Qubit manipulation: Coupled quantum wires in a magnetic field

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Coupled quantum wires that are short ballistic 1D electron systems recently attracted attention because controllable coupling can be achieved, making such devices interesting for solid-state quantum information processing. Superposition states are formed by tunnel coupling between the quantum wires. They can be altered by an applied magnetic field along the wire direction leading to tunable wave function mixing. To implement such quantum logic devices in quantum circuits, one would like to understand and have detailed control over all involved electron levels which calls for a realistic modeling. Two GaAs quantum wells are vertically stacked and are separated by a thin AlGaAs tunnel barrier. A top-gate voltage can be used to tune the electron density, i.e. to shift the ground state from the top to the bottom well or to vary the degree of wave function mixing among the two wells. By locally depleting the two-dimensional electron gas of the double quantum well structure, one is able to produce two electrostatically defined quantum wires on top of each other (Fig. 1 (c)). We have calculated the electronic eigenstates as a function of magnetic field. Our numerical calculations of the energy spectrum reproduce the experimental transconductance maxima [1] very well. These maxima directly image the subband edges of 1D ballistic electron transport in electron waveguides. One can clearly see level anticrossings to occur at certain magnetic fields. For those energies, the tunneling coupling is significantly reduced. Such a structure can be considered a qubit with logic states that are represented by the presence of the electron in the upper or lower quantum wire, respectively, and a coupling window that allows for electron transfer between these wires. By varying the magnetic field, one is able to switch between the different logic states.

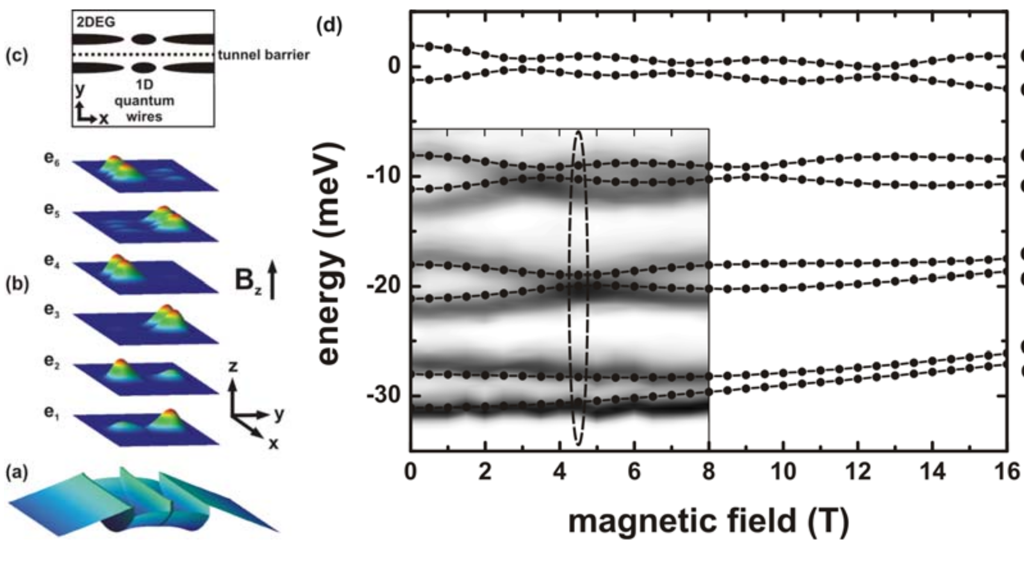

Fig. 1: *(a) 2D conduction band profile of the coupled quantum wires, (b) Electron wavefunctions (ψ^2) for the six lowest states at a magnetic field of 4.5 T, (c) Schematic cross section of the electron systems, (d) Comparison of the calculated energy spectrum as a function of magnetic field with experimental data of the transconductance maxima [1]*

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