 nm where white, gray and black correspond to low, medium and high signal for a dot. The charging events are marked as the PL shifts to the red and (b) power 5 μW, single and multiple exciton states are charged.

to +0.2 V for different pump powers. The value of V_G, at which the X^0 emission was quenched, was found to be strongly dependent on the optical pump power. Increasing the power from 1 to 5 μW shifted V_G at which quenching occurred by 0.3 V towards negative voltage. This shift in V_G was the same for all subsequent charging events, shifting the entire charging curve for the dot along the V_G axis by the same amount, as can be seen in Fig. 1a and b. Increasing the optical pump power has therefore the same effect as applying a positive voltage, and indeed we were able to change the number of electrons trapped in the dot at constant V_G by varying the pump power.

We suggest that holes are trapped at the interface between the GaAs and the SBB where a triangular potential is formed in the valence band. We observe a linear relationship between the pump power and the shift in V_G and implying a linear absorption of the excitation beam, independent of V_G. Furthermore, the shift in V_G of the charging events with pump power is observed for two different sources, one exciting above and one below the bulk GaAs band gap. For optically excited holes to populate the GaAs–SBB interface in the case of below band gap excitation at 850 nm, optical absorption in the strained GaAs region close to the dots is suggested. Below band gap absorption due to the Franz–Keldysh effect can be neglected due to its strong exponential dependence on the applied electric field. Storage of holes in the wetting layer can also be ruled out, as the power induced shift in electric field would be V_G dependent. Approximating the excess holes by a sheet of positive charges inserted between the back contact and the surface gate the measured shift in V_G gives a value of 2×10^{11} cm^{-2} for the change of the photogenerated hole density at the GaAs–SBB interface for an increase in pump power from 1 to 5 μW. At high pump powers in Fig. 1b new features appear, which are attributed to the biexciton ($2X^0$) by its superlinear dependence on excitation power. At more positive V_G also the negatively charged biexciton ($2X^{1-}$) can be distinguished, as observed by Finley et al. [2].

3. Conclusions

We have observed a shift in V_G of electron charging events for individual InAs quantum dots. The shift is caused by the accumulation of holes at the GaAs–SBB interface, resulting in a linear shift of V_G with pump power.

References

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