Designer quantum states in van der Waals heterostructures

Quantum designer materials that realize electronic responses not found in naturally occurring materials have recently attracted intense interest. For example, topological superconductivity [1] - a key ingredient in topological quantum computing – may not exist in any single material. However, using designer van der Waals (vdW) heterostructures, it is possible to realize the desired physics through the engineered interactions between the different components. We use molecular-beam epitaxy (MBE) to grow islands of ferromagnetic CrBr3 on a superconducting NbSe2 substrate [2]. This combines out of plane ferromagnetism with Rashba spin-orbit interactions and s-wave superconductivity and allows us to realize topological superconductivity in a van der Waals heterostructure [3,4]. We characterize the resulting one-dimensional edge modes using low-temperature scanning tunneling microscopy (STM) and spectroscopy (STS).  Achieving topological superconductivity in a vdW heterostructure facilitates its incorporation in future device structures and potentially allows further control through e.g. electrostatic gating. Furthermore, the designer approach can be extended to realize other artificial quantum materials [5].

References

[1] M. Sato, and Y. Ando, Topological superconductors: a review. Rep. Prog. Phys. 80, 076501 (2017).

[2] S. Kezilebieke, M.N. Huda, O.J. Silveira, V. Vaňo, J. Lahtinen, R. Mansell, S. van Dijken, A.S. Foster, P. Liljeroth, Electronic and magnetic characterization of epitaxial CrBr3 monolayers, Adv. Mater. 33, 2006850 (2021).

[3] S. Kezilebieke, M. N. Huda, V. Vaňo, M. Aapro, S. C. Ganguli, O. J. Silveira, S. Głodzik,  A. S. Foster, T. Ojanen, P. Liljeroth, Topological superconductivity in a designer van der Waals heterostructure, Nature 588, 424 (2020).

[4] S. Kezilebieke, V. Vaňo, M.N. Huda, M. Aapro, S.C. Ganguli, P. Liljeroth, J.L. Lado, Moiré-enabled topological superconductivity, arxiv:2011.09760.

[5] V. Vaňo, M. Amini, S.C. Ganguli, G. Chen, J.L. Lado, S. Kezilebieke, P. Liljeroth, Artificial heavy fermions in a van der Waals heterostructure, arxiv:2103.11989.

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Peter Liljeroth (born 1975, Finland) received his Ph.D in physical chemistry and electrochemistry at the Helsinki University of Technology in 2002. Subsequently, Liljeroth was a post-doc at Utrecht University (2003-2006) and IBM Zurich Research Laboratory (2006–2007) working on low-temperature scanning probe microscopy. Before his present appointment (2011-) as a professor at the Department of Applied Physics, Aalto University (Finland), he was an assistant professor at Utrecht University (2007–2010). Prof. Liljeroth has 97 publications. He was awarded the ERC Starting Grant ("Atomically precise nanoelectronic materials") in 2011, ERC Advanced Grant (”Artiﬁcial designer materials”) in 2018, and he currently holds a post of an Academy Professor from the Academy of Finland (2019-2023).