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Press Release

Hamburg, 26.07.2019

Towards topological quantum computation

Quantum computation is one of the most challenging goals of worldwide research activities. While quantum bits (qubits) of various types have already been realized, the operation of a quantum computer still suffers from the sensitivity of qubits to external perturbations. Therefore, more robust qubits have to be identified which are naturally protected. Majorana quasiparticles emerging in a special class of superconductors or superconductor-based hybrid systems may solve the problem due to their intrinsic topological protection. A Majorana fermion is an exotic particle that is its own antiparticle. Its existence has been predicted about 80 years ago by theoretical physicist Ettore Majorana. While Majorana fermions are still ambiguous in the field of particle physics, the condensed matter counterpart, the Majorana quasiparticle, has been observed as localized bound states at the ends of hybrid semiconducting or magnetic nanowires on superconductors. Similar to Majorana bound states in quasi-one-dimensional hybrid systems, chiral Majorana modes are predicted to appear at the edges of quasi-two-dimensional (2D) superconductor-based hybrids. Utilizing state-of-the-art transport measurements or local probe techniques, chiral Majorana modes have recently been investigated in various types of experimental platforms, such as quantum Hall systems or magnetic thin films proximity-coupled to conventional superconductors. However, due to the lack of atomically well-defined geometric structures the nature of these Majorana edge modes could not be investigated in detail so far.

In the July 26th issue of the journal „Science Advances“, a group of physicists from the University of Hamburg headed by Prof. Roland Wiesendanger, in collaboration with theorists from the University of Illinois at Chicago, reports on the first successful atomic-scale interface engineering of a 2D magnet-superconductor hybrid system to realize chiral Majorana edge modes at the periphery of magnetic islands prepared on a conventional superconducting surface. They have utilized a low-temperature scanning tunneling microscope (STM) to directly visualize the chiral Majorana edge modes at atomic-scale spatial and very high energy resolution. In particular, they succeeded for the first time to map the chiral Majorana edge modes near the atomically sharp edges of well-defined monolayer-high magnetic Fe islands on top of an oxygen-reconstructed superconducting Re(0001) surface. Most interestingly, they observe the emergence of the chiral Majorana edge modes near the edges of Fe islands only if these are grown on an oxidized Re surface while the

Majorana modes are surprisingly absent if the magnetic Fe islands are in direct contact with the Re surface. This clearly implies that the atomically thin oxide layer plays a crucial role for driving the investigated magnet/superconductor (Fe/Re) hybrid system into a topologically non-trivial regime as a prerequisite for observing chiral Majorana edge modes. This surprising experimental finding is explained by a theoretical study of the model-type Fe/Re hybrid system. Indeed it turns out that the oxygen layer tunes the coupling strength and the crystallographic relationship between the magnetic Fe island and the superconducting Re substrate such that a topologically non-trivial superconducting state of the hybrid system is achieved. This type of interface engineering of magnet-superconductor hybrids to realize chiral Majorana edge modes, as demonstrated now by the Hamburg group, constitutes a giant leap towards the realization of topological quantum computation.

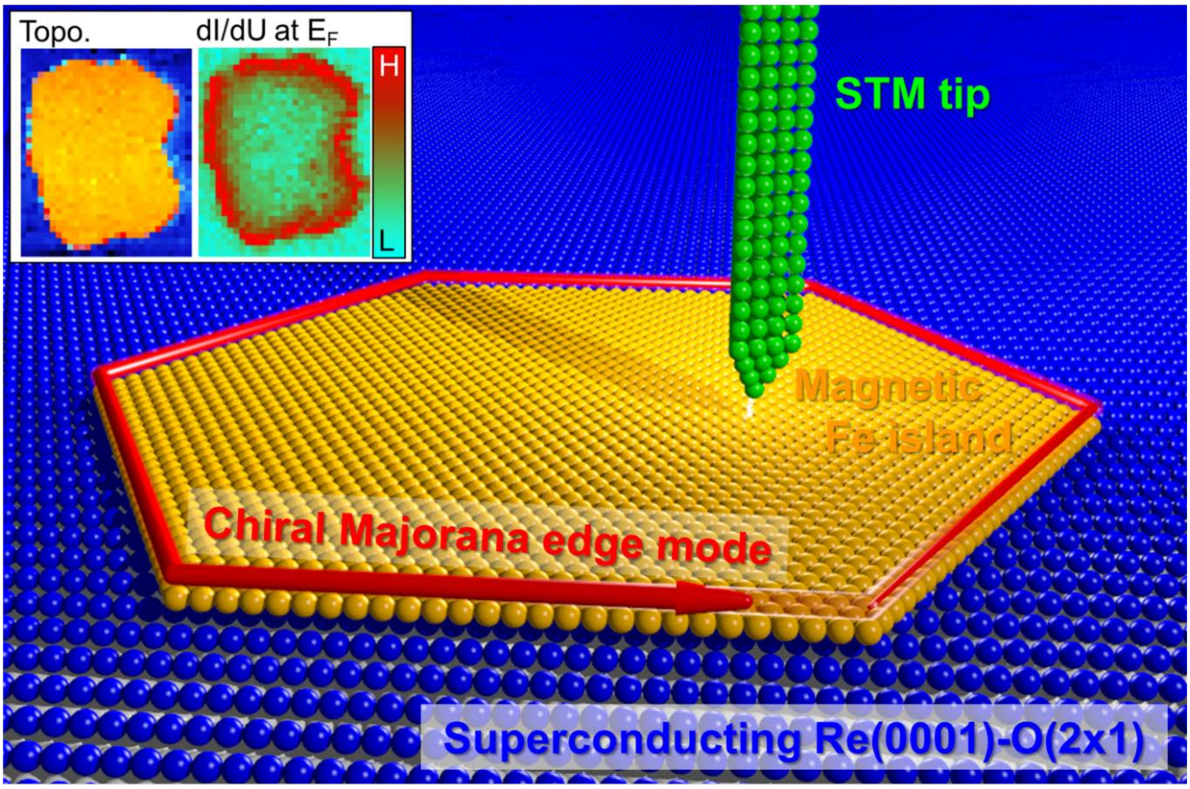

Figure: Illustration of the chiral Majorana edge mode (red arrow) emerging at the periphery of a 2D topological superconductor consisting of a magnetic iron (Fe) island (yellow spheres) on top of an oxygen-reconstructed (blue spheres) superconducting rhenium (Re) surface (gray spheres). The insertion of the atomically thin oxygen layer allows for an adjustment of the interaction and crystallographic relationship between the Fe island and the Re surface such that the hybrid system is driven into a topologically non-trivial superconducting state. Inset: The measured topographic image of the nano-scale Fe island on the oxygen-reconstructed Re surface (left) and the simultaneously measured differential conductance map at the Fermi energy (right) clearly reveal the localization of the Majorana edge mode at the island's periphery.

Original publication:

A. Palacio-Morales, E. Mascot, S. Cocklin, H. Kim, S. Rachel, D. K. Morr, R. Wiesendanger,
Atomic-scale interface engineering of Majorana edge modes in a 2D magnet-superconductor hybrid system,
Sci. Adv. **5**, eaav6600 (2019).

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