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Semiconductor Qubits for Quantum Computation

Course 5: Semiconductor Physics and Nanoscience

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Abstract

The borders of conventional computation are not yet exceeded, a new field attracted much attention over the last years. The heart of Quantum computation is the quantum mechanical nature of our world and all physical systems. Classical computers, like every PC around, only base on the classical rules of nature.

Though it is still not clear, scientists assume that quantum computers may have powers which will eventually exceed the ones of normal computers. That is the reason why many research groups all around the world are trying hard to build up a quantum computer, but still have not succeeded.

To tell, why a quantum computer can be much faster than a conventional one is quite simple. The classical storage unit is the well known "bit". It can have 2 different values: 0 and 1. The new quantum mechanical bit (called "qubit")can not only have two values 0 and 1, but also a superposition of those. Therefore the number of possible qubit values is infinite.

From a theoretical point of view it can be shown that algorithms using qubits are much faster than classical computers. The most popular application is "Shor's prime factorization algorithm". Theoretically, one needs 2^n steps on a classical computer and only n^2 steps on a quantum computer, with n bits or qubits, to factorize an integer.

To realize a qubit as a physical system, one can use different approaches, but the base is always a 2-level system:

(i) energy levels of atoms

(ii) photon polarization

(iii) spin state of electron or nucleus in a magnetic field

At the moment physicists are still trying hard to realize the most simple quantum computer. There are different approaches and this paper deals especially with the semiconductor qubit implementations:

(i) ^{31}P doped Silicon heterostructure: Kane-concept

(ii) Si/Ge heterostructures

(iii) Self-assembled Quantum Dots

(iv) Quantum Dots in 2-dimensional electron gas

(v) NV^- center in diamond

The readout process of a qubit is another problem, but there were some advances in the last years. In case of a spin qubit one can only have to 2 values for measurement(!), spin up and down. To determine the spin state one can use an electrical defined Quantum Dot.

It was achieved to store the spin of an electron for several μs.

The problem indeed is to manipulate the qubit and to build some CMOS like structures, the CNOT - gate. With the universal CNOT-gate at hand, which is the equivalent to the classical NAND-gate, it will be possible to simulate any quantum computer and any algorithm.