Instytut Fizyki Molekularnej Polskiej Akademii Nauk

Rozprawa doktorska

Rozdzielanie i detekcja kwantowego splątania par Coopera

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Abstract

This PhD thesis presents the studies and the theoretical analyses related to the development of a highly efficient and continuous solid-state source of spatially separated spin-entangled electrons as well as nano-devices that allow to detect and investigate entangled electrons effectively. That kind of a source, which is integrated with other electronic elements and magnetic detectors, will have a great impact on the future quantum processors development. They can provide, for example, entanglement distribution which is essential to synchronize quantum circuits and which enables secure communication.

The presented study is based on entangled electrons of Cooper pairs that naturally occur in the ground state of a superconductor. Thanks to the usage of a strong Coulomb interaction in a double quantum dot system the two electrons of the pair can be spatially separated. Subsequently, the separated electrons move towards two different output channels while still maintaining their entanglement. The possibility of using the ferromagnetic electrodes connected to each quantum dot of Cooper pairs splitter, which can work as spin detectors transforming the spin information directly into an electric current due to a spin-dependents electronic transport in the ferromagnetic materials, was theoretically studied as well.

The analysis of an efficiency of the separation of Cooper pairs in systems, where the quantum dots are connected to the two superconducting leads, or to the superconducting and two normal leads was conducted. The cotunneling regime, in which a simultaneous tunneling of electron pairs occur through the whole system, was thoroughly investigated. Additionally, the Aharonov-Casher effect, related to the effective spin precession - a travelling magnetic dipole is affected by an electric field due to the presence of Rashba spin-orbit interaction, was discussed in this system.

The possibility of using the ferromagnetic electrodes as an effective detector of quantum entanglement was also examined. The model of the future experiments investigating the entangled state, with realistic parameters in order to set the proper margins on the required spin-polarization of the ferromagnetic detectors and noise detection limit, was shown. Finally, the method of extracting the quantum information using the classical quantities as an electric current was demonstrated.

The results presented in this dissertation confirm the possibility of a practical application of superconductors as a source of quantum entangled electrons pairs and indicate the possibility of experimental detection of the quantum entanglement state in a solid-state systems.