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Polarizabilities of Shallow Donors in Quantum Well Wires

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Introduction When the Fermi wavelength of charge carriers becomes comparable to the sample dimension the motion in that direction becomes quantized. A dynamically one dimensional system is the one constrained in two dimensions and is often called a quantum well wire (QWW) /1, 2/. Modern growth techniques using compositional or electrostatic confinement need an effectively one-dimensional system. QWWs are usually doped and it becomes important to study impurity effects for device performance. The energy levels of hydrogenic-like impurities in QWWs are studied extensively /3 to 9/. As the dimensionality of the system decreases the binding energy of electrons to impurities increases. The binding energy decreases as the impurity is displaced away from the axis of the wire. There are some limited studies of polarizability in 2D QWs /10 to 13/. In this work, we investigate the polarizabilities of shallow donors in QWWs. The Hasse variational method within the effective mass approximation is used.

Donor polarizabilities In the presence of weak applied electric field in the growth direction (z-direction), the Hamiltonian for the donor electron is

$$H = -\nabla^2 - \frac{2}{r} + \eta z + V_w(x,y) \quad , \tag{1}$$

where we use $a^* = \hbar^2\epsilon_0/m^*e^2$ and $R^* = m^*e^4/2\hbar^2\epsilon_0^2$ as the units of length and energy, respectively. $V_w(x,y)$ is taken as the infinite barrier potential which confines the carrier in QWW for $x \ge w_x$ and $y \ge w_y$ where w_x and w_y represent the dimension of the rectangular wire. The electric field term is written in terms of the dimensionless field $\eta = |e|a^* F/R^*$ thus, η is a measure of the electric field strength.

The polarizability α is defined by

$$E(\eta) = E(0) - \frac{1}{2}\alpha\eta^2 \quad . \tag{2}$$

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