Contribution ID: **424** Type: **Contributed Oral**

M2Or4B-07: Increased nonreciprocal current in iron-based superconductor antiferromagnet interface

Tuesday 20 May 2025 18:00 (15 minutes)

Superconductivity in iron-based materials is an active area of research due to the unconventional nature of the electron-electron interactions. The simplest material in this family is the layered 11 type iron chalcogenides. Iron selenide(FeSe) when alloyed with tellurium(Te) can alter many superconducting properties. The layered nature of this material allows for unique interactions with other materials due to the 2D nature of the interface.

Nickel phosphorus trisulfide($NiPS_3$) is a Van der Waals material with a bandgap of 1.8eV. The layered material undergoes an in-plane zig zag type antiferromagnetic(AFM) ordering at a Neel temperature of 150K. To explore interactions between materials, a 56nm thick sample of $FeTe_{0.7}Se_{0.3}$ was placed, on metal contacts deposited on silicon dioxide, using the hexagonal Boron Nitride(hBN) pickup method. The sample was partially covered with a 13nm thick sample of $NiPS_3$ and all materials were covered with 10nm of hBN. The partial covering allows resistive measurements on the heterostructure and the hBN encapsulated segment of the iron-based superconductor. Assembly occurred in a nitrogen environment with <0.1 ppm O_2 and H_20 to minimize environmental impacts. Four other samples were measured with similar results to those presented.

Resistivity of both materials remains similar until the onset of superconductivity.
The superconducting transition shows the Berezinskii-Kosterlitz-Thouless(BKT) transition, which describes a phase change to bound vortex-antivortex pairs. The heterostructure displays a sharper superconducting transition and increase of the critical temperature of the BKT transition. The Halperin-Nelson model that describes the BKT transition in resistive measurements was fitted to both the $FeTe_{0.7}Se_{0.3}$ and heterostructure measurements. The heterostructure showed an increase in BKT transition from 13.1K ($FeTe_{0.7}Se_{0.3}$ sample) to 13.8K, representing a rise of approximately 0.7K. These results were confirmed when a power law fit was applied to the voltage response of an applied current across various temperatures. The nonlinear I-V characteristic indicates a transition where V is proportional to I^3.

Effective pining energy was estimated according to the thermally activated flux flow theory. The effective pinning energy was extracted from resistivity measurements using an Arrhenius equation. The effective pinning of the heterostructure was 35% higher than the encapsulated sample at zero field. This higher pinning value decreased but remained 20% higher in the heterostructure under a 9T magnetic field. The increase in effective pinning energy enhances the critical current density of the heterostructure. At 2K the critical current density is increased 50% from 0.528 MA/cm^2 in the encapsulated sample to 0.799 MA/cm^2 in the heterostructure.

The superconducting diode effect(SDE) was recently demonstrated in materials that lack inversion and time reversal symmetry. The substitution of Te into FeSe can induce structural changes and topological phases. The breaking of time reversal symmetry occurs from the proximity effect of the AFM. This symmetry breaking leads to a nonreciprocal critical current with an upper and lower critical current. This unequal flow of charge can be exploited to produce low power electronics. Many displays of SDE rely upon an external magnetic field or ferromagnetic junction which can negatively impact superconductivity. The field-free nature of this heterostructure was demonstrated from rectification of a square wave pulse at 1 Hz with a current above the lower critical current for over one hundred cycles. A figure of merit is the diode efficiency which is defined as the difference of the absolute values of the positive and negative current divided by their sum. This device shows a maximum efficiency of 1% at 2K which is not uncommon for simple structures. The device is tunable by an external magnetic field, but a better way to increase efficiency is the inclusion of the AFM in improved superconducting diode devices such as nano bridges or junctions.

In conclusion, a field free superconducting diode was formed from the interface of an iron based superconductor and an AFM. An increase of critical current and field pinning was explored, which has not been reported previously.

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Session Classification: M2Or4B - Growth & Characterization of REBCO and Iron-based Superconductors