

# The Fermi surface in the "Kondo semiconductor" CeNiSn

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## Abstract

We report on the resistivity in CeNiSn at temperatures down to 0.035 K and in magnetic fields up to 20 T. The resistivity as a function of temperature  $T$  exhibits  $T^2$  dependence with a huge coefficient. Clear Shubnikov-de Haas (SdH) oscillations are observed for the two samples where the electrical current is applied along the  $b$  axis, while possible traces of SdH oscillations are noticed for the other two samples where the current is applied along the  $a$  and  $c$  axes, respectively.

*Key words:* Kondo semiconductors; CeNiSn; Fermi surface; Shubnikov-de Haas oscillations

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CeNiSn is a unique variety of Kondo semiconductors. Although there is ample evidence of energy-gap formation below  $\sim 10$  K [1], heat capacity [2] and NMR measurements [3] suggest that the gap is actually a pseudogap with finite density-of-state at the Fermi level. Indeed, we have recently established that CeNiSn is a metal by observing Shubnikov-de Haas (SdH) oscillations [4]. Those SdH measurements were performed on two samples (samples-b1 and -b2, hereafter) with the electrical current  $I$  applied along the  $b$  axis. In this work, we measure two other samples, a1 and c3, with the current along the  $a$  and  $c$  axes, respectively.

Figure 1 shows low-temperature ( $T$ ) resistivity along the three crystallographic axes. The large temperature dependence below  $\sim 1$  K observed for all the directions is remarkable. The samples-b1 (not shown) and -b2 exhibit metallic temperature dependence down to the lowest measured temperature (0.035 K), while the samples-a1 and -c3 exhibit slight increase in the resistivity below  $\sim 0.1$  K. The resistivity increase might be regarded as an indication of inferior sample quality, i.e., it might be ascribed to carrier localization due to

defects or impurities. All the samples exhibit  $T^2$  dependence of resistivity in certain temperature ranges, which dependence is a characteristic of a Fermi liquid. The coefficient of the  $T^2$  term,  $A$ , is however anomalously large. If we apply the Kadowaki-Woods relation [5], the observed values of  $A$  correspond to the electronic specific heat coefficient  $\gamma$  of 1 J/molK<sup>2</sup>, which is far above the experimental value of 40 mJ/molK<sup>2</sup> [2]. It is also interesting to note that the resistivity varies nearly linearly with temperature in a fairly extended temperature range above the  $T^2$  regime.

Figure 2(a) shows the magnetoresistivity at  $T = 0.035$  K for the field  $B$  parallel to the  $c$  axis. For  $I \parallel b$ , the resistivity exhibits oscillatory behavior above  $\sim 6$  T. The periodic oscillations are more clearly visible in the derivative curve,  $d\rho/d(1/B)$ , shown in the inset. Although only the data for the sample-b2 are shown, the sample-b1 exhibits essentially identical oscillations. The Fourier analysis of the oscillation data indicates a single frequency at  $65 \pm 5$  T, and the corresponding orbit area is 0.5% of the Brillouin zone cross-section. The effective mass associated with the orbit is determined from the temperature dependence of the oscillation amplitude to be  $13 \pm 1 m_e$  [4], where  $m_e$  is the free electron mass. On the other hand, for  $I \parallel c$ , SdH oscillations are

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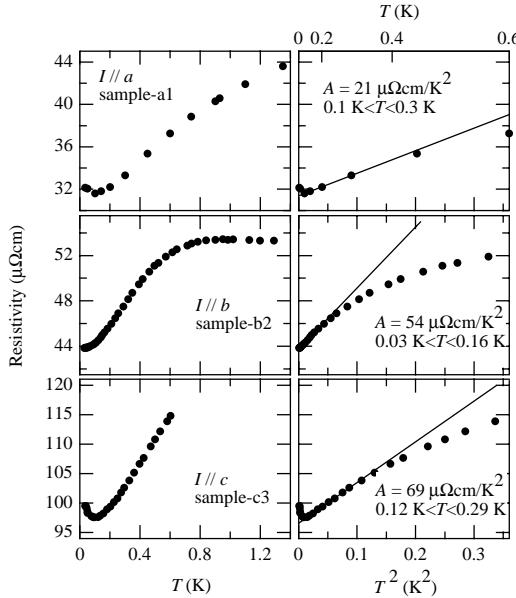


