Chapter-III

Transport properties of Superconducting NbSe2; 
Effect of Ga-intercalation

Introduction

NbSe2 compound belongs to the family of metallic layered compound MX2, (where M = V, Nb or Ta and X = S or Se). The main interest in NbSe2 is the existence of superconductivity (Tc = 7.4K) below a Charge Density Wave (CDW) transitions at 39K. The CDW transition is frequently observed in low dimensional metals. The evidence of charge density wave is found through (i) Neutron scattering by D. E. Moncton et al. [1, 2] (ii) Scanning tunneling microscope by B. Giambtish et al. [3] and (iii) NMR by C. Bertheir et al. [4]. In Neutron scattering experiment, D. E. Moncton et al. showed that, below 39K, q = (1−δ)a*/3 for CDW wave vector. The incommensurability ‘δ’ decreases from δ = 0.025 at 33K to δ = 0.011 at 5K. C.W. Chu et al. [5] found the linear decrease of CDW transition temperature by applying pressure, whereas the superconducting transition temperature increases.

Recently Lin-jun Li et al. [6] found that the CDW transition of the 2H-NbSe2 is suppressed with decreasing residual resistance ratio (RRR) value measured on two different single crystals grown by CVT method. But their superconducting transition temperature is not much affected. They also noticed the violation of Kohlar’s rule in their magnetoresistance measurement. K. Noto et al. [7] and Michio Naito et al. [8, 9] also found the positive magnetoresistance on the 2H-NbSe2. The Hall coefficient was found p-type remaining constant above 50K, below CDW transition it rapidly decreases and changes sign [6, 8].

S. S. Banerjee et al. [10] calculated the superconducting parameters in 2H-NbSe2 (type-II) critical fields (Hc1 and Hc2), coherence length (ξ) and penetration depth (λ) on a clean single crystal. Recently F. Soto et al. [11] studied the fluctuation-diamagnetism
above the superconducting transition temperature in the single crystal grown by the chemical vapor transport method.

The band structure calculation was also carried out by the various workers, using Pseudopotential method by C.Y. Fong et al. [12] and First principle and Augmented plane wave method by L. F. Matheiss [13, 14].

Intercalation of the foreign atoms into the van der Waal’s gap of this layered compound was attempted by different experimentalists. Among these I mentioned here few of them (i) Hydrogen intercalated by L. M. Kulikov et al. [15] (ii) Silver intercalation by O. S. Rajora et al. [16] (iii) Fe doped by K. Noto et al. [7] (iv) Post transition metal intercalation by R. Eppinga et al. [17] and by N. Karnezos [18] (v) Organic molecules intercalation by S. F. Meyer et al. [19].

I intercalated Ga-atom in the 2H-NbSe$_2$ layered compound to better understand electric and thermal properties of the parent compound. A. Niazi and A. K. Rastogi briefly studied the effect of Ga-intercalation on pure 2H-NbS$_2$ compound in polycrystalline sample, prepared at different temperatures [20]. They found the change of symmetry from Hexagonal 2H-NbS$_2$ to the Rombhohedral 3R-GaxNbS$_2$, when x > (0.10 – 0.33). All the 3R-phases are non-superconducting and show a resistance minimum around 18K for more than 10% Ga-intercalation. The resistance minimum temperature is increased with the increasing concentration of ‘Ga’. The pure compound showed the negative S(T). In 3R-phase of NbS$_2$ and up to 25% Ga-intercalation, a fairly constant value of negative S(T) at high temperature was found to change towards positive below 100K.

3.1 Structural details

The polycrystalline samples of pure 2H-NbSe$_2$ as well as the Ga-intercalated specimens are prepared by the reaction of high purity elements Ga = 99.99%, Nb = 99.8% and Se = 99.999% at 750°C for seven days in an evacuated sealed quartz tube. The circular pellets are made at pressure of 8 Ton by a hydraulic press after grinding the reacted mass in a mortar and pestle inside a dry box. Finally the pellets are sintered at 700°C for seven days
in an evacuated sealed quartz tube. It should be remarked that F. Kadjik et al. [21] found more than one polymorphs in the NbSe$_2$ compound 1T, 2Ha, 4Ha, 4Hd$_{I}$ and 4Hd$_{II}$ depending on the method of preparation.

Apart from 2H- NbSe$_2$, 4H-polymorph of the same composition was prepared from high purity elements by sintering at 925$^\circ$C for three days. The crystal flakes of both the pure specimens were prepared by vapor transport technique at 925$^\circ$C and 750$^\circ$C for 4H and 2H respectively.

