INTERLAYER COUPLING STRENGTH IN SUPERCONDUCTORS 2H-TaS2 AND 2H-TaS2 (py)1/2

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INTERLAYER COUPLING STRENGTH IN SUPERCONDUCTORS, $2H-TaS_2$ AND $2H-TaS_2(py)_{1/2}$

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Résumé.- La température de transition et le champ critique supérieur parallèle et perpendiculaire au plan des couches ont été mesurés sur plusieurs monocristaux de $2H-TaS_2$ et $2H-TaS_2(py)_{1/2}$. La supraconductivité dans ces deux types de matériaux est analysée sous l'aspect de la force de couplage intercouche utilisée par Klemm et al. dans la théorie du couplage Josephson.

Abstract.- The transition temperature and the upper critical field parallel and perpendicular to the layer plane are measured on several single crystals of $2H-TaS_2$ and of $2H-TaS_2(py)_{1/2}$. Superconductivity in these two kinds of materials is discussed from the viewpoint of the interlayer coupling strength used in the Josephson coupling theory by Klemm et al.

For several years, we have studied the superconducting properties of single crystals of $2H-NbSe_2$ by measuring the upper critical field, H_{c2} /1/, and the specific heat /2/. In the present paper, we describe on the transition temperature, T_c, and the temperature and angular dependences of H_{c2} on several single crystals of $2H-TaS_2$ and of $TaS_2(py)_{1/2}$, where the latter means layered single crystal 2H--TaS_2 and of $TaS_2(py)_{1/2}$, where the latter means layered single crystal $2H-TaS_2$ containing pyridines intercalated between dichalcogenide planes. We discuss the difference of interlayer coupling strength between these two kinds of superconducting compounds on the basis of our experimental results.

Single crystals of $2H-TaS_2$ were prepared by a method of chemical vapor transport reactions using iodine as a carrier. X-ray Weissenberg photographs and electron diffraction patterns showed that our crystals are of 2H polytype and gave no indication of mixtures of polytypes such as 1T, 4Hb and 6R. The intercalation procedure of pyridines to the crystal is similar to that by Thompson /3/. The measurements were done by the electrical conduction method down to 0.4 K.

Although T_c of pure $2H-TaS_2$ has been reported to be 0.8 to 1.2 K by several researchers, no reliable data exist at present. In figure 1 is shown R(T)/R(4.2 K) as a function of T for one of our best samples, $2H-TaS_2$(RRR = 95), together with $2H-TaS_2(py)_{1/2}$. The transition width, $\Delta T_c/T_c$, is pretty broad even in the smallest current density for the pure samples, where T_c is defined by the extrapolation of the middle temperature of the transition to zero current. This result is in contrast

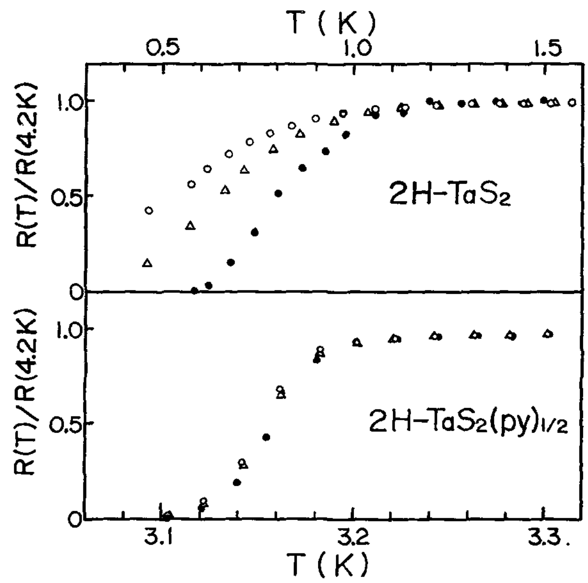

Fig. 1 : R(T)/R(4.2 K) versus T curves for the pure crystal of $2H-TaS_2$ and the intercalated crystal of $2H-TaS_2(py)_{1/2}$. Results for three currents through samples are shown. For $2H-TaS_2$, ($2H-TaS_2(py)_{1/2}$), •, Δ and o are data of 1(1), 5(2) and 10(3) mA, respectively. For $2H-TaS_2$ of RRR = 95, T_c is determined to be 0.86 K. (See text). For $2H-TaS_2(py)_{1/2}$, T_c = 3.16 K and $\Delta T_c \cong$ 60 mK.

to the relatively narrow $\Delta T_c/T_c$ of the intercalated compounds. It is considered that the occurence of the structural transformation such as C. D. W. or the presence of large internal strain introduced in transition between polytypes in making the 2H-structure will give a strong effect to the superconducting to normal transition, especially, in the case of the pure $2H-TaS_2$. From such considerations, T_c of $2H-TaS_2$ of good quality is expected to be less than

Article published online by EDP Sciences and available at http://dx.doi.org/10.1051/jphyscol:19786205

