UNIAXIAL PRESSURE EFFECT ON THE SdH OSCILLATIONS IN HEAVY-FERMION SEMIMETAL $CeRu_4Sb_{12}$*

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We report the first successful Shubnikov–de Haas (SdH) experiment under uniaxial pressure in the anomalous heavy-fermion semimetal $CeRu_4Sb_{12}$. The nature of the quantum oscillations in the magnetoresistance is found to be significantly sensitive to uniaxial pressure. The results reveal that the nearly spherical Fermi surface elongates along the direction of the uniaxial pressure.

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1. Introduction

The filled-skutterudite compounds ($RETr_4Pn_{12}$: RE = rare earth, Tr = Fe, Ru, Os, and Pn =pnictogen) have attracted much attention from the view points of both novel physical properties and their thermoelectric applications [1,2]. $CeRu_4Sb_{12}$ exhibits metallic conductivity in contrast to other Ce-skutterudites which show semiconducting behavior. Non Fermi liquid (NFL) behavior has been reported for the electrical resistivity (ρ) below a few Kelvin, though no clear explanation has been made [1]. We have succeeded to observe both the SdH and the de Haas–van Alphen (dHvA) oscillations in this compound [2,3]. In these studies, the compound has been revealed to be a heavy fermion with a small semi-metallic Fermi surface (FS) made of highly correlated electrons. The characteristic crystal structure of the filled skutterudite would be one reason of the anomalous behavior in $CeRu_4Sb_{12}$. The uniaxial pressure (P_u) lowers the symmetry of the crystal

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and thereby is expected to control the properties associated with the ground state. Study of the SdH effect under P_u would be helpful in understanding the electronic structure and the anomalous behavior. Here we report preliminary results of the first successful study of the SdH effect under P_u in $CeRu_4Sb_{12}$.

2. Experiment

Single crystals of $CeRu_4Sb_{12}$ were grown by Sb-self-flux method [4]. A single crystal of basically the same quality with that used in Refs. [2, 3] was used for the present experiment. Electrical resistivity was measured by the standard dc four-probe method using a top-loading ^{3}He cryostat equipped with a 16T superconducting magnet. The electrical contacts of Ag current leads were affixed to the sample by indium soldering. Au wires of 80-μmϕ were spotwelded to the sample as voltage leads. The uniaxial pressure was generated by using a piston cylinder type CuBe pressure cell, newly designed and constructed [5]. The uniaxial pressure was determined by measuring the superconducting transition temperature of Sn placed below the sample by an induction method.

3. Results and discussions

Figure 1 shows the magnetic field (H) dependence of the transverse magnetoresistance (MR) at 0.3 K in $CeRu_4Sb_{12}$. At ambient pressure, the H dependence of ρ below 4T is anomalous; there is a faint peak near 2T followed by a minimum, which might be a signature of the NFL behavior. The FL behavior recovers from NFL, *i.e.*, temperature dependence of ρ changes from $\sim T^{1.6}$ at $H = 0$ to T^2, across the field range 2–4T [2]. Above 4T, ρ increases gradually with H and exhibits oscillatory variation with increasing H above 6T. The oscillations, growing more prominent at higher H, are periodic with $1/H$ [see the inset of Fig. 1] and hence are identified as SdH oscillations. This behavior is consistent with that in Ref. [2].

Under the uniaxial pressure, the overall features of MR remain similar to that at ambient pressure, however, the SdH oscillations are found sensitive to P_u. For H applied parallel to P_u ($P_u \parallel H$), the faint peak near 2T tends to be suppressed and the amplitude of the SdH oscillations is reduced. On the other hand, when H is applied perpendicular to P_u ($P_u \perp H$), the absolute value of MR increases, the faint peak near 2T tends to be enhanced and the amplitude of the SdH oscillations is suppressed compared to those for $P_u \parallel H$.