**X-ray diffraction:** The X-ray diffraction patterns obtained at room temperature on these compounds are indexed by Hexagonal symmetry of 2H and 4H-polymorphs as shown in fig. 3.1. The 10$l$ lines are found very sharp in the X-ray diffraction pattern of all the powder samples indicating that the quality of the crystallites is good. The lattice constants ‘$a$ = 3.445Å’ and ‘$c$ = 12.551Å’ of the Hexagonal symmetry are calculated from the 110 and 008 peak lines respectively and are given in the table – 3.1. In 4H-specimen we found the lattice constant ‘$c$’ is about twice the value of 2H polymorph. In Ga-intercalated compounds of the 2H-polymorphs, the lattice constants ‘$a$’ and ‘$c$’ increases. Group VB (Nb, Ta) dichalcogenides form intercalation compounds with post transition elements Cu, Ag etc. [22]. These compounds have Cu and Ag in tetrahedral holes between the slabs. In our Ga-intercalated phases we expect Ga to occupy octahedral sites since the value of ‘$c$’ is only marginally increased. The X-ray diffraction results of all the compounds are given in the Appendix-A.

**Table – 3.1**

<table>
<thead>
<tr>
<th>Compound Name</th>
<th>NbSe$_2$</th>
<th>NbSe$_2$</th>
<th>Ga$_{0.03}$NbSe$_2$</th>
<th>Ga$_{0.10}$NbSe$_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Symmetry</td>
<td>4H</td>
<td>2H</td>
<td>2H</td>
<td>2H</td>
</tr>
<tr>
<td>Lattice Constant</td>
<td>$a = 3.436$ Å</td>
<td>$a = 3.445$ Å</td>
<td>$a = 3.450$ Å</td>
<td>$a = 3.453$ Å</td>
</tr>
<tr>
<td></td>
<td>$c = 2 \times 12.596$ Å</td>
<td>$c = 12.551$ Å</td>
<td>$c = 12.592$ Å</td>
<td>$c = 12.605$ Å</td>
</tr>
</tbody>
</table>
3.2 Electronic Properties

The D.C. resistance was measured on pellets and flakes between the temperature ranges of 2 - 300K using four probe method of van der Pauw geometry [23]. All the specimens showed metallic conductivity with room temperature resistance value of the order of mΩ.

The thermopower was measured on the rectangular sintered pellets and flakes in the temperature range of 16-300K in our lab-built setup. The absolute Seebeck Coefficient was found as explained in chapter-II.
3.3 Transport Properties of NbSe₂

3.3.1 Resistivity

The resistivity data of the bulk as well as the crystal flakes of NbSe₂ in the temperature range of 2K to 300K is shown in fig. 3.2(a) on log-log scale. This plot was used to clearly see and compare the resistivity behavior at low temperature for different compounds. From the resistivity of 2H-NbSe₂, I have calculated residual resistance ratio (RRR) ~ 66.7 and 13 for single crystal flake and polycrystalline pellet respectively. 2H-NbSe₂ single crystal flake showed a superconducting transition at 7.4K and a CDW transition (visible as a small bump) around 35K same as reported previously. In polycrystalline specimen of 2H-NbSe₂, the superconducting transition was found at the temperature of 7.4K same as in flake but the anomaly associated with CDW transition was not seen. This may be because of the large anisotropy of the resistivity in these layered compounds. In polycrystalline phase, the dominant contribution of the c-axis resistivity washes out the small changes in the in-plane resistivity at CDW transition.

4H-NbSe₂ is one of the polymorph of NbSe₂ layered compound. In our single crystal flake of 4H-NbSe₂, the RRR value was found equal to ~ 21. The RRR value is small in the 4H-NbSe₂ single crystal flake compare to 67 found in our 2H-NbSe₂ single crystal flake. The CDW transition was at 42K and superconducting transition temperature was also correspondingly reduced to 6.5K.

The inset fig. 3.2(a) showed the normalized resistivity of both the single crystal flakes with respect to temperature. This clearly indicates that the superconducting transition temperature was decreased in 4H-polymorph compare to the 2H-polymorph with the increase in CDW transition temperature.
Fig. 3.2: Resistivity variation with temperature, (a) Plotted on a log – log scale of 2H-NbSe$_2$ and 4H-NbSe$_2$. The inset figure showed the normalized resistivity of two single crystals. (b) Plotted on a log – log scale of 2H-NbSe$_2$ and 4H-NbSe$_2$ after subtracting the residual resistivity $\rho_0$. 
In fig. 3.2(b), I have plotted temperature dependence of resistivity after subtracting $\rho_0$ on a log-log plot. The resistivity below the CDW transition temperature of the above mention compounds are well fitted with the following equation,

$$\rho = \rho_0 + AT^n$$

Here, the superscript ‘$n$’ is found to be $\sim 3.2$ and 2.8 for the two pure single crystal flake specimens of 2H-NbSe$_2$ and 4H-NbSe$_2$ respectively. This value is decreased to $\sim 2.5$ in the case of polycrystalline sample of 2H-NbSe$_2$. Our low temperature $\rho(T)$ behavior (i.e. below the CDW transition temperature) is very close to the previously reported $T^3$-behavior as explained by M. Naito et al. [8]. The $\rho(T)$ behavior and RRR values are strongly affected by the inter-grain boundaries in the polycrystalline samples as we found in our 2H-NbSe$_2$ pellet.

