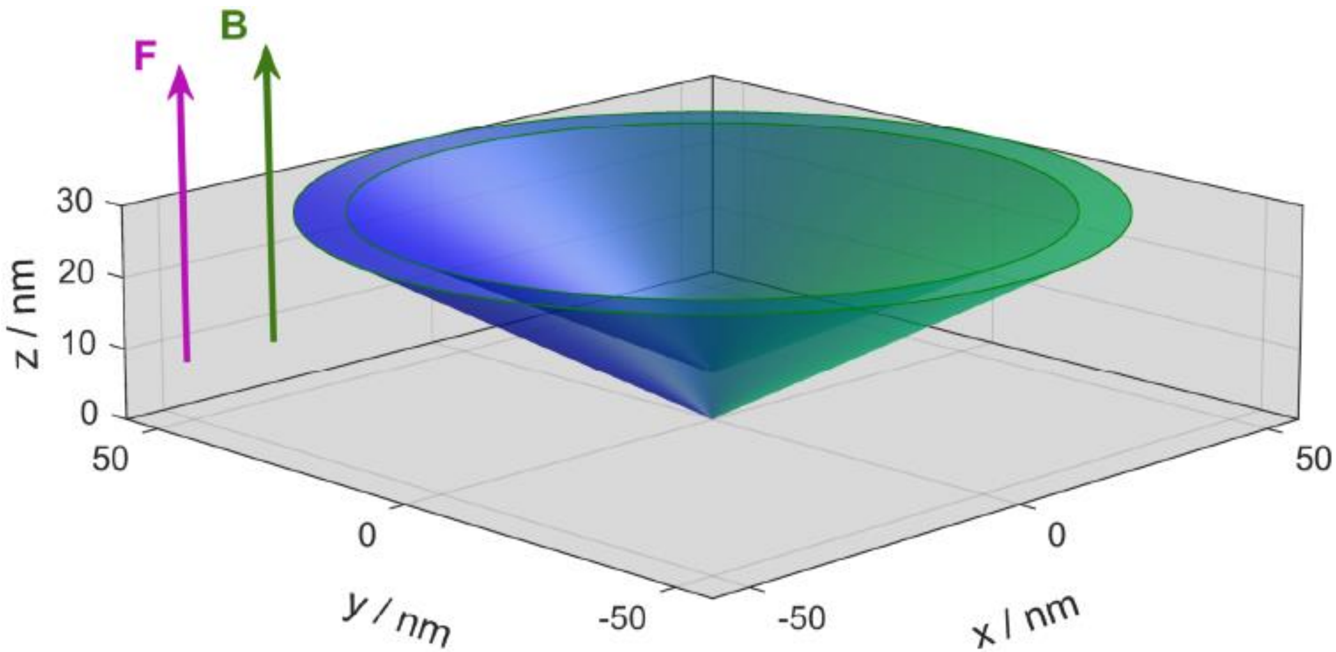
Exciton states in low dimensional systems under external effects



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Carlos A. Duque

2023

The history_1

RAPID RESEARCH LETTER

Cone-Shell Quantum Structures

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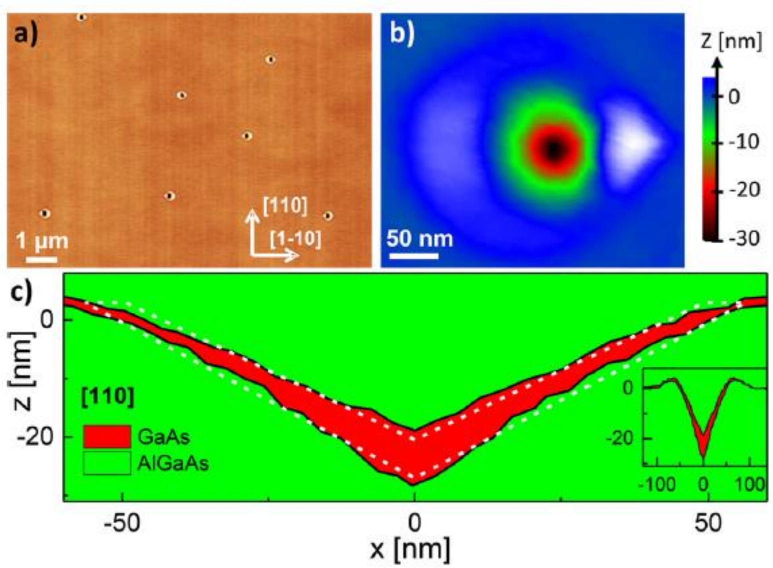
Field-Controlled Quantum Dot to Ring Transformation in Wave-Function Tunable Cone-Shell Quantum Structures

