Instytut Fizyki Molekularnej Polskiej Akademii Nauk

Rozprawa doktorska

Korelacje spinowe i detekcja kwantowego splątania par Coopera metodą nierówności Bella i świadka splątania

mgr Piotr Busz

Promotor: prof. dr hab. Jan Martinek

Promotor pomocniczy: dr inż. Damian Tomaszewski

Zakład Nadprzewodnictwa i Przemian Fazowych

Poznań 2018

Abstract

This doctoral thesis presents theoretical studies on models of experimental determination of spin correlation and detection of quantum entanglement of spatially separated electrons of Cooper pairs.

The presented models are based on electric current cross correlation measurements and, simpler to perform, DC current measurements. The model based on current cross correlation measurements uses a previously analyzed in the literature system for the separation and detection of quantum entangled electrons. In the model based on DC current measurements we propose a modification of a system used for experimental Cooper pair splitting. We analyze various detection techniques using Bell inequality tests and the relatively new entanglement witness method, to determine which is the most effective for a given system. The system behavior is analyzed in different parameter ranges to find the suitable detection range.

In the first part of the thesis we present a model system for the determination of spin correlation and detection of quantum entanglement of Cooper pairs from current cross correlation measurement data. In this system, spatially separated quantum entangled electrons are emitted from a source to two conducting channels with magnetic detectors. Each detector can measure the instantaneous current for different magnetization directions. By analyzing each detection method we determine the minimal detector efficiencies necessary for correct detection of quantum entanglement of a Cooper pair in the singlet state based on current cross correlation. By proper optimization we demonstrate that under certain experimental conditions entanglement detection is even possible with magnetic detectors of any efficiency, and we determine the minimal number of current cross correlation measurements necessary for correct detection of quantum entanglement of a Cooper pair in the singlet state.

In the second part of the thesis we present a model of the system allowing for the determination of spin correlations and the quantum entanglement detection of Cooper pairs from DC current measurements. We analyze a Cooper pair splitter with ferromagnetic electrodes playing the role of magnetic detectors. A superconducting electrode is a natural source of Cooper pairs in this system. Cooper pairs are extracted and split due to the non-local proximity effect and the attachment of a double quantum dot with a strong Coulomb repulsion on each dot. We investigated the influence of the effective exchange field related to the presence of the ferromagnetic electrodes and their magnetization configurations on the intensity of the DC current flowing in the system. For certain optimal system parameter values the complex spin dynamics induced by this exchange field is demonstrated not to distort the measurement data on the spin correlations of electrons of Cooper pairs. For this system we propose methods for the determination of spin correlations and the detection of quantum entanglement of Cooper pairs based on DC current measurements. We compare the ranges of applicability of different detection methods. For each detection model we determine the minimal spin polarization of the ferromagnetic electrodes necessary for the detection of quantum entanglement of Cooper pairs. Also in this system we demonstrate the possibility of optimization for correct detection of quantum entanglement using ferromagnetic electrodes with any spin polarization.

An advantage of the presented detection models over those proposed so far is their easier experimental implementation due to the use of DC current measurements and the reduced system requirements, e.g. in terms of detector efficiency. The proposed methods can be used for experimental detection of quantum entanglement of spatially separated electrons of Cooper pairs, and contribute to the development of the electronic technology of quantum computing.