ANISOTROPY OF THE SUPERCONDUCTING PROPERTIES OF THE MISFIT LAYER COMPOUND $(PbS)_{1.14}NbS_2$

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ABSTRACT

We report on measurements of magnetoresistance of the misfit layer compound $(PbS)_{1.14}NbS_2$ in the superconducting state. The anisotropy of the critical magnetic field Hc_2 is found to be ~ 8.8.

INTRODUCTION

The structure of a class of compounds of general formula $(MS)_nTS_2$ with n = 1.13-1.19, M = Sn, Pb, Bi or rare earth elements, and T = Ti, V, Nb, Ta has been recently intensively studied [1]. These compounds consist of alternating two atoms thick layers of TS in distorted square pyramidal coordination by sulfur and sandwiches TS_2 as in the layered dichalcogenides 2H-TS_2. The matching of the structures TS and TS_2 is perfect along **b** and **c** axis but the mismatch along **a** axis is irrational with $a_{TS}/a_{TS_2} \sim \sqrt{3}$. This incommensurability along **a** axis yields satellite reflections as observed in electronic diffraction patterns. The composition of the different compounds is calculated from the ratio a_{TS}/a_{TS_2}. Thus structures of crystals with composition $(SnS)_{1.17}NbS_2$, $(PbS)_{1.14}NbS_2$, $(PbS)_{1.13}Tas_2$, and $(LaS)_{1.14}NbS_2$ ... have been determined from X-ray diffraction. Very recently the application of the theory of superspace groups has allowed a general and unifying description of the symmetry of the complete structures including the incommensurate modulation and three different types of structures have been deduced according to the stacking of the layers along **c**.

Since a long time these compounds are known to become superconductors [2,3] but however only a few physical properties has been investigated as Hall and Seebeck coefficients or magnetic susceptibility. A huge anisotropy of ~ 10^5 in the transport properties when the current is applied parallel or perpendicular to the layers has been reported [4]. Anisotropy can also be deduced from the angular dependence of the magnetoresistance in the superconducting state. We report below on such measurements on $(PbS)_{1.14}NbS_2$ which yields a much lower anisotropy.

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EXPERIMENTAL

The growth of $(PbS)_{1.14}NbS_2$ has been described before [1,5]. The single crystals appear as thin platelets of a diameter of 1 to 5 mm and a thickness of a few tens of micrometers. The in-plane resistance was measured by the four probe method with contacts made with silver point and using a low frequency ac bridge. The sample can be rotated with respect to the magnetic field produced by an electromagnet with an accuracy of 0.2°. The maximum magnitude of the field was 0.8 T.

RESULTS AND DISCUSSION

Fig. 1 shows the temperature variation of the resistance of $(PbS)_{1.14}NbS_2$. The resistance ratio between room temperature and 4.2 K is ~17. The inset shows the superconducting transition with T_c=2.475 K. The width of the transition is very sharp and ΔT between 0.1 R_N and 0.9 R_N is 0.1 K.

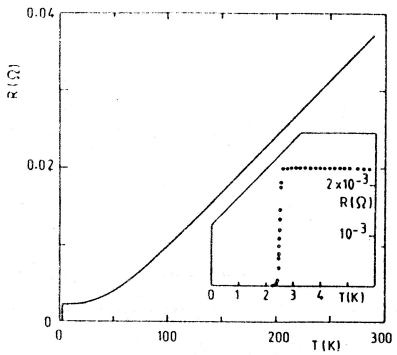

Fig. 1 - Temperature variation of the resistance of $(PbS)_{1.14}NbS_2$. The inset shows the superconducting transition.

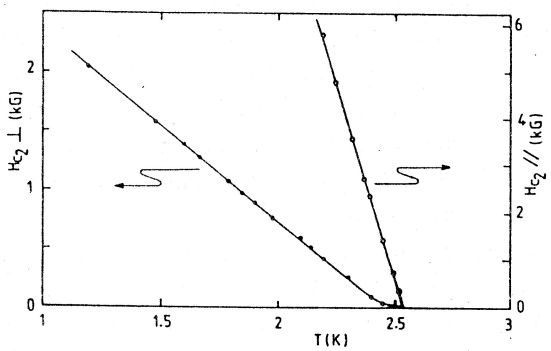

Fig. 2 - Variation of H_{c_2} of $(PbS)_{1.14}NbS_2$ as a function of temperature when the magnetic field is applied perpendicular or parallel to the layer structure.

