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論 文 要 旨

THESIS SUMMARY

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要旨（英文 800 語程度）
Thesis Summary（approx.800 English Words ）

The superconducting transition temperature T_C in the monolayer FeSe grown on $SrTiO_3$ is over 40 K, while it is only 8 K for bulk FeSe. Our previous research revealed that electron doping and superconducting gap size depend on the $SrTiO_3$ surface superstructures. Different $SrTiO_3$ superstructures have different amounts of oxygen vacancies, which generate extra electrons and contribute to doping. Considering that the oxygen vacancies, which construct the $SrTiO_3$ surface superstructures, are relatively localized features, it is interesting to investigate how the $SrTiO_3$ superstructure locally modulates the superconductivity in monolayer FeSe.

FeTe is isostructural to the FeSe and can be regarded as the parent material of the superconducting FeSe since it undergoes an antiferromagnetic (AFM) phase transition at 65 K, like the other iron-based superconductors. However, bulk FeTe holds a bicollinear AFM order, which differs from general iron-based superconductors. Furthermore, the extra Fe can modulate the AFM order from bicollinear order to helix order, and the electron doping from Fe could be the key reason. According to theoretical calculation and the experimental results, the localized Fe spin seems to interact with the conduction electrons, indicating that FeTe locates at an intriguing place on the phase diagram, which means that FeTe has similar properties to the heavy-Fermion materials (Kondo lattice). These facts show that the FeSe(Te) system is near the quantum critical point where various ground states compete, resulting in superconductivity similar to heavy-Fermion materials. However, there are not many works on atomically thin film growth of such systems except for the case of FeSe, and the local influence of the substrate in terms of electron doping and structural effects has rarely been reported. Therefore, the purpose of this thesis is to clarify how the $SrTiO_3$ substrate locally modulates the ground states of FeSe and FeTe films at the atomic scale.

To this end, we employ the $SrTiO_3(001)$-$\sqrt{13}\times\sqrt{13}$ substrate surface, which can be reproducibly fabricated in annealing in an oxygen atmosphere ($P_{O2} \approx 1\times10^{-5}$ Torr). Then FeSe and FeTe films are grown by molecular beam epitaxy, and the thickness is monitored with reflection high energy electron diffraction. Finally, the films are measured by scanning tunneling microscopy/spectroscopy (STM/STS) at 5 K.

Concerning monolayer FeSe/$SrTiO_3$-$\sqrt{13}\times\sqrt{13}$, due to the Se-rich deposition, the extra Se atoms intercalate between the $SrTiO_3$ substrate surface and the monolayer FeSe, and they block electron doping from the substrate, leading to a non-superconducting monolayer FeSe. Thus, the film needs a post-annealing process to achieve a superconducting state. In the atomically resolved topographic images of the sufficiently annealed monolayer FeSe, I observed bright 2×3 cells showing "Z" patterns arranged in √13×√13 periodicities, which lowers the rotational symmetry on monolayer FeSe to C_2 symmetry. Furthermore, atom-resolved STS measurements show the local tunneling conductance and superconducting gap size variation within the √13×√13 unit cells. The quasiparticle interference patterns also reveal the C_2 feature in the QPI intensity, and the deduced band structure consists of the electron-like band measured by the angle-resolved photoemission spectroscopy (ARPES). And the size of the vortex was confirmed to be the same order as $SrTiO_3$-√13×√13 cell (~ 2 nm), indicating that the substrate may influence the FeSe superconductivity. The results exhibited the influence of $SrTiO_3$-√13×√13 substrate surface on the deposited thin film in two ways: 1. alternating the surface morphology of monolayer FeSe; 2. local variation of the superconducting order parameter of monolayer FeSe due to the combination of electron doping variation due to oxygen vacancies and the short coherence length of FeSe.

Similar to FeSe, the monolayer FeTe is deposited in a Te-rich condition, and the extra Te atoms also block electron doping from the substrate. However, the post-annealing process cannot remove the extra Te atoms; thus, the influence of the $SrTiO_3$ substrate was limited to structural distortion. In the atomically resolved topographic images of monolayer FeTe, bright 2×3 cells arranged in √13×√13 periodicities were also observed, leading to a similar C_2 symmetric √13×√13 pattern, which indicates that the $SrTiO_3$-√13×√13 substrate surface similarly influences the deposited monolayers FeSe and FeTe. In the STS measurements, dI/dV spectra with asymmetric Fano-shaped features were observed near the Fermi level, showing the interaction between the relatively localized Fe moments and the conduction electrons. Furthermore, two types of Fano-shaped dI/dV spectra were observed to have a spatial relation to the √13×√13 periodicities. This is evidence that the structural distortion from the $SrTiO_3$ substrate can also modulate the electronic structure of monolayer FeTe. Similar to the FeSe case, the length scale of the Kondo cloud was revealed to be identical to the size of the √13×√13 unit cell.

These results undoubtedly reveal the ability of substrates to influence the ground state of atomically thin films deposited on them from both structural and electronic origins.