DESCRIPTION FOR THE GENERAL PUBLIC (IN ENGLISH)

(State the objective of the project, describe the research to be carried out, and present reasons for choosing the research topic - max. 1 standard type-written page)

This project is devoted to studies of the properties of nanosctructures composed of semiconductor and superconductor materials. Such hybrids allow to engineer a novel phase of matter – topological superconductivity (discovery of topological phases of matter was awarded the Nobel Prize in 2016) and host, long predicted, exotic quasiparticles that are their own antiparticless – Majorana fermions. Those appear as zero-energy modes at the ends of the semiconductor proximitized by the superconductor and are protected by the superconducting gap defining a topologically protected quantum bits. They allow for realization of quantum gates by the means of braiding operations, hence rendering the superconducting hybrids as perfect candidates for implementation of fault-tolerant quantum computation. Despite the possible practical implementation of the hybrids, they constitute a unique tool for studies of fascinating physics of super- and semiconductors at the nanoscale.

The hybrid superconductors are realized by connecting semiconducting nanostructures – as nanowires – to mesoscopic superconductors. However, only this year it become possible to create structures with a richer geometry – by creating crossing branches of the wires, structures as quantum crosses and quantum loops become available. This opens unprecedented opportunity to employ interference and non-local effects for studies of topological superconductivity. This project provides the immediate answer to that development and undertakes the task of theoretical description of such structures to guide and interpret forthcoming experiments.

We will explain how a quantum interference in a quantum ring – well known in the form of Aharonov-Bohm effect in semiconducting rings – can be used to determine the topological properties of the proximitized device. We will also study interference of quasiparticles – combination of electron and holes – inside a Josephson junction defined on a quantum loop that will constitute a superconducting counterpart of tunable single- and double-slit interferometers. Moreover the project will develop tools applicable in analysis of voltage biased Josephson junction, whose present description still relies on methods developed for conventional superconducting devices, and do not allow to tackle the full spectrum of the physical phenomena present in hybrid nanostructures.

The successful realization of the project will be allowed by the application of state-of-the-art computational methods for quantum transport. The studies will provide conductance and current response of the hybrid nanostructures – quantities that can be directly measured and compared in the experiments. Understanding the physics of superconducting hybrid devices brought by the project will not only satisfy the fundamental curiosity in discovering the laws of condensed matter physics at the nanoscale, but will also contribute to the pursuit for creation of fault-tolerant quantum computing, that takes advantage of the non-Abelian nature of Majorana bound states.