The superconductivity is destroyed by the application of a magnetic field exceeding H_{c_2} when the sample recovers its normal state resistivity. Fig. 2 shows the temperature dependence of H_{c_2} with H applied perpendicular and parallel to the layers. The temperature dependence of H_{c_2} is linear as expected from the Ginzburg-Landau theory and $dH_{c_{2\perp}}/dT = 0.16$ T/K and $dH_{c_{2//}}/dT = 1.72$ T/K. Thus the anisotropy of H_{c_2} near T_c is 8.75.

The anisotropy can also be derived from the angular dependence of H_{c_2} with θ the angle between H and the (a,b) plane. Fig. 3 shows such a variation at T = 2.14 K. The full curve is the fit with the theoretical variation given by the model of the anisotropic effective mass derived by Lawrence and Doniach [6] in the case of layered compounds and by Barisic and de Gennes [7] in the case of chain-like structures as A 15 compounds. The angular variation of H_{c_2} is :

$$\frac{H_{c_2}(\theta)}{H_{c_{2\perp}}} = \frac{\varepsilon}{(\varepsilon^2 \sin^2\theta + \cos^2\theta)^{1/2}} \qquad (1)$$

with $\varepsilon = \frac{H_{c_{2//}}}{H_{c_{2\perp}}} = \left(\frac{m_\perp}{m_{//}}\right)^{1/2}$.

The better fit corresponds to $\varepsilon = 8.97$ but it can be easily seen in Fig. 3 that the fit is not perfect in the intermediate range of the θ variation which might indicate an interaction between the vortex lattice and the layer structure.

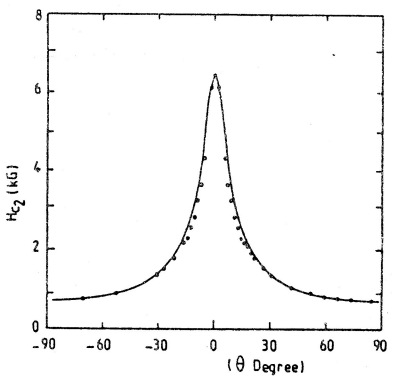

Fig. 3 - Angular dependence of H_{c_2} of $(PbS)_{1.14}NbS_2$ at T = 2.14 K. The curve is the fit with Equat. 1 with $\varepsilon = 8.97$.

Thus the electrical anisotropy that we deduce from our measurements is $(8.8)^2 \sim 70$, two at three orders of magnitude lower than reported in ref. 4. But in this work [4] the measurements were made with only two probes which may lead to overestimate the anisotropy because contact resistance or inhomogeneous current distribution. The superconducting properties of $(PbS)_{1.14}NbS_2$ should be compared to those of 2H-NbS_2. For this latter compound T_c=6.3 K, $dH_{c_{2\perp}}/dT$ = 7.8 kG/K, $dH_{c_{2//}}/dT$ = 22.3 kG/K and thus an anisotropy of 2.93 ~ 3 [8]. The inclusion of a layer two atoms thick of PbS has first the effect to decrease T_c. This result can be understood by a proximity effect between the superconducting NbS_2 layers and the insulating layer PbS which weakens the order pa-

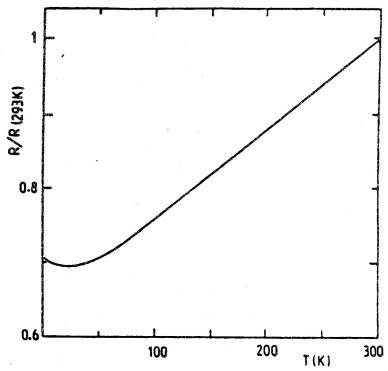

Fig. 4 - Variation of the resistance of "$PbNb_2S_5$" as a function of temperature

rameter in the NbS_2 layers. However single crystals of "$PbNb_2S_5$" have also been synthetized. Its structure consists of one PbS layer in sandwitch between two NbS_2 layers [9]. In this case, one should think that the superconducting properties of "$PbNb_2S_5$" would be more similar to those of 2H-NbS_2 and the intercalation of PbS to have a less importance. Fig. 4 shows the temperature dependence of the resistivity of "$PbNb_2S_5$". Although metallic, the variation of the resistance with T is weak, 40 % between room temperature and helium temperature. There is no superconducting transition down to 1.2 K which seems unconsistant with the model of layers coupled by proximity effect. Results on other misfit layer compounds as $(SnS)_{1.17}NbS_2$, $(PbS)_{1.13}NbS_2$, $(LaS)_{1.14}NbS_2$ will be published elsewhere [10].

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