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Response of Magnetic Field by Conduction Electrons at Low Temperature in 2H-$NbSe_2$

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Abstract

Here, we have presented the magneto-resistance (MR) on polycrystalline and single crystal of 2H-$NbSe_2$. The obtained MR on single crystal shows anisotropic nature associated with small longitudinal MR i.e. $(\Delta\rho/\rho_0)_{II}$ in which $H\ II$ direction of current flow compared to transverse MR i.e. $(\Delta\rho/\rho_0)_{\perp}$ in which $H \perp$ direction of current flow. This anisotropy behaviour is associated with the complex Fermi surface found from the analysis of two-band model and Kohler's rule.

Keywords: *Transition metal compound, magneto-resistance, two-band model, Kohler's rule*

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INTRODUCTION

The chemical composition of transition metal dichalcogenide compounds (TMDC) is represented by MX_2, where M= transition metal atom and X=S, Se and Te, in which M-atoms are sandwiched between two X-layers. 2H-$NbSe_2$ is one of TMDC, which shows trigonal prismatic coordination. Its high purity compounds show a charge density wave (CDW) at 35 K followed by a superconducting (SC) transition at 7.3 K [1–7]. Due to the coexistence of these two transitions in 2H-$NbSe_2$, the scientific community has been contributed lots of information by different ways [8–18]. Regardless of its SC transition, the CDW transition is found very sensitive to residual resistance ratio (RRR), which measures the purity of the compounds [2].

Here, we have presented the magneto-resistance (MR) data of 2H-$NbSe_2$ in both single crystal and polycrystalline compounds of 2H-$NbSe_2$. This MR provides the hypothetical picture of the Fermi surface, which depends on the concentration of electrons.

EXPERIMENTS

The polycrystalline compound of 2H-$NbSe_2$ is prepared by solid-state reaction method from high purity elements in an evacuated sealed quartz tube at 700°C. Then single crystals are grown by chemical vapour transport technique at 750°C from the above polycrystalline compounds, same as reported earlier [1]. The single phase of hexagonal structure with lattice constants a≈3.445 Å and c≈12.551 Å are calculated from room temperature X-ray diffraction on polycrystalline compounds. Then magneto-resistance (MR) is measured below 10 K by applying magnetic field parallel and perpendicular to the single crystal plane of $NbSe_2$ along which current is passed. The lowering of compound temperature is achieved through a cryogenic free Helium close cycle refrigerator.

RESULTS AND DISCUSSION

Magneto-Resistance

The temperature dependence resistance with and without field on 2H-$NbSe_2$ polycrystalline and single crystal are reported elsewhere [19]. From that, one can easily notice the existence of positive MR. In single crystal, the longitudinal MR is found small compared to transverse MR. But in polycrystalline compound, however, the MR is very close to the longitudinal MR of single crystal. This anisotropy can be understood from two-band model and Kohler's rule as discussed below. The two-band model is based on the concentrations of charge carriers in the two bands which can at present be used to discuss the anisotropic and saturation effects of MR in large fields. The two-band model [20] for metal is given by:

$$\frac{\Delta\rho}{\rho_0}=\frac{\left(H/ec\right)^2\left(\frac{\sigma_{01}}{n_1}+\frac{\sigma_{02}}{n_2}\right)^2\frac{\sigma_{01}\sigma_{02}}{\left(\sigma_{01}+\sigma_{02}\right)^2}}{1+\left(H/ec\right)^2\left(\frac{n_1-n_2}{n_1n_2}\right)^2\left(\frac{\sigma_{01}\sigma_{02}}{\sigma_{01}+\sigma_{02}}\right)^2} \tag{1}$$

Here, we have assumed two types of charge carriers having n_1 electron concentration and n_2 hole concentration which gives rise to σ_{01} and σ_{02} conductivity respectively. If external magnetic field 'H' is small then $\Delta\rho/\rho_0 \sim H^2$; but for high fields, it has two solutions at $n_1=n_2$ provides anisotropic effect and $n_1 \neq n_2$ provides saturation effect. But Kohler's rule is used to discuss about the motion of charge carriers associated with a universal mean free path or scattering time.

Two-Band Model

For the anisotropic behaviour of $\Delta\rho/\rho_0$ in 2H-$NbSe_2$, we assumed the case of equal density of states in both bands i.e. $n_1=n_2=n$ which implies that; $\sigma_{01}=\sigma_{02}=\sigma_0/2$.

