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Fermi Surface Studies of the Nematic Superconductors FeSe1-xSx Using Combined Chemical and Applied Hydrostatic Pressures

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Introduction

Nematic electronic order is believed to be responsible for the unusual pairing mechanism in different unconventional superconductors. Iron-based superconductors offer a vast playground for understanding nematic electronic phases. The nematic phase of the superconducting FeSe is found in the absence of magnetism at ambient pressure [7]. However, a magnetic phase is stabilized at high pressure and superconductivity is enhanced four-fold [1]. By combining chemical pressure with hydrostatic pressure in the series $FeSe_{1-x}S_x$, it is possible to separate the nematic and magnetic phases [2,3]. Hydrostatic pressure is a unique tuning parameter to study the characteristics of a nematic quantum critical point in the absence of long-range magnetic order in a single material and to gives access to the electronic structure and correlations of new magnetic and structural phases.

Experimental

Using the 45T DC hybrid magnet at the National High Magnetic Field Laboratory in Tallahassee, we performed quantum oscillation studies on different single crystals of $FeSe_{1-x}S_x$ with varying sulfur concentrations of x = 0.04 to x = 0.18 (Fig. 1C and D), complementing previous studies on x~0.11 [4]. Measurements were performed as a function of hydrostatic pressure up to 22 kbar and temperatures as low as 0.35 K. Based on these measurements, we could trace the evolution of the Fermi surface across different nematic and tetragonal phases. From the temperature dependence of the quantum oscillation's amplitude, we determined the effective mass of several distinct orbits to understand the changes in the strength of electronic correlations in the proximity of nematic critical points and the high superconducting region.

Results and Discussion

Our study focuses on understanding the evolution of the complex Fermi surfaces and electronic interactions across the nematic phase transition in $FeSe_{1-x}S_x$ using applied hydrostatic pressure up to 22 kbar in different single compositions (see Fig. 1C for x=0.04 and Fig. 1D for x = 0.18). We observed quantum oscillations in the normal state above 20T in high magnetic fields up to 45T in the low temperature regime. On the border of the nematic state, we find an unusual Lifshitz-like transition associated with the disappearance of a small Fermi surface, while other orbits continue to expand with applied pressure. Similar trends in the electronic structure were also observed as a function of chemical pressure in $FeSe_{1-x}S_x$ [3]. Our findings are in stark contrast to the suggested reconstructed Fermi surface in FeSe under applied external pressure in vicinity of magnetic transitions [5, 6]. The effective masses are largest inside the nematic state and they monotonically decrease avoiding divergence in the tetragonal phase. Our findings provide the key ingredients of the electronic structure related to the emergence and disappearance of the nematic electronic phase, its role played in stabilizing superconductivity and how nematic critical fluctuations manifest [4,7].

Acknowledgements

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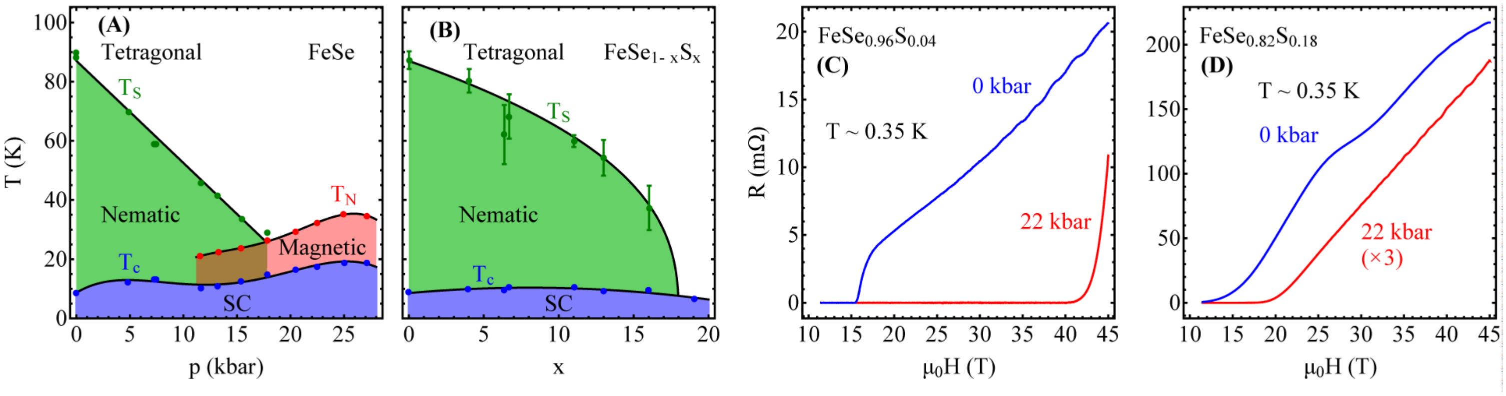

Fig. 1 Phase diagrams as a function of a) applied hydrostatic pressure for FeSe [1, 6] and b) chemical pressure for $FeSe_{1-x}S_x$ (by iso-electronic substitution of Se by S) at ambient pressure [3]. d) The evolution of superconductivity and quantum oscillations under applied pressure in c) $FeSe_{0.96}\,S_{0.04}$ and d) $FeSe_{0.82}S_{0.18}$.