0.9 K, while T_c of 2H-$TaS_2(py)_{1/2}$ in 12.01 Å-phase /3/ is about 3.1 to 3.2 K.

In figure 2 is shown H_{c2} as a function of T for a 2H-TaS_2 crystal with the highest purity obtained and for a 2H-$TaS_2(py)_{1/2}$ compound. The data

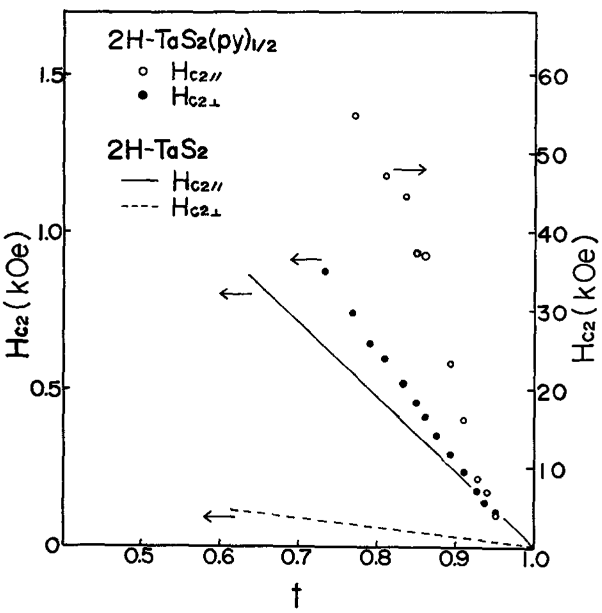

Fig. 2 : H_{c2} versus ($t = T/T_c$) curves for 2H-$TaS_2(py)_{1/2}$ and 2H-TaS_2 (the same one as fig. 1), where $H_{c2//}$ and $H_{c2\perp}$ mean H_{c2} parallel and perpendicular to the layer plane, respectively. For 2H-$TaS_2(py)_{1/2}$, o and o are $H_{c2//}$ and $H_{c2\perp}$, and for 2H-TaS_2, — and --- express the $H_{c2//}$ and $H_{c2\perp}$ behaviors, respectively.

of pure crystals should be considered to be preliminary because of the broad width of T_c and the narrow temperature region in the ^{3}He cryostat used. It is emphasized that $H_{c2//}/H_{c2\perp}$ is quite large and the behavior of $H_{c2//}(T)$ near T_c is characteristic of positive curvature for 2H-$TaS_2(py)_{1/2}$. The characteristics are similar to pure 2H-$NbSe_2$ /1/ to some extent, and much more remarkable both in magnitude and in temperature dependence. Though not shown in figure 2, $H_{c2//}/H_{c2\perp}$ of 2H-TaS_2 decreases with increasing purity, but the anisotropy is still pretty large even in the purest sample.

In order to study the superconducting coupling strength between layers, the Klemm thoery on the basis of the Josephson phase-coupling model /4/ is used for these quasi-two-dimensional layer superconductors. The temperature dependence of $H_{c2//}$ for the low-field limit (1) and high-field one (2) is given as follows, assuming the dirty case within the layer,

$$H_{c2//}(T) = (M/m)^{1/2}(4\phi_0/\pi^2\hbar D)k_B(T_c - T), \qquad (1)$$

and

$$H_{c2//}(T) = (m/M)\ (\phi_0/4s^2\pi)\ (\pi\hbar D)^{1/2}(T - T^*)^{1/2} \qquad (2)$$

where $T^* = T_c(1-\pi\gamma/8)$, $M/m = (H_{c2//}/H_{c2\perp})^2$ near T_c and D is the intralayer diffusion constant.
$\gamma = (2m\hbar D/Ms^2k_BT_c)$ is the coupling constant, where s is the separation between layers.

From our experimental results, we estimate γ as follows ;

for	2H-$TaS_2(py)_{1/2}$,	$\gamma \cong 2$,
for	2H-TaS_2 ,	$\gamma \cong 2500$,
for	2H-$NbSe_2$,	$\gamma \cong 100$ /1,2/.

For 2H-$TaS_2(py)_{1/2}$, $\xi_\perp$ is estimated to be 7.6 Å. This is smaller than the layer spacing of 12 Å.

We conclude that the Josephson coupling model in which the order parameter in adjacent layers is weakly coupled by Josephson tunneling can be applied to the intercalated superconductors such as 2H-$TaS_2(py)_{1/2}$because of the small γ and $\xi_\perp$ values. On the other hand, the γ value of pure 2H-TaS_2 is so large that the Josephson coupling model cannot be applied to this material. The situation is similar to the 2H-$NbSe_2$ case. For nonintercalated layer compounds, the theory on anisotropic superconductors such as reference /5/ is newly necessary.

We are grateful to Pr. M. Tanaka and Dr. Y. Watanabe for the structural analysis.

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