Christian Heyn, Achim Küster, Michael Zocher, and Wolfgang Hansen*



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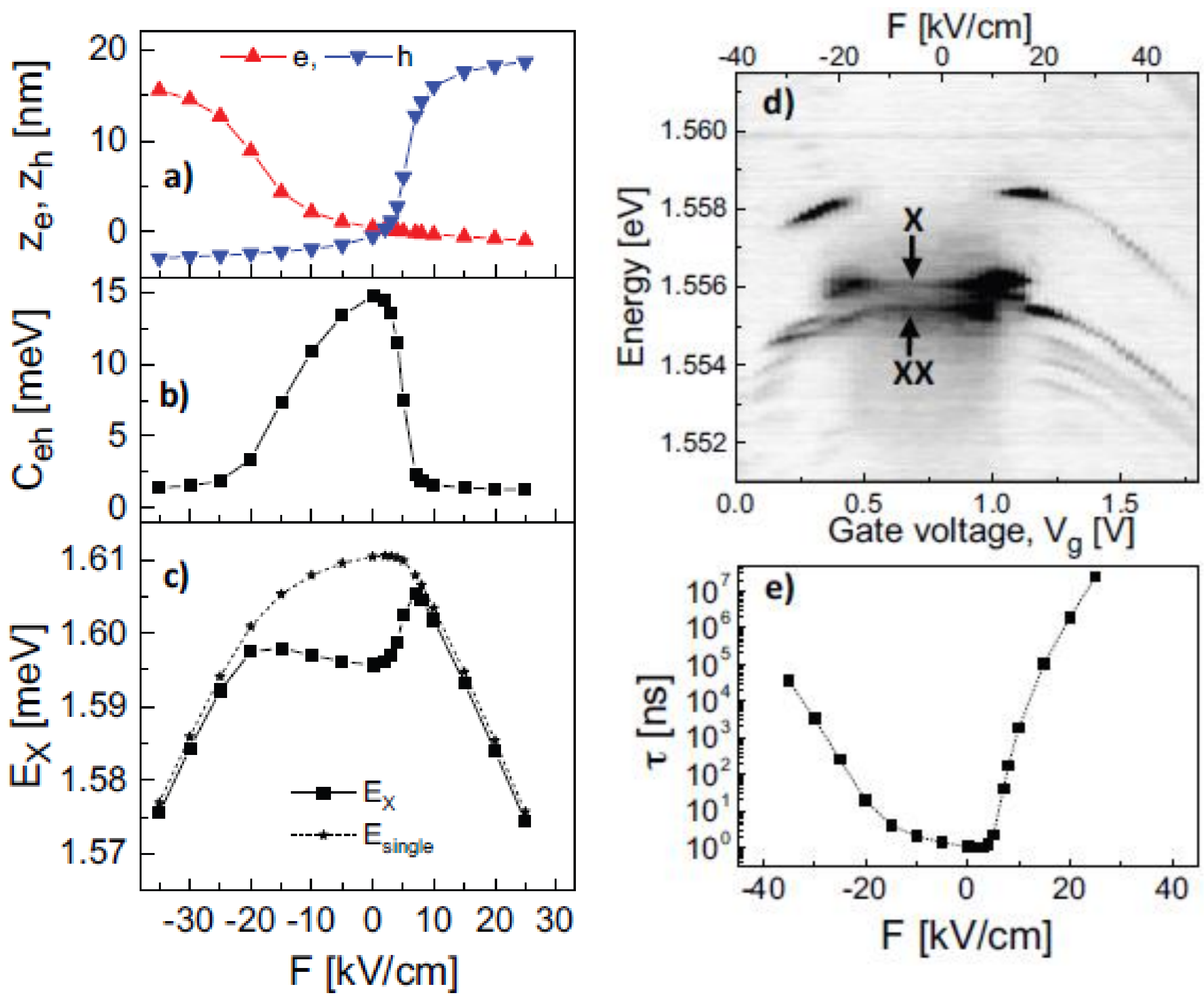
The history_2



Theoretical framework_1

$$H = H_e + H_h - \frac{e^2}{4\pi\varepsilon\varepsilon_0 \left|\overrightarrow{r}_e - \overrightarrow{r}_h\right|}, \qquad (1)$$

$$H_i = \frac{1}{2m^{*,i}_{W,B}}\left(i\hbar\overrightarrow{\nabla}_i + q_i\overrightarrow{A}_i\right)^2 - q_i F z_i + V_i\left(x, y, z\right), \quad (2)$$

here $i = e$ for electrons and $i = h$ for holes

$$H_i = \quad -\frac{\hbar^2}{2m^{*,i}_{W,B}}\overrightarrow{\nabla}_i^2 + \frac{i q_i \hbar}{m^{*,i}_{W,B}}\overrightarrow{A}_i \cdot \overrightarrow{\nabla}_i + \frac{q_i^2}{2m^{*,i}_{W,B}}\overrightarrow{A}_i^2 - q_i F z_i + V_i(x, y, z) \quad (3)$$

