Integer Filling Factor Phases in Vertical Diatomic Artificial Molecules

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We investigate integer filling factor phases of many-N-electron (up to ~40) vertically coupled semiconductor quantum dot artificial molecules (AM’s) for different values of the inter-dot coupling \cite{1}. The experimental results are analyzed within local-spin density functional theory (LSDFT) \cite{2}, and we determine a simple lateral confining potential law that can be scaled for the different coupling regimes. Maximum density droplets composed of electrons in both bonding (B) and anti-bonding (AB), or just B states are revealed, and interesting isospin physics (e.g. “isospin-flip” transitions) occurs that may also be relevant to double quantum well bilayer systems.

(a) The AM devices are fabricated from a triple barrier structure with a central barrier thickness, b, between 2.5 nm (strong coupling) and 6.0 nm (weak coupling) \cite{1}. The current (I_0) flowing through two dots located inside circular mesas (diameter, D<1 \textmu m) is measured at a temperature \sim100 mK as a function of voltage between the substrate and top contact (V_d\sim0.2 mV), and voltage on the gate (V_g). The magnetic field (B//) is applied parallel to the current.

(b-d) Experimental B//-N phase diagrams for AM’s with b=2.5, 4.7, and 6.0 nm showing evolution of Coulomb oscillations (ground state electrochemical potentials). (b) is strikingly similar to a single dot phase diagram. We identify two threshold lines marking the end of the Fock-Darwin level crossings (filling factor, \nu_B=2), and the start of the spin-polarized compact maximum density droplet (MDD\textsubscript{B}, \nu_B=1). Only B states are relevant. The \nu_B=1 line originates from the N=2 singlet-triplet (S-T) transition. (c) and (d) are clearly very different to (b) since now AB electrons play a role as the inter-dot coupling is reduced. We can identify the onset of two cohabiting MDD’s- one is made of B states (MDD\textsubscript{B}), and the other is made of AB states (MDD\textsubscript{AB}), so we call this phase MDD\textsubscript{B+AB} (\nu_T=2 i.e., \nu_B=1 + \nu_{AB}=1). In the MDD\textsubscript{B+AB} phase, there are features (some connected by dashed lines) that we argue are due to the depopulation of AB-states. Cartoons of the arrangement of electrons in B and AB single particle states, for certain integer filling factors are shown as insets.

(e-g) Calculated B// -N phase diagrams for QM structures with b=2.5, 4.7, and 6 nm. The low and high field boundary of each integer filling factor phase of finite width is drawn. Only values corresponding to N=4M (M=3-9) are meaningful here, and we assume the two dots are identical. The effective lateral harmonic oscillator potential has strength kN_{B}^{-1/4}, where k=6.91 meV is deduced from a fit to the onset of MDD\textsubscript{B} in (b), and N_{B}(N_{AB}) is the number of electrons in B (AB) states at 0 T. This we found crucial to achieve a good quantitative description of the phases. Consistent with the experimental data, as the inter-dot coupling is reduced, we find the stability of the MDD\textsubscript{B} decreases, and the MDD\textsubscript{B+AB} phase appears in which isospin transitions occur. Within certain phases (\nu_T=4 and 2), regions of different isospin, I_Z=(N_B-N_{AB})/2, are identified by LSDFT, and I_Z is generally found to increase with N and B//. Additionally, we discuss the range of stability of the phases, the \nu_B=2 phase for the b=2.5 nm AM, and the \nu_T=4 phase (\nu_B=2+\nu_{AB}=2) for the b=4.7 and 6.0 nm AM’s for which LSDFT predicts isospin transitions that are 'spin-flip-driven'.