Fig. 1. Temperature  $T$  dependence of resistivity  $\rho$  in CeNiSn for the three current directions,  $I \parallel a$ ,  $I \parallel b$ , and  $I \parallel c$ . The right panels show  $\rho$  as a function of  $T^2$ . The straight lines are fits to the formula  $\rho = \rho_0 + AT^2$ .

not obvious. The humps at  $1/B \sim 0.07$  and  $0.09$  in the derivative curve (inset) might be due to the SdH effect.

Figure 2(b) shows the magnetoresistivity for  $B \parallel b$ . The derivative curves of the  $I \parallel a$  and  $I \parallel c$  data (inset) exhibit some features for  $1/B < \sim 0.1$ , which might be attributed to SdH oscillations. The frequency would then be of the order of 100 T. It appears that the oscillation phase differs by  $\sim \pi$  between the two current directions, i.e., the two samples. This could be explained by less than 10% difference in the SdH frequencies. For  $I \parallel b$ , no trace of oscillations is found even in the derivative curve. This may be attributed to that the resistivity for this current-field configuration is small at high fields and hence that the signal-to-noise ratio is not large enough to see weak oscillations.

For the samples-b1 and b2, SdH oscillations are observed for a wide range of field directions in the  $ac$  and  $bc$  planes. For the samples-a1 and -c3, although we have tried various field directions, what we have observed is only possible faint traces of SdH oscillations like the ones shown in the insets of Fig. 2. This contrast might be ascribed to the current-direction dependence of the SdH oscillation amplitude. On the other hand, it might be attributed to the possible inferior quality of the samples-a1 and -c3. This interpretation is in line with the resistivity upturn below  $\sim 0.1$  K observed for these samples. The possible difference in the SdH frequencies between the samples-a1 and -c3 might indicate slight difference in the chemical composition or impurity concentration between the samples. Although

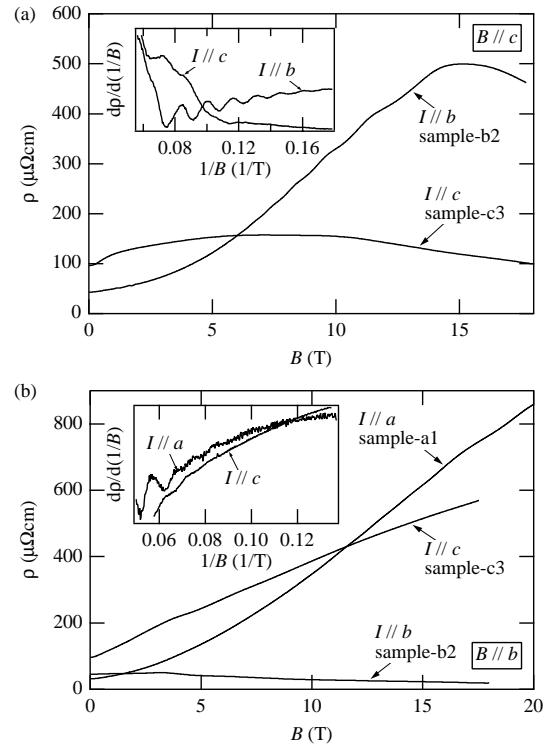


Fig. 2. Magnetic-field  $B$  dependence of resistivity  $\rho$  at  $T = 0.035$  K for (a)  $B \parallel c$  and (b)  $B \parallel b$ . The insets show the derivatives with respect to  $1/B$ ,  $d\rho/d(1/B)$ , except for the  $B \parallel I \parallel b$  data. For the sake of clarity, each derivative curve is scaled arbitrary.

the samples-a1 and -c3 were cut from the same ingot as b1 and b2, a tiny variation in the composition or impurity concentration across the ingot may result in an appreciable difference of transport behavior, since the carrier concentration in CeNiSn is as small as the order of  $10^{-3}$  electron/Ce.

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## References

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