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Theoretical framework_2

$$H_i = -\frac{\hbar^2}{2m^{*,i}_{W,B}}\overrightarrow{\nabla}^2_i - \frac{i\,q_i\,\hbar\,B}{2m^{*,i}_{W,B}}\left(y\frac{\partial}{\partial x} - x\frac{\partial}{\partial y}\right) + \frac{q_i^2\,B^2}{8m^{*,i}_{W,B}}\left(x^2+y^2\right) - q_i\,F\,z_i + V_i\left(x,y,z\right). \quad (4)$$

$$H_i\Psi_i(x,y,z) = E_i\Psi_i(x,y,z) \quad (5)$$

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Theoretical framework_3

Coulomb integral for the ground state

$$C_{eh} = \int_{V_e}\int_{V_h} \frac{e^2 \left|\Psi_e^0\left(\overrightarrow{r}_e\right)\Psi_h^0\left(\overrightarrow{r}_h\right)\right|^2 d\overrightarrow{r}_e\, d\overrightarrow{r}_h}{4\pi\varepsilon\varepsilon_0\left|\overrightarrow{r}_e - \overrightarrow{r}_h\right|}, \quad (6)$$

The overlap integral

$$I_{eh} = \left|\int_V \Psi_e^0\left(\overrightarrow{r}\right)\Psi_h^0\left(\overrightarrow{r}\right) d\overrightarrow{r}\right|^2 \quad (7)$$

The ground state lifetime of the electron-hole pair

$$\tau = \frac{12\pi\hbar^2 c^3 \varepsilon_0 m_0}{n e^2\left(E_e^0 + E_h^0 + E_g\right) E_p I_{eh}}, \quad (8)$$

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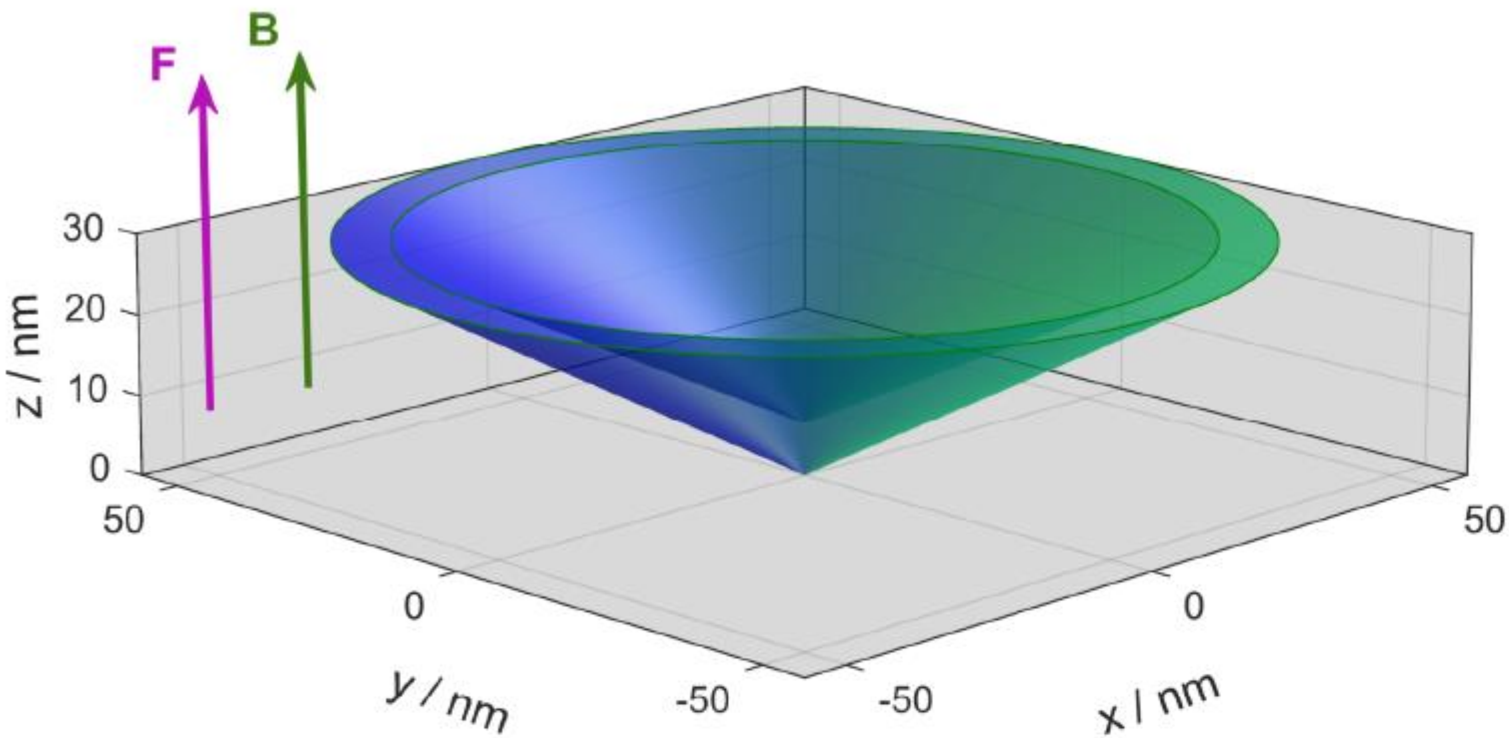
Pictorial view of the cone-shaped



