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Original Paper

# 2D optical photon echo spectroscopy of a self-assembled quantum dot

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*Simulations of two dimensional coherent photon echo (2D-PE) spectra of self-assembled InAs/GaAs quantum dots (QD)*

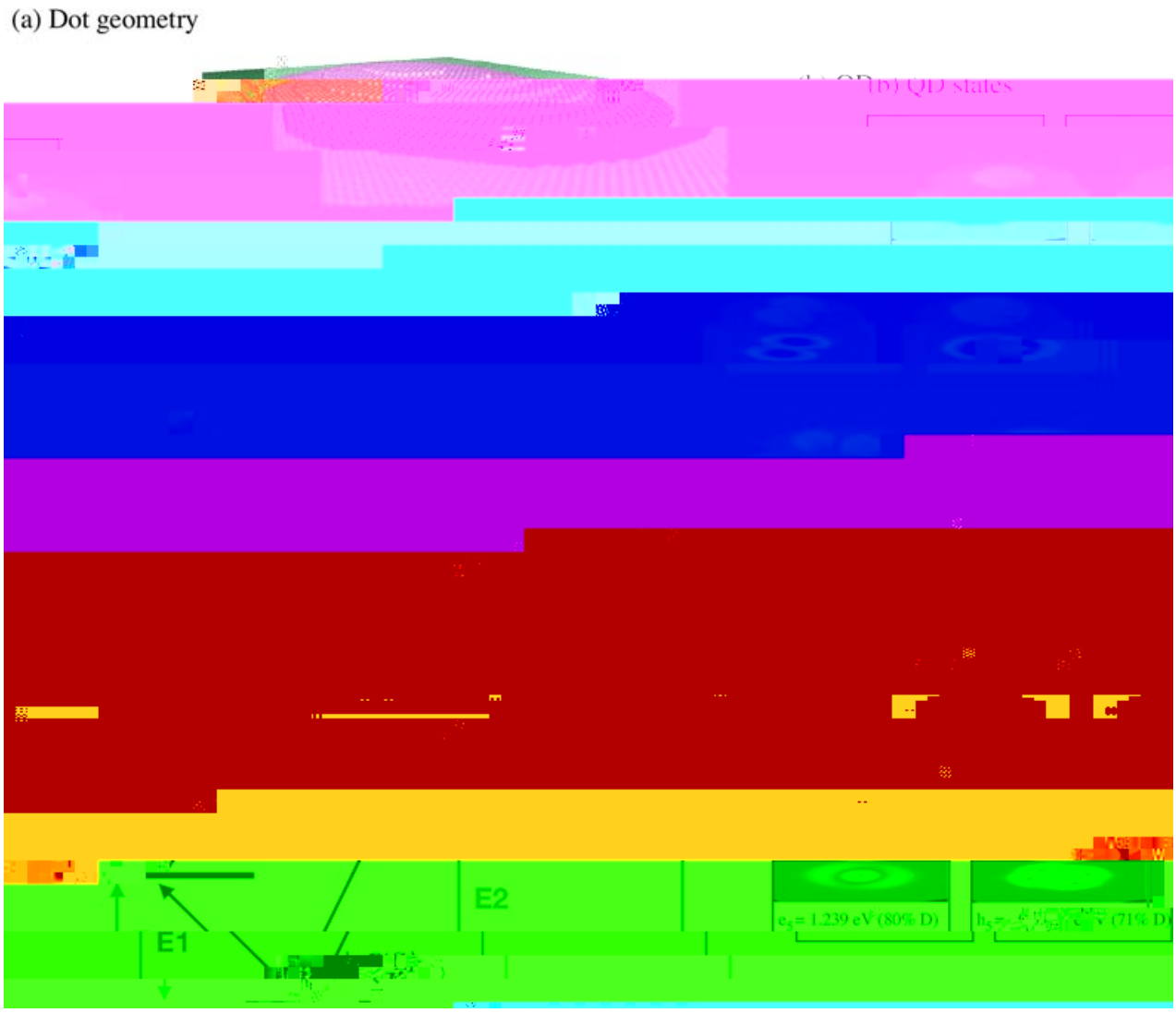


**Figure 1** (online color at: www.ann-phys.org) (a) Schematic of a lens-shaped InAs dot with base of 25 nm and 2 nm heigh, sitting on one monolayer wetting layer, embedded in a GaAs matrix. The dot contains 41,776 atoms and the matrix contains 1,948,880 atoms. (b) Wavefunction square of six lowest energy single-particle electron states and six highest hole states. The percentage of its dominant orbital character (S, P and D) and its energy with respect to $h_0$ are given underneath the corresponding wavefunction plot. (c) Ladder diagrams excited state emission (ESE), ground state bleach (GSB) and excited state absorption (ESA) contributing to the 2D photon echo signal $S^{(3)}_{k_I}$. (d) Schematic of the bi-exciton stabilization due to many-body e ects in QD.

