Abstract

The rich phase diagrams with multiple orders and the interrelationship between these orders in the iron-based superconductors have attracted wide attentions. A tetragonal to orthorhombic structural phase transition is found to be coinciding with, or closely prior to a stripe-type antiferromagnetic phase transition. The electronic nematic phase forms when the C_4 rotational symmetry is broken, while the translational symmetry is retained. The superconductivity emerges to a large extent in the presence of the nematic order or the nematic fluctuations, which indicates they may share the same origin. Clarifying the driving force of the nematic phase transition, whether is the underlying lattice, the orbital or the spin, is very helpful for understanding the superconducting mechanism in the iron-based superconductors.

As a phase sensitive probe that probes multiple collective excitations of controlled symmetry, Raman scattering is an ideal method to investigate the fluctuations in the high temperature phase and the broken symmetries across the phase transition. In this research, we use electronic Raman spectroscopy to study the origin of the nematic phase transition.

This thesis is organized as follows. In chapter 1, we introduce the general properties of the iron-based superconductors and summarize the previous Raman studies on the iron-based superconductors. Chapter 2 is concerned about the basic principles of Raman scattering and the aspects on the Raman scattering experiment. In chapter 3 to 5, we present the main works on the iron-based superconductors and the Cr-based superconductors:

1. Investigation of the nematic phase transition in iron-based superconductors. In order to clarify the origin of the nematic phase transition, we performed electronic Raman scattering measurement for the representative parent compound of the 122 family iron-based superconductors $EuFe_2As_2$ and $SrFe_2As_2$. Critical fluctuations of the XY symmetry are observed in a large temperature range from room temperature to the structural phase transition

temperature T_S. The critical fluctuations increase with cooling as $\propto (T-\theta)^{-1}$, indicating a hidden phase transition of Pomeranchuk instability at θ, which is over 60 K below T_S. Moreover, an acoustic phonon of the tetragonal to orthorhombic lattice distortion is observed together with the nematic orbital fluctuations, from which we settle the electron-phonon coupling strength $V_{ep} \approx 100\ cm^{-1}$, smaller than the Jahn-Teller energy needed to lift the nematic transition from θ to T_S, which indicates that the structural phase transition at T_S and the hidden nematic transition at θ have different origins.

2. Comparative study of the strain-induced nematicity in the iron-based superconductors. The splitting of the doubly degenerate Fe-As in plane displacement E_g phonon is a fingerprint of the lattice C_4 rotational symmetry breaking in the iron-based superconductors. We study the temperature evolution of the E_g phonon on two differently prepared sample XZ surfaces in $EuFe_2As_2$. We demonstrate that the E_g splitting energy is directly proportional to the lattice nematic order parameter. From a fine polished surface, the onset of the C_4 symmetry breaking is observed at the nominal structural phase transition temperature T_S, which suggests that the fine polishing leaves the samples free of residual internal strain. However, cutting the side surface induces permanent C_4-symmetry breaking strain fields that are distinct from dynamic nematic fluctuations above the tetragonal to orthorhombic structural transition. From the cut surface, the E_g mode is found to broaden with cooling at above T_S, which may provide an explanation for the observed anisotropy above T_S in various measurements of detwinned samples.

3. Phonon spectra and the electron-phonon coupling in superconductor $K_2Cr_3As_3$. We performed a polarized Raman scattering study of quasi-one-dimensional superconductor $K_2Cr_3As_3$. We observe two and three phonon modes with the A_1' and E' symmetries, respectively. Surprisingly, one of the A_1' phonons exhibits a Fano lineshape, nearly temperature-independent from 12 K to room temperature, which is characterized by a coupling strength factor $1/q = -0.29$. Under the BCS framework, the electron-phonon coupling strength is not enough to get $T_c = 6.1$ K, which suggests that $K_2Cr_3As_3$ is an unconventional superconductor. Our theoretical analysis indicates that this mode involves the

in-plane movement of the Cr atoms, which directly modulates the Cr-Cr bonding identified to be critical to the magnetic fluctuations in this system. Although our results are not sufficient to make a conclusive statement about the origin of superconductivity in this material, they are suggestive of a lattice-mediated coupling between electrons and magnetic fluctuations, which may be of crucial importance in elaborating models for superconductivity in this material.

Chapter 6 is the concluding remarks, which summarize the results and discuss about the prospects.

Keywords: iron-based superconductors, electronic Raman spectroscopy, phononic Raman spectroscopy, nematic order, nematic fluctuations, electron-phonon coupling, Cr-based superconductor