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Axisymmetric view

The parameters used in this work will be the following:

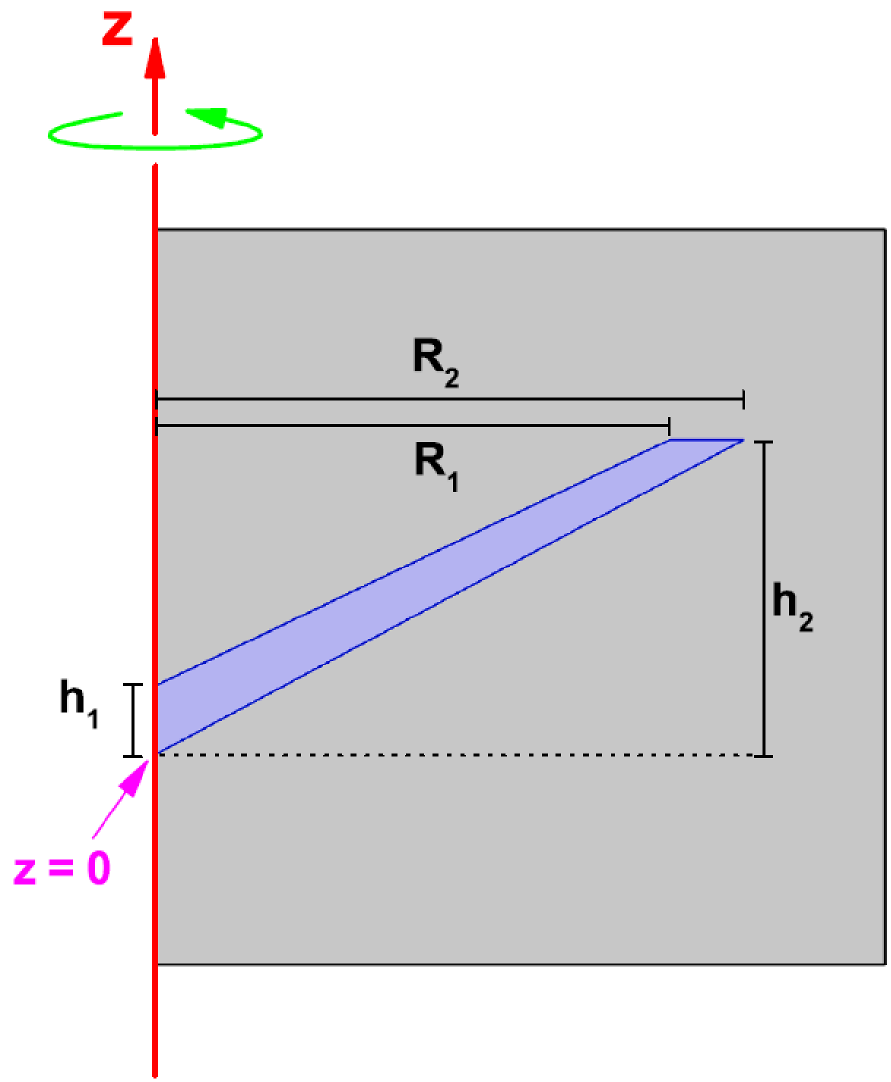
i) all calculations are made for a structure whose dimensions are $R_1 = 49.4\,\mathrm{nm}$, $R_2 = 56.5\,\mathrm{nm}$, $h_1 = 6.55\,\mathrm{nm}$, and $h_2 = 30\,\mathrm{nm}$,

ii) the electron effective masses $m_W^{*,e} = 0.067\,m_0$ and $m_B^{*,e} = 0.092\,m_0$,

iii) the heavy-hole effective masses $m_W^{*,h} = 0.51\,m_0$ and $m_B^{*,h} = 0.6\,m_0$,

iv) $V_0^e = 300\,\mathrm{meV}$ in the barrier material,

v) $V_0^h = 177\,\mathrm{meV}$ at the barrier material.



