Roles of structural defects on vortices in atomically-thin superconductors

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Surface state superconductivity, which emerges in metallic electronic states formed by a few-monolayer deposition of metallic elements on a semiconducting substrate, has unique properties if compared with other two-dimensional (2D) superconductors. Because of the thermal stability through the self-organized structural reconstruction, atomically well-ordered structures can be formed in macroscopic dimensions. Basic properties such as atomic structure and electronic states are well characterized by standard surface science techniques including scanning tunneling microscopy (STM), and one can modify the properties through controlled deposition on them.

One ubiquitous feature of the 2D electronic systems is the natural presence of atomic steps. Atomic steps are considered to strongly affect electron transport because they potentially decouple neighbouring surface terraces. So far, we have demonstrated that the steps of the $\sqrt{3}\times\sqrt{3}$-In/Si(111) surface superconductor behave as a Josephson junction and hold elongated vortices called Josephson vortices, whose elongation depends on the coupling strength [1]. On striped incommensurate (SIC) phase of Pb/Si(111) the steps are found to block the propagation of the superconducting proximity effect and enhance it when they are located within the coherence length [2].

In two-dimensional superconductors usual orbital pair breaking of the superconductivity by in-plane magnetic field can be suppressed, allowing the Zeeman pair breaking to determine the critical magnetic field. Unfortunately, they do not have protection against perpendicular fields. In the present study using STM, we found the protection of the superconductivity under perpendicular magnetic field in narrow terraces of the Pb/Si(111) surface superconductor whose width is comparable to the coherence length. It is presumably due to the suppression of orbital pair breaking by the step confinement. Unlike the case of nanowire network [3], where the protection persist until the magnetic length becomes equal to the half of the terrace width, the step-confined terrace survives up to the magnetic length equal to quarter of the terrace width, indicating the different role of the steps from the edge of the samples. Since the density and the coupling strength of the steps can be controlled, our study opens a way to design 2D superconductors that maintain the pairing under magnetic field in all directions.

References

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