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Pressure-Induced Magnetoresistance in $NbSe_3$

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Currently, a great deal of attention is being paid to the magnetotransport accompanying the charge- or spin-density-wave (CDW or SDW) states in low-dimensional electron systems as related to the topology of the Fermi surface (FS).[1)] This occurs via a variety of physical phenomena, such as rapid oscillations, magic angles, and Shubnikov-de Haas oscillations.[1,2)] Applying pressure generally leads to a drastic change in the topology of the FS in these systems.[2,3)] Therefore it is of great interest to study the effect of pressure on magnetotransport in these systems.[1-3)]

$NbSe_3$, which undergoes CDW transitions at $T_1 = 142$ K and $T_2 = 58$ K,[4)] exhibits large magnetoresistance (LMR)[5)] just below T_2 in a magnetic field perpendicular to the high-conductivity axis (b-axis). There is a long-standing controversy over whether the origin of the LMR can be explained in terms of the magnetic-field-induced enhancement of the CDW gap or not.[6)] The present authors[7)] discovered recently that the LMR immediately vanished in a high strength magnetic field of $H = 12$ T when the T_2-CDW was suppressed by pressure. Based on these observations as well as many previous transport[8-10)] and X-ray studies,[11)] the LMR has been explained simply by considering the response of normal carriers in small pockets created by an imperfect nesting of the T_2-CDW, showing that it is negative for the magnetic-field-induced enhancement of the CDW gap.[7)]

By contrast, the magnetoresistance (MR) in the T_1-CDW phase ($T \geq T_2$) of $NbSe_3$ is negligibly small at ambient pressure.[5)] This is probably due to nearly perfect nesting in the T_1-CDW transition.[12)] It is known that applying pressure causes the collapse of nearly perfect nesting, that is, imperfect nesting induced by high pressure. Therefore, MR due to imperfect nesting under high pressure may appear even in the T_1-CDW phase. We will focus our investigation on whether a new MR is induced by pressure in the T_1-CDW phase or not.

$NbSe_3$ crystals were grown by vapor transport in sealed evacuated quartz tubes using Nb wire and Se shots heated at 740°C for two weeks. The resistance was measured using the conventional four-probe DC method, where current is parallel to the b axis. A modified-Bridgman anvil device[13)] was employed in order to generate high pressure with H parallel to the a^*-axis.

Figure 1 shows the temperature dependence of resistance (left-hand scale) for $H = 0$ and 12 T and the MR for $H = 12$ T (right-hand scale) between 0 and 80 K at $P = 0$ kbar. The magnetic field enhances the resistance anomaly due to the T_2-CDW formation ($T_2 = 55$ K at $H = 0$ T). A large $\Delta\rho/\rho_0$ appears immediately upon the formation of the the T_2-CDW phase; a LMR is observed below T_2. However, above T_2 $\Delta\rho/\rho_0$ is negligibly small. T_2 is independent of the magnetic fields within our experimental error of ±0.5 K. These results agree well with previous results.[5)]

Figure 2 shows the temperature dependence of resistance (left-hand scale) for $H = 0$ and 12 T and the MR for $H = 12$ T (right-hand scale) between 0 and 40 K at $P = 7.2$ kbar. The T_2-CDW transition temperature ($T_2 = 23$ K) and the resistance anomaly associated with T_2-CDW formation are suppressed by increased pressure. Despite the considerable suppression of the T_2-CDW phase however, a large hump in resistance can clearly be observed below T_2 for $H = 12$ T. Again, $\Delta\rho/\rho_0$ increases below T_2, and a LMR is observed even under pressure. These results agree with our previous results measured for H parallel to the c-axis.[7)] By contrast, $\Delta\rho/\rho_0$ is small above T_2, with a magnitude of about 0.1 at 30 K. However, this value is about two orders of magnitude larger than that at ambient pressure, which is about 3×10^{-3} at 70 K. Even if the temperature factor is considered in the temperature dependence of $\Delta\rho/\rho_0 \sim (\omega_c\tau)^2$, where ω_c is the cyclotron frequency and τ is the relaxation time, the $\Delta\rho/\rho_0$ above T_2 obtained at 7.2 kbar is significantly large. This indicates the new appearance of the MR

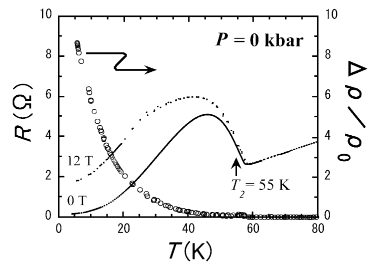

Fig. 1. Temperature dependence of resistance (left-hand scale) for $H = 0$ and 12 T and magnetoresistance for $H = 12$ T (right-hand scale) between 0 and 80 K at $P = 0$ kbar.

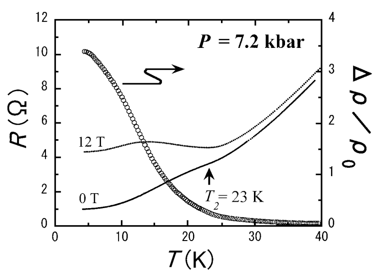

Fig. 2. Temperature dependence of resistance (left-hand scale) for $H = 0$ and 12 T and magnetoresistance for $H = 12$ T (right-hand scale) between 0 and 40 K at $P = 7.2$ kbar.