Then $\Delta\rho/\rho_0$ in SI unit is represented as follows:

$$\frac{\Delta\rho}{\rho_0}=\frac{\sigma_0^2}{\left(2ne\right)^2}H^2=\left(\frac{e\tau}{2m}\right)^2H^2 \tag{2}$$

This expression is equivalent to a straight-line equation with zero intercept constant, which provides information about the scattering time (τ) of the charge carriers. The fractional change in MR ($\Delta\rho/\rho_0$) around 8 K is plotted with respect to H^2 for 2H-$NbSe_2$ single crystal and polycrystalline in Figure 1, which clearly shows that the MR rapidly increased in $\left(\Delta\rho/\rho_0\right)_{\perp}$ i.e. $H\perp$ plane of $NbSe_2$ compared to $\left(\Delta\rho/\rho_0\right)_{II}$ i.e. $H\ II$ plane of $NbSe_2$. From the slope of $\Delta\rho/\rho_0$ vs. H^2, however, we have calculated average scattering time $\sim 1.48\times10^{-12}$ sec in $\left(\Delta\rho/\rho_0\right)_{\perp}$ for single crystals. This scattering time is found to be reduced $\sim 5.11\times10^{-13}$ sec and 2.53×10^{-13} sec in $\left(\Delta\rho/\rho_0\right)_{II}$ below and above 3Tesla in 2H-$NbSe_2$ single crystal respectively. But in case of polycrystalline compound, it is found $\sim 4.55\times10^{-13}$ sec very close to $\left(\Delta\rho/\rho_0\right)_{II}$ scattering time.

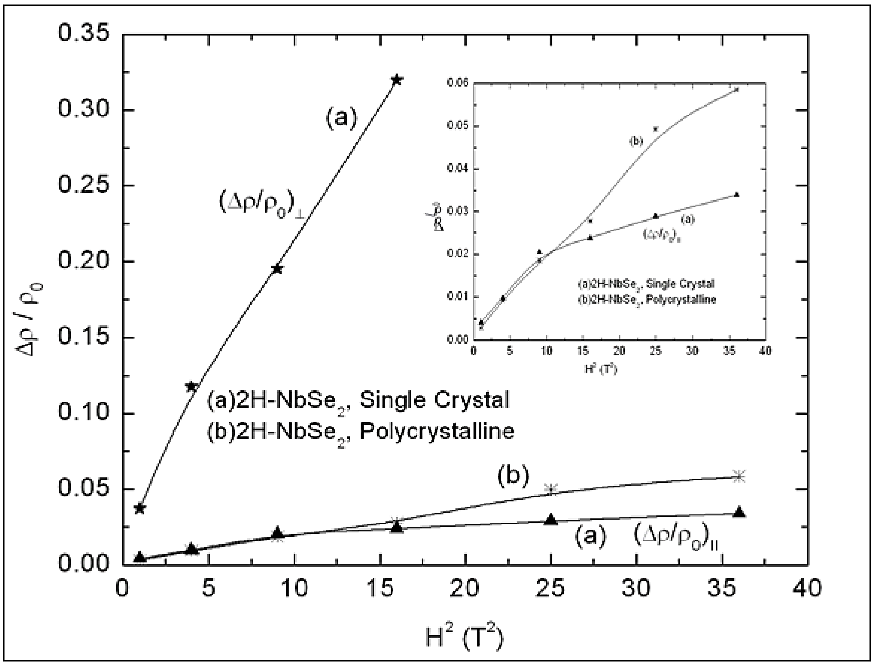

Fig. 1: *$\Delta\rho/\rho_0$ vs. H^2 for 2H-$NbSe_2$ Single Crystal and Polycrystalline Compounds.*

