Superconducting double quantum dot hybrids in parallel InAs nanowires

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Nowadays, the experimental realization of so-called Majorana fermions is intensively researched in the field of quantum electronics. These exotic quasi-particles with non-Abelian statistics are topologically protected against external noise in contrast to conventional quantum bit concepts. Due to this attractive feature, they are promising candidates to perform fault-tolerant operation of quantum computers in the future.

Majorana fermions are predicted to appear in a one-dimensional chain consisting of an array of quantum dots (artificial atoms) and superconductors. The basic building block of such an array is a parallel quantum dot connected to a superconductor. In this reduced system, one can study the interplay of the quantum dots mediated by the superconductor and explore the undergoing hybridization processes, which can maintain a long-range interaction in a chain. In the thesis, I examine these processes experimentally and explore their impacts in different limits.

The superconducting-double quantum dot hybrids in question are created in a novel material of parallel InAs nanowires connected by a thin superconducting layer. The advantage of these semiconductor nanowires is that the distance between the quantum dots can be minimized, thus maximizing the interaction between them. Additionally, the epitaxial superconducting layer provides a high-quality interface with the semiconductor inducing a strong proximity in the wires. By integrating the wires into nanocircuits, I investigated the behavior of the superconducting hybrid at ultra-low temperatures.

In the weak coupling limit of the quantum dots, I detected a strong Cooper pair splitting taking place in the system. By measuring positive correlations between the currents flowing through the parallel quantum dots, I showed that despite the presence of the strong Coulomb repulsion, a higher splitting efficiency can be achieved in the double-nanowire geometry compared to single-nanowire ones. The details of the experiments and results are summarized in Chapter 3 of the thesis.

In the strong limit, I investigated the interaction of two Andreev bound states. Since the separate bound states residing in the two quantum dots were formed by a joint superconductor, the states hybridized and constituted an Andreev molecule. By discovering the excitation spectrum of the system, I identified the spectral peculiarities of the molecular state, which were also reproduced by simple numerical simulations. The realization of this 2-atomic Andreev molecule is discussed in detail in Chapter 4 of the thesis.

In Chapter 5 of the thesis, I examine the superconducting-double quantum dot hybrid in the Coulombic limit where the superconducting electrode is replaced by a finite-size superconducting island acting as a quantum dot as well. In this case, the quantum dots form such an artificial, 3-atomic molecule, where superconducting correlations are present on the central atom. By investigating the stability diagram of the superconducting island systematically, I demonstrated the appearance of this special molecular state, which corresponds to a 3-atomic Andreev molecule.