SPIN QUBITS IN ARTIFICIAL MOLECULES

DESCRIPTION FOR THE GENERAL PUBLIC

Semiconductor quantum dots (QDs) are very small (nanometer-size) artificial structures, like pyramids or domes, formed from one semiconductor compound surrounded by another compound. In semiconductors, one deals with two kinds of "particles" (charge carriers): negatively charged electrons and positively charged holes (the latter being just an empty place left after removing an electron). With a proper choice of materials, a QD can be a trap for both electrons and holes. Each of these carriers, apart from its charge, has an intrinsic angular momentum referred to as "spin", which is an entirely quantum degree of freedom. While similar to atoms in terms of quantized energy levels, the QDs offer the advantages that their properties can be tailored either in the manufacturing process or by applying electric or magnetic fields.

Spins of carriers confined in QDs can be used to store information, which can enhance the functionality of nano-devices, as compared to the current technology standard, where only charge is relevant. This concept, known as *spintronics*, is exciting but still far from the ultimate breakthrough that would be brought in if the intrinsically quantum nature of spin is exploited. Implementing this revolutionary idea of *quantum computing*, requires extremely high level of control over the confined spins and their environment, in order to perform desired manipulations (computations) and avoid the destruction of the very gentle *quantum coherence* by external noise (referred to as *decoherence*).

The researchers at the Schottky Institute at Munich Technical University are able to manufacture QD structures in which quantum spin states can be preserved over long time periods. They can also experimentally control the spins of individual electrons and holes in QDs and to test their state by investigating the properties of light emitted by these structures. However, the degree of control and protection against environmental noise is still far from satisfactory. In order to understand these limitations, the scientists at Wrocław University of Science and Technology, in collaboration with researchers from the Institute of Physics of the Polish Academy of Sciences, developed theoretical models of carrier states in QDs and their dynamics driven by external fields, as well as by uncontrollable environmental influences.

In the present project, these research groups join their efforts in the search for structures that will allow a much more controllable and stable implementation of quantum computing using semiconductor spins. They have chosen to produce and investigate *quantum dot molecules*, that is, systems composed of two coupled QDs, like a molecule made of two atoms. They will describe the dynamics of spin states in such self-assembled QD-molecules, identify and characterize the relevant dephasing processes, and develop methods for the control of confined spins and of their environment in order to reduce its destructive effect. Achieving this goal requires strong experimental-theoretical collaboration in order to design and manufacture appropriate QD-molecules, find appropriate methods to initialize, control and read out the spin states, and understand the mutual interactions between the charge carriers in QD-molecules and nuclear magnetic moments (which are one of the main reasons for decoherence). The researchers believe that accurate theoretical modeling in combination with sophisticated manufacturing procedures and advanced experimental techniques will allow them to reduce the environmental effects and to develop new control schemes, which may pave the road to a semiconductor-based quantum computing device.