Uniaxial-Strain Control of Nematic Superconductivity in $Sr_xBi_2Se_3$

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Nematic states are characterized by rotational symmetry breaking without translational ordering [1-4]. Well-known examples of nematic states are in liquid crystals and in electron liquids. Recently, nematic superconductivity, in which the superconducting gap spontaneously lifts the rotational symmetry of the lattice, has been discovered [5-10]. However, the pairing mechanism and the mechanism determining the nematic orientation remain unresolved. According to the Ginzburg-Landau (GL) theory, nematic superconductivity belonging to the two-dimensional E_u representation can exhibit linear coupling to the external symmetry-breaking field (SBF), here assumed to be strain [5]. Therefore, a first step is to demonstrate control of the nematicity through application of an external SBF, such as uniaxial strain, and to determine the sign and strength of coupling to the lattice deformations.

The goal of this thesis, is through application of an externally applied uniaxial strain, utilizing a custom-made piezoelectric actuator-based strain cell with high strain throughput and homogeneity, to control the superconducting nematic states in $Sr_xBi_2Se_3$. Specifically, we seek to induce switching among the possible essentially degenerate nematic superconducting states. Through such experiments, we are able to determine the sign and strength of the nematic coupling constant. This work, demonstrating in-situ uniaxial-strain control of topological superconductivity by making use of its nematic nature, must be interesting for the expanding community of topological materials science as a key step toward future engineering of the Majorana quasiparticles in a novel way.

Toward the goal two major achievements are reported. Firstly, we propose a newly designed and constructed piezoelectric actuator-based strain cell that minimizes effects originating from the asymmetry of the original strain cell design [11], in particular with minimal bending moments, by placing the sample at the axis of mirror symmetry of the device to balance out the reactive forces [12]. The high performance is then simulated by finite element analysis (FEA). Secondly, through externally-applied uniaxial stress, we aim to control the nematic orientation of the superconductivity, as measured by the in-plane upper critical field, of $Sr_xBi_2Se_3$. To this end, we affix a sample in the custom-made strain cell and measure the strain-dependent magnetoresistance using a vector magnet.

The summary of the results are as follows. We have constructed a symmetry-

motivated design of a piezostack-based uniaxial strain cell that transmits largely homogeneous strain thus reducing sample bending and lowering risk of sample failure. FEA indicates that placing the sample offset to the axis of the mirror symmetry indeed causes an increase of strain inhomogeneity up to 10%, both at room temperature and at 4.2 K. Furthermore, we found that this bending reduces the overall achievable strain down to 30% of its maximal value without the bending.
The enhanced homogeneity of the strain has an advantage that, in strain-sensitive materials, the broadening of the material's properties will be avoided. We also experimentally demonstrate the potential of our constructed device by tracking the displacement of the anvils of the strain cell with a parallel plate capacitor. The full range of motion of the piezo stacks were demonstrated at room temperature. With a sample and at 0.9 K, we achieved a uniaxial strain of -1.5%, which is enough to induce electronic change in typical materials. Therefore, this newly constructed strain cell design was evaluated to be suitable for investigating the nematic superconductivity of $Sr_xBi_2Se_3$.

With the improved strain cell, we succeeded in controlling the nematic superconductivity in situ by uniaxial strain. The strain dependence of the in-plane H_{c2} was measured. In addition to the two-fold anisotropy of the in-plane H_{c2}, a weak six-fold component, indicating additional nematic domains, were observed under small strains. These domain structure were suppressed with increasing compressive strain. Given that the dominant domain was stabilized, we determined that the sign of the nematic coupling constant is negative, i.e. compression favors Δ_{4y} state.

To conclude, we provide the first experimental demonstration of uniaxial-strain control of nematic superconductivity in doped Bi_2Se_3. Firstly, suppressing minor domains while stabilizing the Δ_{4y} state. Secondly, we determined the sign of the nematic coupling constant. These findings should provide bases toward resolving the open issues of this highly attractive superconductor. Additionally, this work points to possible engineering of topological nematic superconductivity by uniaxial strain.

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