

AC magnetostriction as a new probe of superconducting response masked by ferromagnetism

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Superconductivity (SC) and ferromagnetism (FM) are two fundamental quantum orders that usually compete with each other, and their coexistence in a single material provides a unique platform for studying quantum phase competition. The Eu-based iron pnictide $\text{EuFe}_2(\text{As}_{1-x}\text{P}_x)_2$ is such a system, in which superconductivity coexists with the ferromagnetism of the Eu^{2+} sublattice near $x \approx 0.2$ [1]. However, the huge magnetic signal from the Eu^{2+} moments usually masks the superconducting response in conventional measurements such as magnetization and resistivity, which has long hindered a microscopic understanding of the SC-FM interplay [2,3].

Recently, Chai and co-workers [4] addressed this challenge using a bulk-sensitive AC composite magnetoelectric technique. In this method, the crystal is bonded onto a piezoelectric substrate, and the voltage induced by an AC magnetic field is used to directly measure the complex AC magnetostrictive coefficient $(d\lambda/dH)_{\text{ac}}$. Because the superconducting and magnetic contributions have opposite signs, a single measurement simultaneously resolves the upper critical field H_{c2} , the irreversibility field H_{irr} , and the magnetic phase boundaries, including those invisible to standard probes. The assignments are further supported by a framework combining composite magnetoelectric thermodynamics, collective vortex dynamics, and spin-lattice coupling in several typical superconducting families [5].

With this technique, the team mapped the complete H - T

phase diagrams of two samples of $\text{EuFe}_2(\text{As}_{1-x}\text{P}_x)_2$, one with $T_c < T_{\text{FM}}$ and the other with $T_c > T_{\text{FM}}$, and revealed two distinct mechanisms by which magnetism suppresses superconductivity. In the crystal with $T_c < T_{\text{FM}}$, a quantitative Jaccarino-Peter fit of the high-field $H_{c2}(T)$ branch gives a negative effective exchange field, showing that the applied field partially compensates the internal exchange field from the Eu sublattice. Once the multi-domain ferromagnetic state sets in, H_{c2} drops below this compensated baseline, indicating a weakening of the compensation together with magnetic scattering between domains, while domain walls promote vortex-antivortex nucleation that reduces H_{irr} . In contrast, in the crystal with $T_c > T_{\text{FM}}$, the strongest suppression of H_{c2} occurs near the spin-polarized-paramagnetic crossover and the magnetic triple point, demonstrating that short-range spin correlations and the boundaries of the multiphase coexistence regime act as highly efficient pair-breaking centers [4].

These results indicate that the anomalies of H_{c2} and H_{irr} can serve as thermodynamic fingerprints of the underlying magnetic state in unconventional superconductors: static domain structures dominate the suppression in one regime, while dynamic spin fluctuations dominate in the other [4]. The work thus provides the first comprehensive bulk-thermodynamic picture of the SC-FM interplay in this material family, complementing earlier microscopic imaging studies.

From a methodological perspective, this study paves a new way to explore hidden or “invisible” superconducting phases in magnetic and strongly correlated materials where tradi-

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tional probes fail. When combined with local probes such as magnetic force microscopy, the AC magnetostriction approach is expected to become a general tool for mapping competing orders, and may open an avenue for identifying superconducting phases in a broader class of quantum materials.

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