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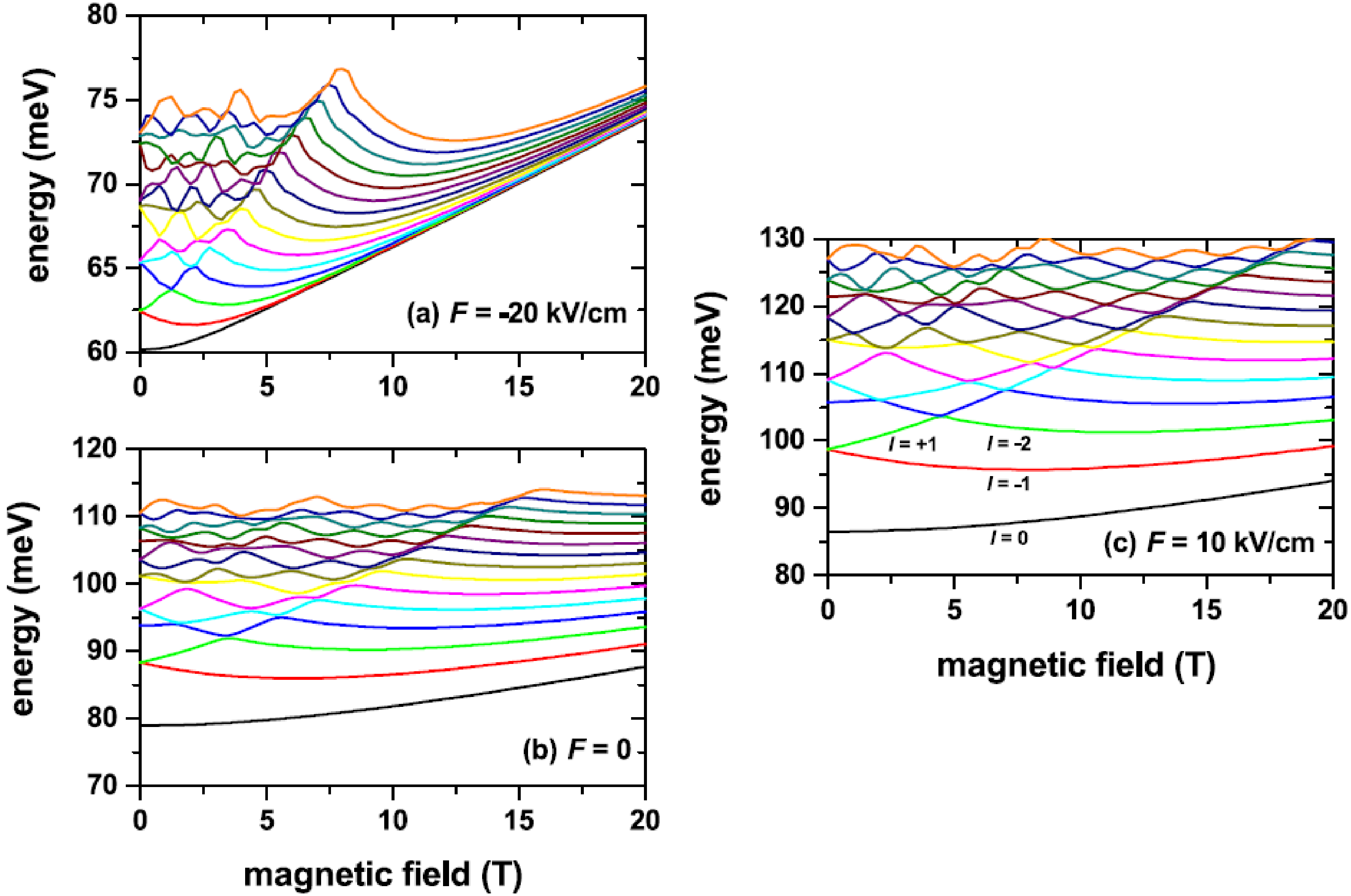
Energy levels for electron