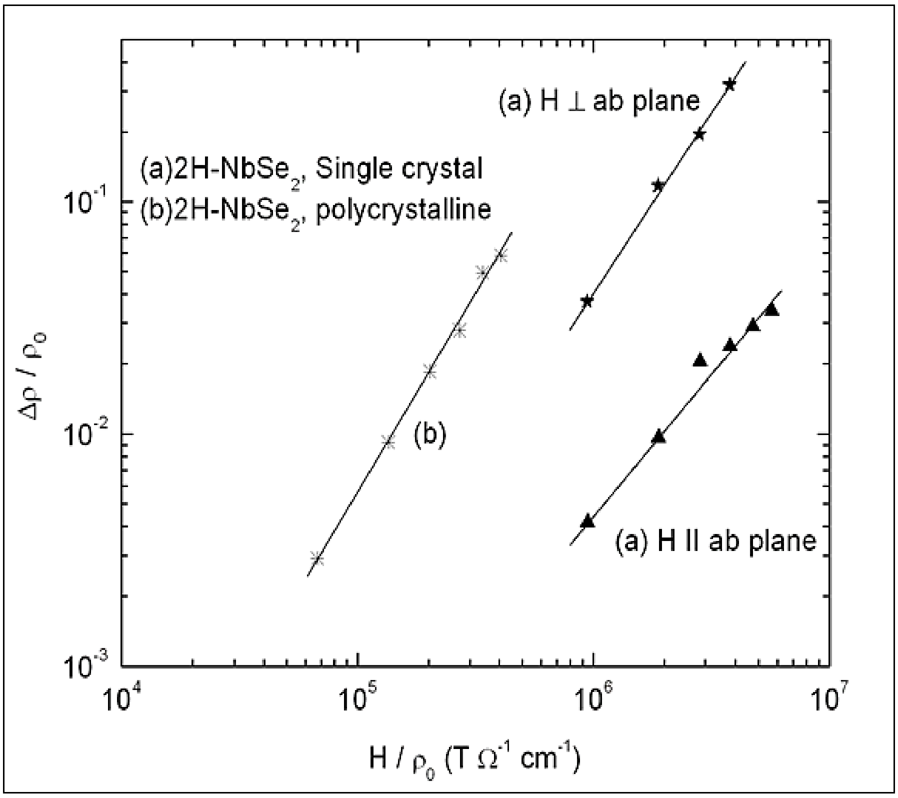

Fig. 2: *$\Delta\rho/\rho_0$ vs. H/ρ_0 for 2H-$NbSe_2$ Single Crystal and Polycrystalline Compounds.*

Kohler's Rule

Although this rule is derived only for the isotropic model of closed Fermi surface, it describes experimental data better than $\Delta\rho/\rho_0 \sim (\Omega\tau)^2$ where $\Omega = eH/2m$ in SI unit and τ = scattering time. Then non-linear behaviour of $\Delta\rho/\rho_0$ in metallic compounds are described by Kohler's rule as given below [20]:

$$\frac{\Delta\rho}{\rho_0} = f\left(\frac{H}{\rho_0}\right) \sim \left(\frac{H}{\rho_0}\right)^p \quad (3)$$

Eq. (3) implies that $\Delta\rho/\rho_0$ is a function of H/ρ_0. Suppose, if p is the exponent of H/ρ_0 then depending on the value of p, metals are divided in to two groups: group-1 if $2 \geq p \geq 1$and group-2 if $p < 1$. In group-1, the MR rises to infinity with H/ρ_0 whereas in group-2 MR saturates at finite value of H/ρ_0.

On the other hand, the movement of charge particle in a constant energy surface between the zones known as open orbit provides the increase of MR to infinity and saturation of MR at finite value of H/ρ_0 is related to the movement of charge particle within the single zone known as closed orbit.

In Figure 2, the fractional change in MR ($\Delta\rho/\rho_0$) around 8 K is plotted with respect to H/ρ_0 for 2H-$NbSe_2$ single crystal and polycrystalline in log-log scale known as Kohler's plot. Within the applied magnetic field of 6.0Tesla, the exponent is found ~1.6 in $(\Delta\rho/\rho_0)_\perp$ and ~1.2 in$(\Delta\rho/\rho_0)_{II}$. As both the exponents are greater than one, at present, we can say that there exist multiple connected Fermi surfaces along which the charge particles move. But the difference in exponent implies the anisotropy scattering same as we found in two-band model. Though $(\Delta\rho/\rho_0)_\perp$ of polycrystalline compound is very close to single crystal, it can't be compared with single crystal because the MR obtained in polycrystalline compound is an effect of average over the separate crystallites.

CONCLUSION

Here, we have tried to figure out a hypothetical Fermi surface in 2H-$NbSe_2$ using low temperature MR data. Regardless of 2H-$NbSe_2$ polycrystalline $\Delta\rho/\rho_0$, the single crystal shows anisotropic nature of $\Delta\rho/\rho_0$. First we have attempted to describe this anisotropy by two-band model with the condition $n_1 = n_2$. But it fails to account the reason for saturation like behaviour above 3Tesla with small magnitude in $(\Delta\rho/\rho_0)_{II}$ as shown in Figure 1. Therefore, Kohler's plot as shown in Figure 2 is used to understand it through electron path in k-space which follows lines of constant energy perpendicular to the direction of magnetic field. As a consequence, a complex Fermi surface is established associated with different scattering time along different direction.

