Summary of thesis:

Effect of impurity scattering and electron correlations on quasiparticle excitations in iron-based superconductors

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When a new class of materials exhibits superconductivity, determining the superconducting gap structure and symmetry is one of the key issues to elucidate the mechanism of the superconductivity. In iron-based superconductors, a large number of experiments have been performed, and they have reported a variety of gap structures from nodal to nodeless superconducting gaps depending on the materials. On the other hand, several gap structures and symmetries are suggested theoretically such as *s*-wave, *d*-wave, and other exotic ones without time-reversal symmetry. This is in sharp contrast with the copper-oxide-based superconductors, where *d*-wave superconductivity has been established theoretically and experimentally. In the case of iron-based superconductors, however, a decisive experiment on the superconducting gap structure and symmetry has been missing.

In order to solve this issue, we study the effect of impurity scattering on the superconducting gap structure of iron-based superconductors $BaFe_2(As_{1-x}P_x)_2$ in a controllable manner using electron irradiation. By using electron irradiation, we can introduce atomic-scale point defects into samples and control the number of defects in the same sample with the dosage of the irradiation. In this thesis, we report on the evolution of the magnetic penetration depth, which is a direct measure of quasiparticle excitations in the superconducting states, with increasing irradiation.

The magnetic penetration depth exhibits non-monotonic change of the temperature (T) dependence with increasing point defects, where the T dependence changes as T-linear, T^2, exponential, and T^2. This behavior is markedly different from the impurity effect observed in the copper-oxide-based superconductors, where the temperature dependence of penetration depth monotonically changes from T-linear to T^2 with increasing impurity scattering. The observation of the non-monotonic change of the penetration depth is explained by a two-band model assuming sign-reversed *s*-wave superconductivity with accidental nodes, providing bulk evidence

that the superconducting symmetry is A_{1g}.

The interplay between superconductivity and a quantum critical point is one of the most important issues to reveal the mechanism of high-transition-temperature (high-T_c) superconductivity. When an ordered phase is suppressed by control parameters such as chemical compositions or magnetic field, strong quantum critical fluctuations may arise at the end point of the ordered phase. This point is called quantum critical point (QCP). In strongly correlated electron systems, this type of phase diagram is established in several materials, and unconventional superconductivity including high-T_c superconductivity often occurs around the QCP. However, it remains unclear how the quantum critical fluctuations affect the physical properties in the superconducting states.

To reveal this issue, we perform the magnetic penetration depth measurements on the series of iron-based superconductors AFe$_2$As$_2$ (A = K, Rb, and Cs). In this system, it has been reported that effective mass of electron in the normal state is enhanced up to the values comparable to the ones in moderately heavy-fermion materials due to a possible QCP with the increase of the alkali-ion radius. Therefore, the systematic study on the quasiparticle excitations in this series is of crucial importance to reveal the effect of quantum critical fluctuations on the superconducting properties.

The quasiparticle excitations in CsFe$_2$As$_2$, which has the largest effective mass of electrons in this series, are significantly changed at low temperatures compared to the ones in KFe$_2$As$_2$. This evolution of quasiparticle excitations is reproduced by the multigap calculations considering the momentum dependence of the effect of quantum critical fluctuations in the superconducting state, which has been recently proposed to explain the anomalous superfluid density in heavy-fermion materials close to a QCP. This observation suggests a novel relation between the momentum dependence of the effect of quantum critical fluctuations and quasiparticle excitations in the superconducting states.