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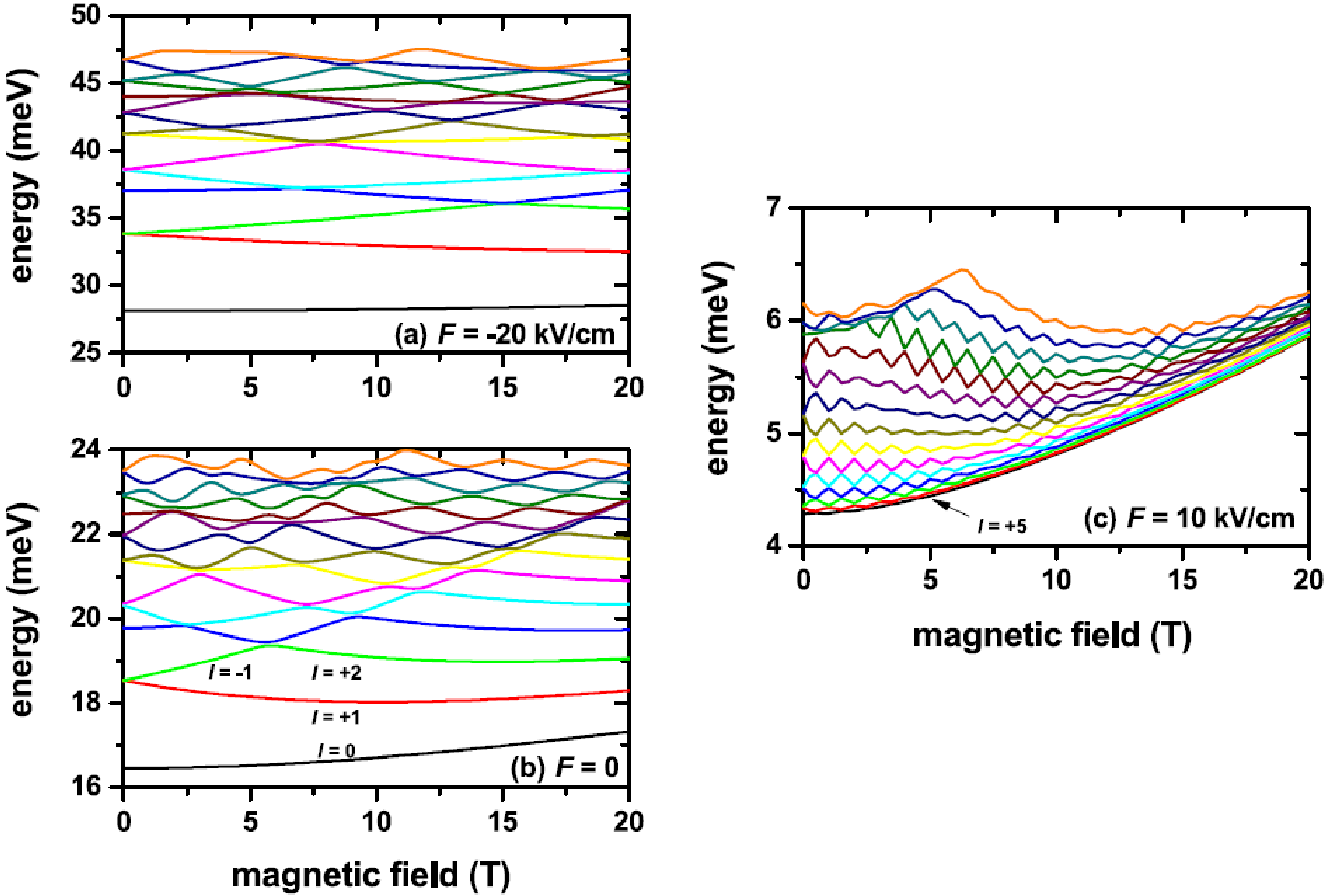
Energy levels for hole



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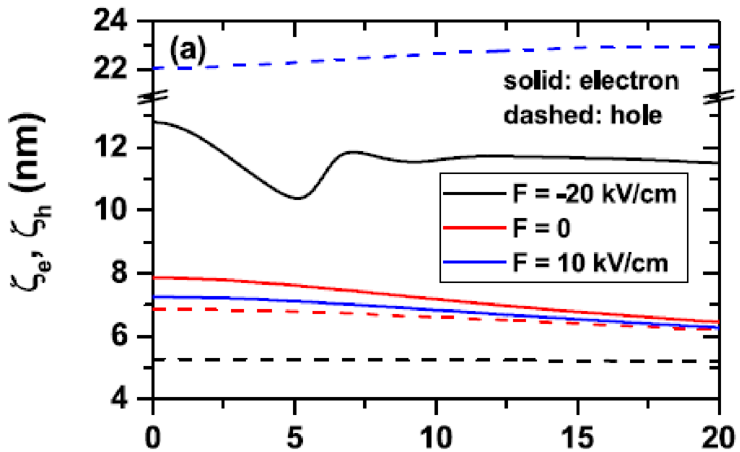
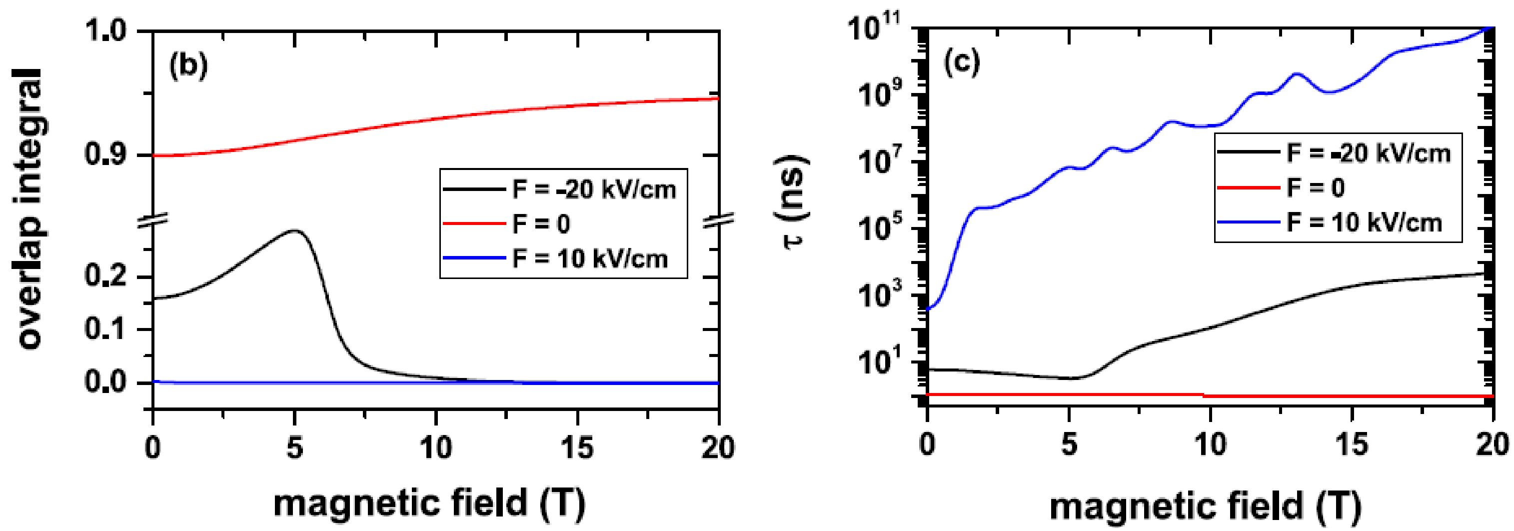
Results for exciton



