Coupling between electronic and lattice symmetry in unconventional superconductor URu_2Si_2

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The heavy fermion compound URu_2Si_2 undergoes a second order phase transition at T_0~17.5 K under hydrostatic ambient pressure. Since the order parameter of the transition has not ever been clearly identified, such order has been termed "hidden order".

Owing to the tetragonal crystal structure of URu_2Si_2 (space group I4/mmm), the physical properties of the paramagnetic state of this compound exhibit 4-fold rotational symmetry in the basal (001) plane. Thus, uniaxial pressure in the basal plane lowers the lattice symmetry and can induce a significant modification of the phase diagram.

In recent in-plane measurements of the static magnetic susceptibility, the 4-fold symmetry was reported to be spontaneously broken below T_0, and a 2-fold rotationally symmetric state was found to appear [1]. In this case, in-plane 2-fold electronic symmetry appears spontaneously below T_0.

In the present study [2], the phase diagram of URu_2Si_2 under uniaxial pressure $\sigma_{[100]}$ along the [100] and $\sigma_{[110]}$ along [110] directions in the basal plane is investigated based on the thermal expansion coefficient. Both the phase diagram and the thermal expansion anomaly at T_0 with hydrostatic pressure P are found to be different for uniaxial pressures along the [100] and [110] directions.

Single crystals of URu_2Si_2 were grown using the Czochralski method in a tetra-arc furnace under an argon gas atmosphere. The high quality of the samples was confirmed by the resistivity ratio between 300 K and 2 K (RRR), which is over 50. In order to realize homogeneous uniaxial pressure conditions, the sample shape is important. For a rectangular geometry, the sample length along the direction of uniaxial pressure should be at least twice as great as the sample length perpendicular to the uniaxial pressure. In the present study, single crystals with the shape of a rectangular parallelepiped are prepared.

Figure 1 shows the uniaxial pressure cell. Using a bellows system pressurized with helium gas at low temperatures at CEA-Grenoble, uniaxial pressure has been applied at low temperature (5 K) while monitoring pressure with a piezoelectric device. The thermal expansion was measured using strain gauges by the active dummy method with a Wheatstone bridge.

It appears that the observed value $dT_0/d\sigma_{[110]}$ is larger than that of $dT_0/d\sigma_{[100]}$ and dT_0/dP as shown in Fig. 2. As discussed previously [3], $\sigma_{[110]}$ and $\sigma_{[100]}$ induce symmetry-breaking strains ε_{xy} and $(\varepsilon_{xx}-\varepsilon_{yy})\sqrt{2}$, respectively, in addition to symmetry-invariant strains $(\varepsilon_{xx}+\varepsilon_{yy}+\varepsilon_{zz})\sqrt{3}$ and $(\varepsilon_{zz}-0.5(\varepsilon_{yy}+\varepsilon_{xx}))\sqrt{(2/3)}$, which are also induced in the hydrostatic case. The observed difference between σ- and P-dependences of T_0: $dT_0/d\sigma_{[110]}>dT_0/d\sigma_{[100]}>dT_0/dP$ indicates that the onset of hidden order is prompted by symmetry-breaking strains, particularly by the ε_{xy} strain. This fact is consistent with the appearance of 2-fold ordering with a [110] principal axis that is coupled with an ε_{xy} strain, i.e., the 2-fold electronic state is coupled and stabilized with 2-fold lattice distortion.

So far many theoretical models have been proposed in order to interpret the hidden order state. As the proper model should reproduce the observed relation, the number of possible models will be considerably reduced. In addtion, uniaxial pressure is found to be useful to controle the electronic state in the present study.

Fig. 1 The uniaxial pressure cell. The sample (black) is located between two clamps (red).

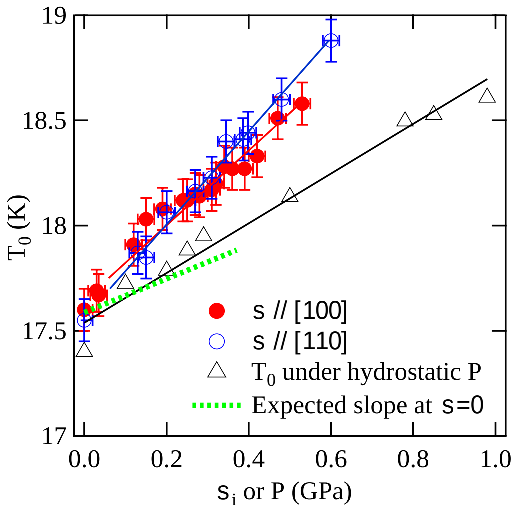

Fig. 2 σ- and P-dependences of the hidden order transition temperature T_0. The solid lines are obtained using linear least-squares fits. $dT_0/d\sigma$ is larger for $\sigma_{[110]}$. The expected $dT_0/d\sigma$ slope at σ=0 from the Ehrenfest relation is presented as a green dashed line.

References

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