Neutral and Charged Donor in a 3D quantum dot

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Negatively charged donors are one of the simplest "many body" systems, therefore they can be used as test for the electron-electron interaction. The presence of a nanostructure influences the properties of the charged donor and provides us with a "simple" lab to study the behaviour of the electron-electron interaction. A wide literature exists on the negatively charged donor in quantum wells, which has shown the existence of spin-singlet spin-triplet transitions for negatively charged donors when the donor center is placed away from the well center. Since modern techniques allow the production of quantum dots containing one, two or more electrons and the doping of the semiconducting structures is of great importance for physical and technological reasons, it is reasonable to wonder what is the behaviour of the charged donor in the presence of the extra confinement provided by a quantum dot, with respect to the quantum well.

We investigated the neutral and negatively charged donor in a quantum disk modeled as a quantum well in the z-direction and a parabolic confinement in the xy-plane. We compared two different techniques to compute the highly correlated two electrons state that can be used for the solution of the problem: the finite difference method and the fractional dimensional method. The finite difference method has already been used effectively to the tackle the problem of the off center charged donor in quantum wells[1]. The fractional dimensional method has been used to study the neutral and charged center donor[2]. We calculated the energy of the ground and excited states of the system. The dependence of such energies on the strength of the parabolic confinement, the position of the donor with respect to the center of the quantum disk and the presence of an external magnetic field applied along the z-direction are investigated.

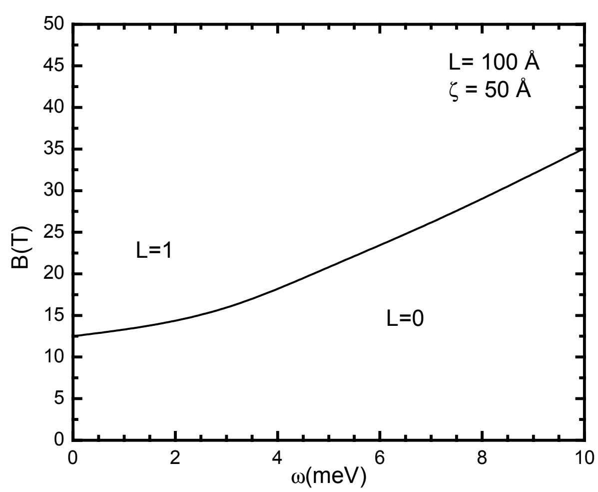

Figure 1 Phase diagram for a quantum disk of thickness 100 Å , when the donor is at the edge of the quantum well along the z-direction

We present our results for the case of a quantum disk in GaAs/AlGaAs with a thickness of 100 Å. In particular we found that the ground state binding energy of the charged donor increases with increasing frequency of the parabolic confinement at low magnetic field, e.g. for a disk with a thickness of 100 Å this means $B < 10$ T. On the other hand it is practically unaltered at high magnetic fields, i.e. for the same thickness it means $B > 10$ T. For the first excited state we found that the binding energy decreases with increasing parabolic confinement. As a consequence of this behaviour we found that the presence of a parabolic confinement in the xy-plane shifts the magnetic field where the singlet-triplet transition happens as compared to the case where no parabolic confinement is present (see Fig.1). Thus, the lateral confinement stabilizes the singlet state.

We also studied higher excited states of the neutral donor and negatively charged donor, and analyzed the effect of the donor position, the magnetic field and the strength of the parabolic potential on the system's wave function through the calculation of the correlation functions.

References:

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