$$\zeta_e = \langle \psi_e | z_e | \psi_e \rangle \text{ and}$$

$$\zeta_h = \langle \psi_h | z_h | \psi_h \rangle$$



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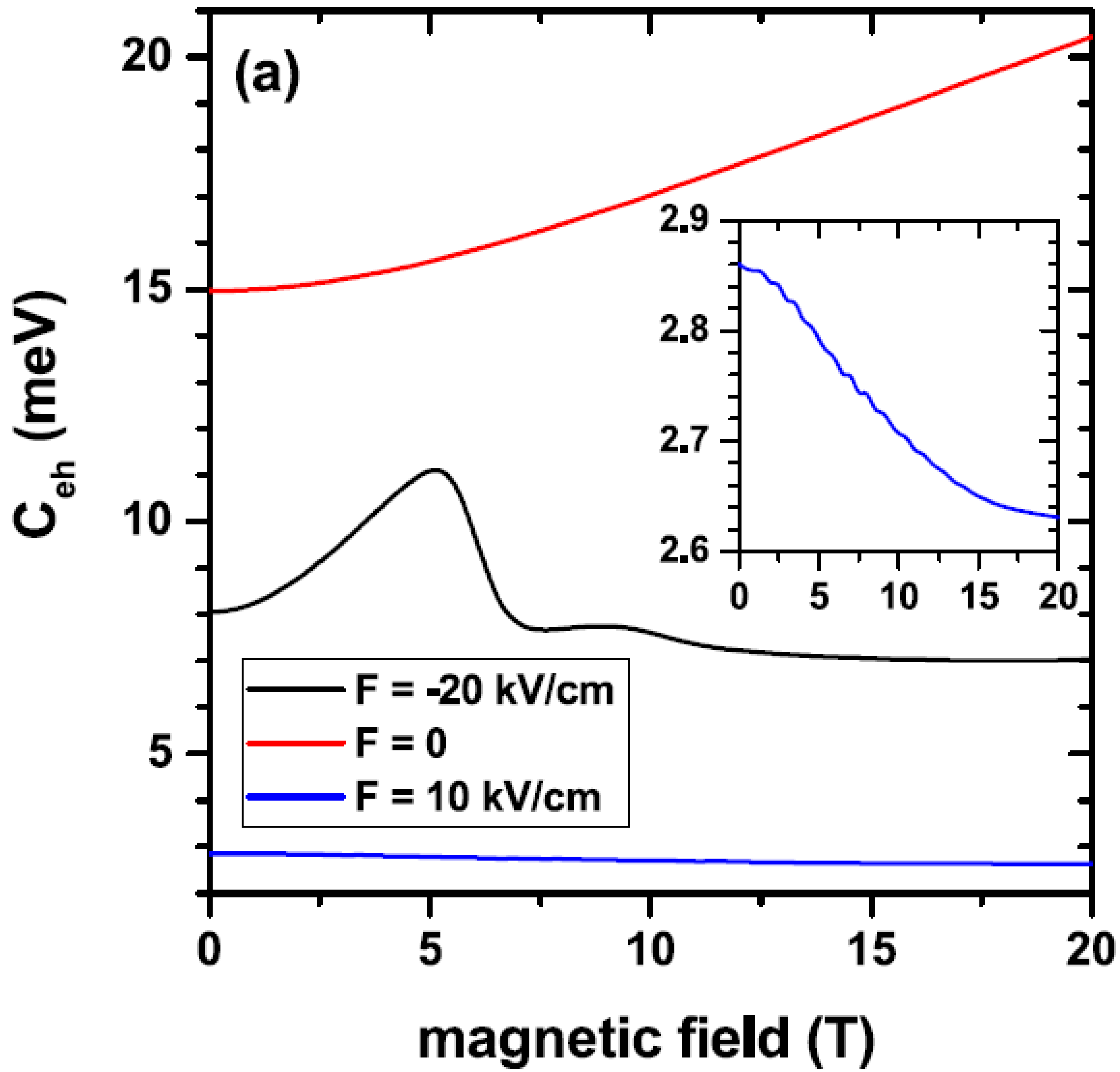
Results for exciton