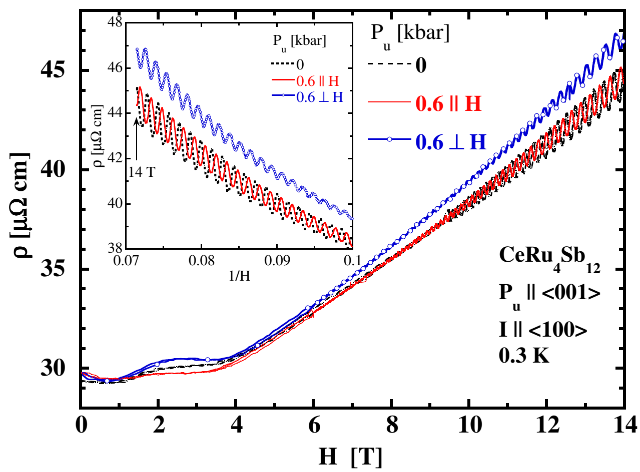

Fig. 1. Magnetic field dependence of transverse magnetoresistance in $CeRu_4Sb_{12}$ at ambient and uniaxial pressure. The inset shows the resistivity as a function of $1/H$ in the high magnetic field region.

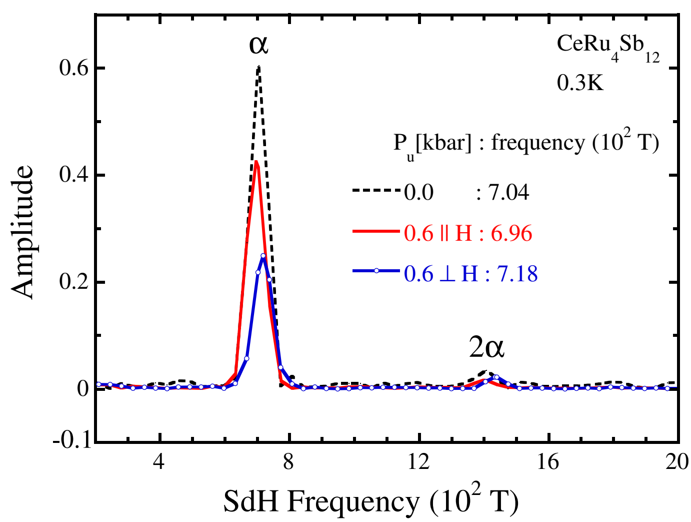

Fig. 2. Fourier spectra of the quantum oscillations in magnetoresistance (SdH effect) in $CeRu_4Sb_{12}$

Figure 2 shows the fast Fourier transform (FFT) spectra of the SdH oscillations. At ambient pressure, there exists only a single frequency branch α with frequency $F \simeq 7.04 \times 10^2$T. 2α is the 2^{nd} harmonic of the α-branch. Using the frequency, the extremal cross-sectional area A_{ext} of the FS perpendicular to H is estimated by $A_{\text{ext}} = (2\pi e/\hbar)F$. This gives the volume of the FS $\simeq$ 2.11% of the Brillouin zone ($\simeq$ 0.0422 holes/f.u.) assuming a spherical FS. Under $P_\mathrm{u} \parallel H$, no new branch appears and the frequency of the α branch decreases as $F \simeq 6.96 \times 10^2$T. On the other hand, under $P_\mathrm{u} \perp H$ the frequency increases as $F \simeq 7.18 \times 10^2$T. Therefore, this increase (decrease) of the frequency under H applied perpendicular (parallel) to P_u suggests that the FS is elongated along the direction of P_u. From the temperature dependence of the amplitudes of the α-branch (not shown), the effective masses (m_c^*) are estimated. At ambient pressure, $m_c^* \simeq 4.8 \pm 0.2 m_0$, reflecting highly correlated electron states. m_c^* decreases as $3.8 \pm 0.1 m_0$ and $3.6 \pm 0.1 m_0$ for $P_\mathrm{u} \parallel H$ and $P_\mathrm{u} \perp H$, respectively.

Using the elastic constants and the Poisson ratio at 4.2 K reported in [6], the change of the lattice constant (9.273 Å at ambient pressure [1]) under $P_\mathrm{u} \simeq 0.6$ kbar is estimated as 9.2694 Å along P_u, while 9.2765 Å perpendicular to P_u. These modified lattice constants and the frequencies under P_u reasonably explain the elongation of the FS along P_u: In $P_\mathrm{u} \simeq 0.6$ kbar, the volume of the FS $\simeq$ 2.17% of the Brillouin zone size ($\simeq$ 0.0424 holes/f.u.) simply assuming an ellipsoidal FS, which is almost the same as that at ambient pressure.

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