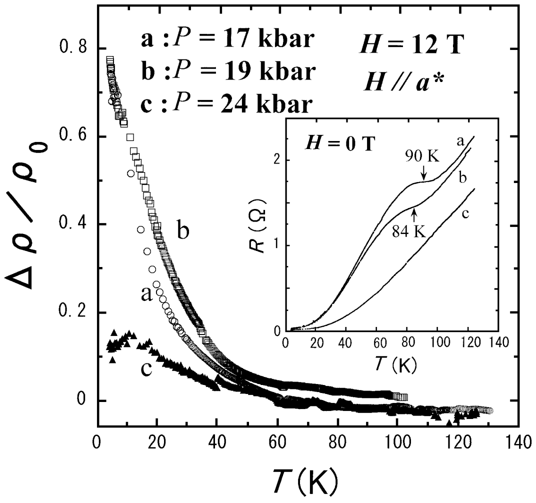

Fig. 3. Temperature dependence of magnetoresistance $\Delta\rho/\rho_0$ for $H = 12$ T under three pressures. Inset is resistance between 0 and 140 K under three pressures for $H = 0$ T.

above T_2 under pressure. We call this pressure-induced magnetoresistance (PIMR).

Temperature dependence of the MR is shown in Fig. 3, where $\Delta\rho/\rho_0$ is plotted for $H = 12$ T under pressures including those above P_1, where the T_1-CDW phase disappears completely. The superconducting transitions take place near 4.0 K at $H = 0$ T. As seen in the inset in Fig. 3, small humps corresponding to the T_1-CDW phase transition are observed at around $T_1 = 90$ K at 17 kbar and 84 K at 19 kbar, whereas at $P = 24$ kbar, the T_1-CDW phase is completely suppressed. P_1 can be estimated to be below 24 kbar. This is quite a bit smaller than that found in the previous study ($P_1 = 35$ kbar),[14] which may be due to the difference in the pressure transmitting medium; in the previous work, a solid medium was used, whereas in the present work a fluid medium (3M Fluorinert) was used.

When the T_1-CDW phase is present, the PIMR increases with decreasing temperature below T_1 for $P =$ 17 kbar and 19 kbar, and then rises sharply below about 40 K. The values of $\Delta\rho/\rho_0$ at 4.2 K are about 1. The PIMR for $P = 24$ kbar increases gradually even below 40 K, and the value at 4.2 K is one order smaller than those for 17 kbar and 19 kbar. The PIMR increases with pressure up to P_1, above which the PIMR decreases rapidly. We find that the PIMR effectively vanishes as soon as the T_1-CDW phase is completely suppressed by pressure, exhibiting the same behavior as the case of LMR appearing in the T_2-CDW phase.

The most reasonable explanation for the pressure dependence of the PIMR is that the number of normal carriers in the pocket, as caused by a collapse of nearly perfect nesting, increases with increasing pressure. However, if the T_1-CDW phase vanishes under higher pressure, the pockets will disappear at the same time, resulting in the strong decrease of PIMR. Namely, PIMR substantially disappears as the T_1-CDW is completely suppressed. Thus, we can explain consistently the appearance and disappearance of PIMR by assuming the existence of normal carriers generated at ungapped FS as induced by pressure.

By comparing the pressure dependence of LMR with that of PIMR, we find that the existence of the T_2- and T_1-CDW phase are essential to the occurrence of LMR and PIMR, respectively. This means that tiny residual pieces of FS created by imperfect nesting due to CDW formation can generally lead to MR even at relatively high temperature.

In conclusion, we discovered that MR newly appears in the T_1-CDW phase at elevated pressures. The results can be explained by pressure-induced changes in the topology of the FS as a result of the nesting effect in the formation of T_1-CDW in $NbSe_3$, indicating that the application of pressure is a powerful tool in changing the topology of the FS in CDW and SDW systems.

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1) T. Ishiguro, K. Yamaji and G. Saito: *Organic Superconductors* (Springer, Berlin-Heidelberg, 1998).
2) A. Briggs, P. Monceau, M. Núñez Regueiro, J. Peyrard, M. Ribault and J. Richard: J. Phys. C **13** (1980) 2117.
3) J. Kuh, Y. T. Tseng, K. Wagner, J. Brooks, G. X. Tessema and M. J. Skove: Phys. Rev. B **57** (1998) 14576.
4) P. Monceau, N. P. Ong, A. M. Portis, A. Meershant and J. Rouxel: Phys. Rev. Lett. **37** (1976) 602.
5) R. V. Coleman, M. P. Everson, Hao-Au Lu, A. Johnson and L. M. Falicov: Phys. Rev. B **41** (1990) 460.
6) C. A. Balseiro and L. M. Falicov: Phys. Rev. Lett. **55** (1985) 863; Phys. Rev. B **34** (1986) 863.
7) S. Yasuzuka, Y. Okajima, S. Tanda, K. Yamaya, N. Takeshita and N. Môri: Phys. Rev. B **60** (1999) 4406.
8) T. M. Tritt, A. C. Ehrlich, D. J. Gillespie and G. X. Tessema: Phys. Rev. B **43** (1991) 7254.
9) O. Laborde, A. Briggs, J. Richard and P. Monceau: Europhys. Lett. **3** (1987) 1019.
10) L. S. Yuan, D. H. Min and Z. Dian-Lin: Europhys. Lett. **5** (1988) 169.
11) V. Kiryukhin, D. Casa, B. Keimer, J. P. Hill, M. J. Higgins and S. Bhattacharya: Phys. Rev. B **57** (1998) 1332.
12) N. Shima: J. Phys. Soc. Jpn. **51** (1982) 11.
13) N. Môri, T. Nakanishi, M. Ohashi, N. Takeshita, H. Goto, S. Yomo and Y. Okayama: Physica B. **265** (1999) 263.
14) M. Núñez Regueiro, J.-M. Mignot and D. Castello: Europhys. Lett. **18** (1992) 53.