Coulomb energy for a confined electron-hole pair. The inset shows the behavior for the *F* = + 40 kV/cm case

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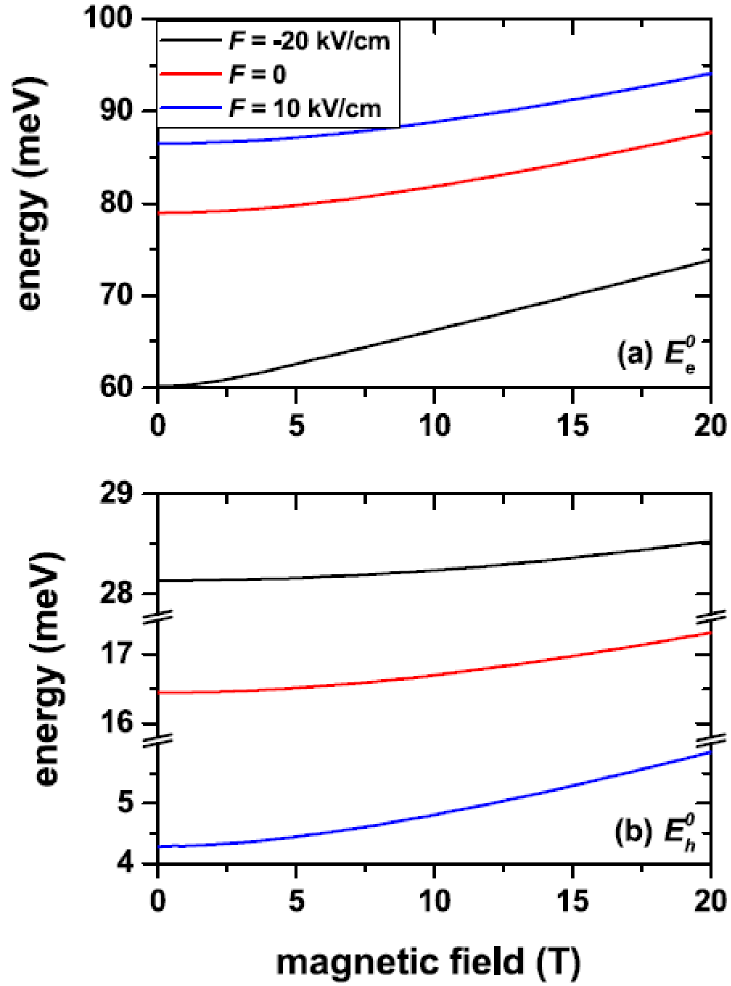
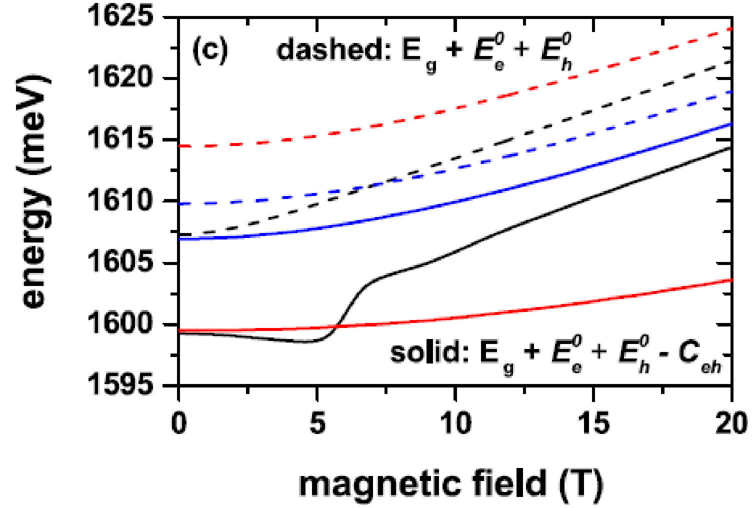
Results for exciton





Ground state energy, with $m = 0$, for an electron (a) and heavy-hole (b). In (c) the results come from the sum between the GaAs bandgap and the corresponding energy curves for electron and holes (PL-peak energy transition, dashed lines).

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Reference

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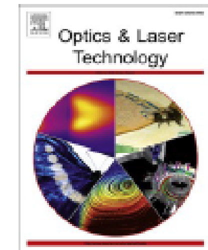

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Full length article

Exciton states in conical quantum dots under applied electric and magnetic fields

Christian Heyn [a], A. Radu [b], J.A. Vinasco [c], D. Laroze [c], R.L. Restrepo [d], V. Tulupenko [e,k], Nguyen N. Hieu [f,g], Huynh V. Phuc [h], M.E. Mora-Ramos [i], J.H. Ojeda [j], A.L. Morales [k], C. A. Duque [k,*]

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