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REFERENCES

1. Naik I, Rastogi AK. Charge Density Wave and Superconductivity in 2H- and 4H-$NbSe_2$: A Revisit. *Pramana-J. Physics.* 2011; 76(6): 957p.
2. Li L, Xu Z, Shen J, *et al.* The Effect of a Charge Density Wave Transition on the Transport Properties of 2H-$NbSe_2$. *J. Phys.: Codens. Matter*. 2005; 17: 493p.
3. Giambattista B, Johnson A, Coleman RV, *et al.* Charge Density Waves Observed at 4.2K by Scanning Tunnelling Microscope. *Phys. Rev. B.* 1988; 37: 2741p.
4. Naito M, Tanaka S. Electrical Transport Properties in 2H-NbS_2, -$NbSe_2$, -TaS_2 and -$TaSe_2$. *J. Phys. Soc. Japan.* 1982; 51: 219–8p.
5. Noto K, Morohashi S, Arikawa K, *et al.* Temperature and Magnetic Field Dependence of the Electrical Resistance in Pure and Fe-Doped 2H-$NbSe_2$. *Physica B* 1980; 99: 204p.
6. Thompson AH. Pauling's Ionicity and Charge Density Waves in Layered Transition Metal Dichalcogenides. *Phys. Rev. Lett.* 1975; 34: 520p.
7. Iwaya K, Hanaguri T, Koizumi A, *et al.* Electronic States of $NbSe_2$ Investigated by STM/STS. *Physica B.* 2003; 329–333: 1598p.
8. Chu CW, Diatschenko V, Huang CY, *et al.* Pressure Effect on the Charge Density Wave Formation in 2H-$NbSe_2$ and Correlation Structural Instabilities and Superconductivity in Unstable Solids. *Phys. Rev. B.* 1977; 15: 1340p.
9. Berthier C, Molinie P, Jerome D. Evidence for a Connection between Charge Density Waves and the Pressure Enhancement of Superconductivity in 2H-$NbSe_2$. *Solid State Comm.* 1976; 18: 1393p.
10. Huntley DJ, Frindt RF. Transport Properties of 2H-$NbSe_2$. *Can J. Phys.* 1974; 52(10): 861p.
11. Whitney DA, Fleming RM, Coleman RV. Anomalous Magneto-Resistance and Hall Effect in Iron Alloys of the Layer Structure $TaSe_2$. *Solid State Comm.* 1976; 18: 309p.
12. Long JR, Bowen SP, Lewis NE. Anomalous Resistivity of Iodine-Free 2H-$NbSe_2$. *Solid State Comm.* 1977; 22: 363p.
13. Suderow H, Tissen VG, Brison JP, *et al.* Pressure Induced Effects on the Fermi Surface of Superconductor 2H-$NbSe_2$. *Phys. Rev. Lett.* 2005; 95: 117006p.
14. Du C-H, Lin WJ, Su Y, *et al.* X-Ray Scattering Studies of 2H-$NbSe_2$, a Superconductor and Charge Density Wave Material, under High External Field. *J. Phys.: Condens. Matter*. 2000; 12: 5361p.
15. Weber F, Rosenkranz S, Castellan JP, *et al.* Extended Phonon Collapse and the Origin of Charge Density Wave in 2H-$NbSe_2$. *Phys. Rev. Lett.* 2011; 107: 107403p.
16. Moncton DE, Axe JD, Disalvo FJ. Neutron Scattering Study of the Charge Density Wave Transitions in 2H-$TaSe_2$ and 2H-$NbSe_2$. *Phys. Rev. B.* 1977; 16: 801p.
17. Schmalzl K, Strauch D, Hiess A, *et al.* Temperature Dependent Phonon Dispersion in 2H-$NbSe_2$ Investigated using Inelastic Neutron Scattering. *J. Phys.: Condens. Matter* 2008; 20: 104240p.

18. Berthier C, Jerome D, Molinie P. NMR Study on a 2H-$NbSe_2$ Single Crystal: A Microscopic Investigation of the Charge Density Wave State. *J. Phys. C: Solid State Phys.* 1978; 11: 797p.
19. Naik I. Upper Critical Field of 2H-$NbSe_2$: Effect of Ga-Intercalation. *AIP Conf. Proc.* 2011; 1349: 883p.
20. Wilson AH. *The Theory of Metals*. 2nd Edn. Cambridge at University Press; 1958.

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