Investigation of the hybrid structures hosting Majorana Bound States.

In 1937 Ettore Majorana ushered a new symmetry into to the realm of quantum physics. In his research he proposed a seemingly impossible state of affairs – for a particle to be simultaneously its own antiparticle. For a typical particle, e.g. an electron, an interaction with its antiparticle, a positron would imply an instantaneous annihilation within a flash of „light" of total energy of 1.022 MeV. For a Majorana fermion, this effect would be quite different – it would stay in eternal suspense, unfortunately to this date it has not been experimentally verified. To meet those demands, scientists from entirely different domain of physics, solid state physics, proposed conditions for artificial creation allowing for Majorana quasiparticle to exist.

In „Cosmos" TV series, an astrophysicist Carl Sagan once said: „If you wish to make an apple pie from scratch, you must first invent the Universe." Stemming from this idea, devising a system where Majorana quasiparticle could manifest required imagining a theoretical model, which after years of trial and error came to fruition, with a creation of a „pie", consisting of following ingredients: a superconductor – a material, which cooled to the near absolute zero conducts electricity with no resistance and shields the external magnetic field, a strong spin–orbit coupling nanowire – few micrometers long row of atoms, which interaction between motion of particle and its spin influences the energy levels of atoms and magnetic field – separating the energetic levels with regards to the spin, favoring one of them. All of this together make up the topological superconductor, a *Universe* (spanning across few micrometers) where Ettore Majorana's 80 year old idea came to life – a Majorana quasiparticle.

Quasiparticle, as it does not behave as *any* other, other particle – something between a fermion and a bozon, an *anyon*. Majorana quasiparticles can be employed in quantum computing due to the fact, that as anyons they behave in accordance with non–abelian statistics which enables them to be used in the *braiding* process – a quantum computing method based on the order of position swapping of quasiparticles It allows for saving quantum information within the order of particles and not within themselves, therefore bypassing one of the crucial problems regarding quantum computing – decoherence, a time dependent loss of information about a quantum state due to its interaction with the rest of the quantum world.

Quantum computing can be an answer for Moore's law saturation and therefore a bottleneck in information processing that our technology and therefore, our civilization is on the verge of. As a result, developing a „*braiding*–friendly" nanodevice employing Majorana quasiparticles is undoubtedly essential for quantum computing and also for progress of science as a whole. In this grant, we propose a theoretical development and investigation of multi–dimensional hybrid nanodevices capable of hosting and manipulation of Majorana quasiparticles. Study of such systems should surpass the experimentally acquirable tuning via magnetic and electrostatic means with the study of spin–orbit coupling, different superconducting energy gaps resembling different materials and especially the geometrical composition of studied devices.

Therefore, we suggest an investigation of such systems by an analysis of its energetic structure and electronic transport properties. While having those information, we can propose novel solutions, which could harness exceptional phenomena related to the Majorana quasiparticles even better. Additionally, a study of topological phase transitions in nanodevices should widen the scope of its understanding via the use of complementary method and benefit the interpretation of intricate web of processes taking place within the nanodevices capable of creating Majorana quasiparticles.

Proposed research raise fundamental problems of topological phenomena in condensed matter physics and will allow for understanding of properties of topological states of matter e.g. zero–bias conductance, fractional AC Josephson effect or non-abelian statistics. Moreover, innovative nanodevices can allow for expanding the knowledge of such systems and can stimulate the further experimental research or even an application in *braiding* of quasiparticles in working quantum computing systems. Thorough analysis of density of states and transport characteristics of nanodevices can allow for fine–tuning of properties systems for future experimental realization and ultimately in the realm of quantum computing. Time–dependent calculations concerning the nanowires and other geometries can shed additional light on the process of MBS formation within topological states of matter. In order to create a quantum computer capable of changing the tomorrow, we have to investigate the nature of necessary phenomena by today.