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## 2 Theoretical methods

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- . 25 2

- $XX^q$ . - ( . 1 ( )). 41,776

/ 1, 48,880 . -1.3

.(-613.5 ) ( ), ()0.3

( )

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. $G^q$ , , - $G_0^q$. $X^q$ $XX^q$ $P_e - P_h$ (1.1 , . 2) $G^q \to X^q$ $\approx 2.31$ $G^q - XX^q$ - . 2 - - . - - . 144 $X^0$ 4356 $XX^0$ , 500 $X^+$ $X^-$ 1000 $XX^+$ $XX^-$ - 2 - . $G^q$ (12 ) $6 \cdot 10^7$ 2 - . - . 2 . 1, - ( - . 1 - . 2). - - . $G^q \to X^q$ - )-2 7.6( ) .-378.24( (()02.7(- .7( 5( ) .()02.743 . (252-0 )0( )0 )-7.625214. ( )-2( ) 833.8346-60 )-7.4( )

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$e_0 - h_4$ ) -
- ( . . $S_e - S_h$ $P_e - P_h$

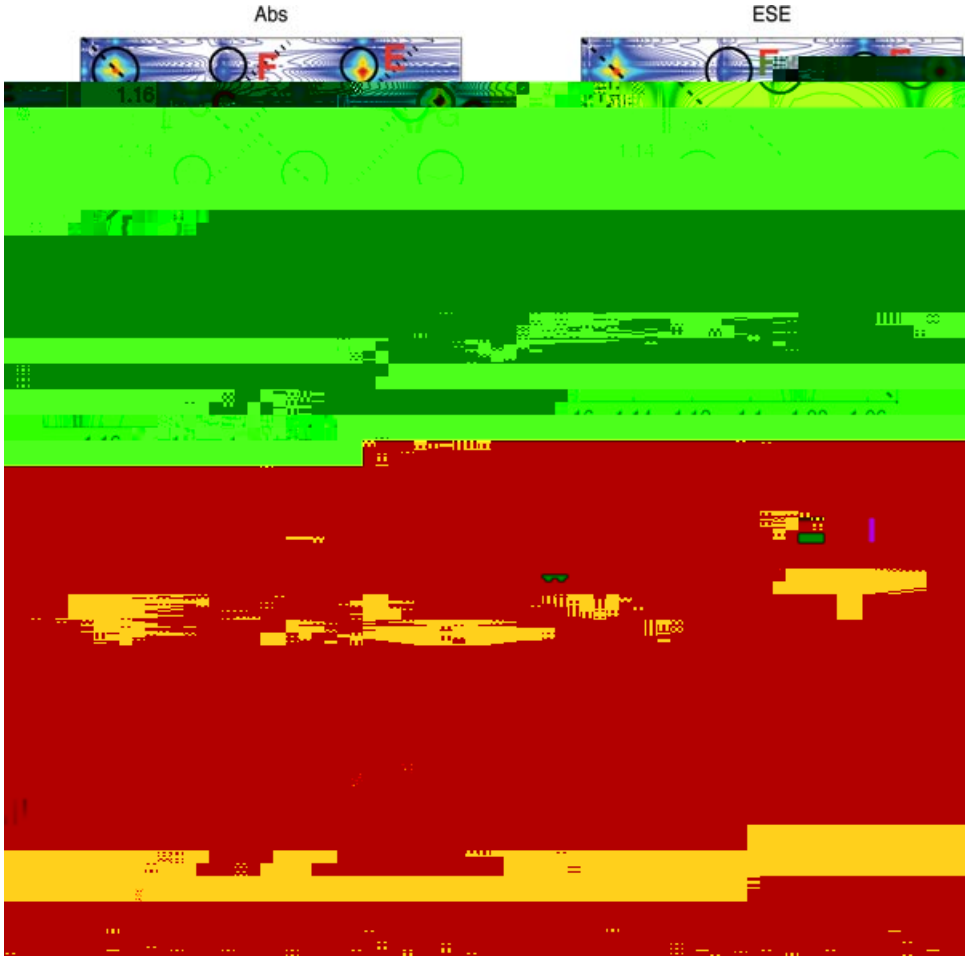


**Figure 3** (online color at: www.ann-phys.org) 2D-Photon echo signal $S_{k_I}^{(3)}(\hbar\Omega_3, t_2, \hbar\Omega_1)$ of the neutral QD: the three ladder diagrams excited state emission (ESE), ground state bleach (GSB) and excited state absorption (ESA, compare Fig. 1) contribute to the total signal $S_{k_I}^{(3)}(\hbar\Omega_3, t_2, \hbar\Omega_1)$ (depicted as absolute value (Abs)). The signals are depicted on a nonlinear scale, de ned by eq. (10). The colour scale is the same as in Fig. 2

$A$ $C$ $P_e - P_h$ (ß -
$e_0 - h_4$ ( $B$). ß , . 2 ,
$A$ ß -
($S_e - S_h$ $-\hbar\Omega_1 = \hbar\Omega_3 = 1.083$ , . 2 ( )) ß $S_e - S_h$ $e_0 - h_4$ ( -
ß $D, D^{\prime}, -\hbar\Omega_1 \approx 1.08$ $\hbar\Omega_3 \approx 1.13$ ) ß
ß $e_0 - h_4$ $P_e - P_h$ ( - $F, F^{\prime}, -\hbar\Omega_1$
- ($X^q \leftarrow G^q$). $\approx 1.13$ $\hbar\Omega_3 \approx 1.17$ ). $\hbar\Omega_1$
ß ß ( -
) ß , $\hbar\Omega_3$
$-\hbar\Omega_1 \approx 1.08$ , $\hbar\Omega_3 \approx 1.16$ (ß ß ( - $G, G^{\prime}, H, \hbar\Omega_3 \approx 1.07$
) ß ß $S_e - S_h$ $P_e - P_h$ $\hbar\Omega_3 \approx 1.158$ $\hbar\Omega_3 \approx 1.115$ ).
( - $E, E^{\prime}, G, G^{\prime}$). ß ß ß -
( . 2 ( )) ß ß
- $E$ $G$, ß - ß - $X^q$ - $XX^q$ -
( . 2 ( ) ( )) . 1 ( ).
ß ß - $E$ $G$. ß 2 - $S_{k_I}^{(3)}(\hbar\Omega_3, t_2, \hbar\Omega_1)$ $X^q \leftarrow G^q$ -
- ß - . $A$

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**Key words.** Self-assembled quantum dots, non-linear optical spectroscopy, many-body e ects.

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