Hybrid quantum control in single solid-state systems

Quantum mechanics has been and still is a breakthrough not only in understanding physics but also in technology. It quickly found its application in science and engineering, from the revolution in physics and chemistry themselves to micro- and nanotechnologies. Finally, it became possible to design and create systems in which electrons are spatially limited by nanometer pieces of matter, semiconductor material, called quantum dots. These are one of the systems that will revolutionize the technology we know in a few years, and they can already be found in the latest TV models.

The dynamically developing fields that use quantum mechanics are quantum information processing, encryption, and telecommunication, which are to bring unprecedented security to information and its transmission. The upcoming breakthrough seems to be the creation of a fully functioning quantum computer, whose capabilities in certain problems will be incomparably greater than traditional computers. The elementary component of such a computer will be quantum bits called *qubits*, which are elementary units of quantum information. One candidate for the realization of a qubit is electron *spin*, which is an intrinsic property of particles offered to us by their quantum nature, with no counterpart in the classical world. The spin of the electron, or more precisely, its projection on some axis, can take two values, which can be thought of as an up and down arrows. These are two *quantum states*. The peculiarity of a quantum system is that it can, in a sense, be in both of these states at once, and two complex numbers describe their proportion. Graphically, this can be expressed as a point on a sphere, commonly called the *Bloch sphere*. Each point on it corresponds to a different *superposition* of states. All operations performed on quantum states are described as rotations on this sphere, i.e., moving a point along its surface.

The electron spin in a quantum dot can be controlled by visible laser light, but it is not a universal method. The easiest way is to use microwaves, but these are very long waves (those used in our kitchens are 12 cm long), which greatly limits the miniaturization of future chips. So it seems that we need other tools to fully exploit the potential of quantum systems. In addition to spin qubits, also *charge qubits* are of great interest. Such a qubit is created by an electron interacting electrostatically with a *hole*, i.e., the lack of an electron in the place where it should be. The latter are so-called quasiparticles that theoretically describe the positive charge left behind by the missing electron. Here, the control is also done with laser light, but a recently invented method requires precise control of laser pulses.

Acoustic control comes in handy here, i.e., using sound waves, vibrations of atoms in solid materials. With its help, we can easily circumvent both the issue of precise control of pulses in charge qubits and the problem of microwave length by using a thousand times shorter acoustic waves. As part of the project, we will propose methods to control both types of qubits by combining laser excitation with the "shaking" of a quantum dot using acoustic waves. We will derive equations describing the behavior of spin and charges when excited in this way and then solve them numerically using high-performance computers. This will allow us to assess how precise control is possible and how much the environment, which is always waiting to destroy quantum information, affects the effectiveness of the methods we propose.