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Maximum Density Droplet State in Quantum Dot Atoms and Molecules

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The effects of magnetic field on the stability of a "maximum density droplet (MDD)" state, in which all electrons are spin polarized and occupy successive angular momentum states, are studied for artificial atoms and molecules. For the artificial atom the MDD state is reconstructed to a lower density droplet with increasing magnetic field. This reconstruction is accompanied by a redistribution of charge which abruptly changes the area of the electron droplet. The MDD state is more unstable in the artificial molecule due to magnetic depopulation of antisymmetric states.

Key words: Magnetic field, quantum dot, artificial atom, artificial molecule

Introduction

We have recently fabricated a circular disk-shaped quantum dot, and observed atom-like properties of electronic states such as shell filling and beyance of Hund's rule[1]. These properties are all associated with the high degree of cylindrical symmetry as well as the parabolicity in the lateral confinement. In the presence of magnetic field (*B*-field) vertical to the disk plane the electronic states are readily modified, and the *B*-field dependence is well outlined by that of the single-particle Fock-Darwin states in the low *B*-field. However, as the *B*-field increases, the effect of Coulomb interactions becomes enhanced, and leads to a variety of transitions in the many-particle ground state (GS). In this paper we first discuss the effect of *B*-field on the electronic states of artificial atoms in the vicinity of filling factor 1. A stable electronic phase, so called "maximum density droplet (MDD)" is well defined at the filling factor of 1[2, 3]. We show that as the *B*-field increases, MDD becomes consecutively reconstructed to the lower density droplet. For the next set after artificial atoms, we outline how vertically coupled two disk-shaped quantum dots can be employed to study the electronic states in artificial molecules. Symmetric and antisymmetric states are formed due to the vertical tunnel, and each of them has an identical set of lateral states. We observe an electron droplet state at the filling factor 1, which is similar to the MDD state observed in the artificial atom. This MDD-like state becomes significantly unstable due to magnetic depopulation of antisymmetric lateral.

Quantum dot atoms

Our quantum dot atoms are fabricated by making circular sub-micron mesas from a double barrier tunneling structure. The barriers and the well are made from AlGaAs and InGaAs, respectively. A Schottky gate is placed on the side of the mesa wrapping the double barrier structure[4]. The quantum dot is strongly confined by the heterostructure barriers in the vertical direction, and parabolically confined by the gate-induced depletion potential in the lateral direction. This lateral confinement leads to systematic sets of degenerate states. A Schottky gate is used to tune the number of electrons one-by-one, starting from zero. We study the electronic properties by measuring Coulomb oscillations as a function of longitudinal *B*-field.

As the *B*-field is increased, approaching the filling factor = 1, the electronic states become all degenerate in the spin-polarized lowest Landau level via a number of spin flips. This spin flip regime is naturally connected to the formation of MDD at the filling factor = 1. As the *B*-field is further increased, the MDD becomes consecutively reconstructed to the lower density droplet. We measure Coulomb diamonds (current vs drain voltage and gate voltage) in the *B*-field range before, at, and after the reconstruction of the electron droplet. A well defined diamond is observed before and after the reconstruction, whereas the diamond is significantly distorted at the reconstruction. This is explained in terms of a redistribution of charge during the reconstruction, because such a charge redistribution at the same time modifies the influence of background electrostatic potential against the electron droplet.

Quantum dot molecules

The quantum dot molecule has two quantum dot atoms vertically coupled via a tunnel barrier[5]. The tunnel coupling gives rise to a split Δ_{SAS} of symmetric and antisymmetric states. These two states have an identical set of lateral states, which are also the same as those for the quantum dot atom.

A signature of MDD is observed in the presence of *B*-field at the filling factor 1. However, in contrast to that in the quantum dot atom, the MDD is more unstable with magnetic field. This is assigned to the influence of magnetic depopulation of antisymmetric states because the filling of symmetric states are more favoured as the *B*-field is increased. This behaviour is also confirmed by Hartree-Fock calculation.

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