### 3.3.2 Superconducting Properties

The layered compound of 2H-NbSe$_2$ belongs to the type-II superconductor as reported previously [10]. Fig. 3.3 shows the resistance vs. temperature of the NbSe$_2$ single crystal flakes at various magnetic fields applied parallel and perpendicular to the layer (ab-plane). Fig. 3.3(a) and (c) -- where the field is perpendicular to the layers -- clearly show the significant increase in resistivity in the normal phase before the superconductivity sets in. In contrast, there is hardly any change in the resistance of normal phase when the magnetic field is applied parallel to ab-plane as seen in fig. 3.3(b) and (d). We can also clearly see that the upper critical field $H_{c2}$ for the complete suppression of superconductivity is lower for the perpendicular direction than when it is applied parallel to the layer in both the polymorph. $H_{c2}$ is larger for 4H- polymorph.
Fig. 3.3: Superconducting behavior measured in plane of 2H and 4H-NbSe$_2$ single crystal flakes under different magnetic fields. For a & c magnetic field is perpendicular to the a-b plane and for b & d field direction is in-plane of the flakes.
3.3.3 Seebeck Coefficient

In fig. 3.4, I plotted the Seebeck coefficient 'S' of the polycrystalline and single crystal flakes of pure NbSe₂ in the temperature range from 16K to 320K. The Seebeck coefficient on all of them was found negative around 320K as shown in fig. 3.4. On cooling, the magnitude of Seebeck coefficient decreases for all the three specimens and changes over to positive value at lower temperatures. This change over is commonly observed for solids showing CDW instability. 'S' is about twice as large for 4H -NbSe₂ than for 2H polymorph, but its temperature dependence is qualitatively similar for both specimen. We observe a clear anomaly in both the specimen, where 'S' shows a perceptible decrease associated with the onset of CDW transition on cooling. The drop in 'S' at CDW is more for 2H specimen, which has more RRR than 4H – polymorph.

In case of sintered pellet thermopower shows much rapid changeover to positive value on cooling. Moreover as distinct from flakes, there is a broad maximum around 50K. A broad maximum in Seebeck coefficient at low temperature is also reported for 2H-NbS₂ (showing no CDW transition) by A. Niazi and A. K. Rastogi [20]. The origin of maximum in the thermopower of polycrystalline pellets, especially with large crystalline anisotropy, is not understood at present. It should also be recalled that these pellets, the RRR value is much smaller, and the anomaly in resistivity from CDW is also absent. This is most likely due to large contribution of resistance along c-axis in polycrystalline samples, which also affects the thermopower behavior.

Here, we explain the behavior of thermoelectric power in the relaxation time approximation method expressed by Mott called diffusion thermopower,

\[ S_d = \frac{\pi^3 k_B^2 T}{3e} \left( \frac{\partial \ln \sigma}{\partial e} \right) \]  \quad \text{where,} \quad \sigma = \frac{e^2 l(\varepsilon) \varepsilon(\varepsilon)}{12 \pi^3 h} \quad \text{(3.3b)} 

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The contribution of this diffusion thermoelectric power \( S_d \) to TEP associated with the system of electrons that interacts with random distribution of scattering centers that are assumed to exist in thermal equilibrium at the local temperature \( T \). The charge carriers and the derivative of the logarithmic of \( \sigma \) determines the sign of \( S_d \).

Since NbSe\(_2\) is a multi-band metal. Here the negative thermopower at room temperature arises due to the low mobility of electrons in the narrow d-band and large mobility of holes in the broad valence band gave the positive Hall coefficient \( R_H \) as reported previously [6, 8]. The behavior of \( S(T) \) increases with decreasing temperature associated with the anisotropic increase in electron mobility.

![Fig. 3.4: Absolute Seebeck coefficient vs. temperature on pure NbSe\(_2\) specimens.](image)
3.4 Transport properties of 2H-Ga$_x$NbSe$_2$ ($x = 0.05, 0.10$)

3.4.1 Resistivity

In fig. 3.5(a), the resistivity of Ga-intercalated as well as pure 2H-NbSe$_2$ is shown. The resistivity at room temperature is tabulated in table – 3.2. The RRR value decreases with the increasing concentrations of intercalation ions. With the increase in Ga concentration, superconducting transition temperature rapidly decreases. The anomaly associated with CDW transition, if present, could not be seen in polycrystalline Ga-intercalated specimens due to very poor quality of the sample which have low RRR value. A definite answer to the presence of CDW transition would require study on single crystals, with good crystalline order.
Fig. 3.5: Resistivity variation with temperature, (a) Left y-axis is used for 2H-Ga\textsubscript{x}NbSe\textsubscript{2} (x = 0 and 0.05) polycrystalline pellets. (b) Plotted on a log-log scale of 2H-Ga\textsubscript{x}NbSe\textsubscript{2} after subtracting the residual resistivity \( \rho_0 \). The inset fig. 3.5(b) showed the normalized resistivity of the Ga-intercalated polycrystalline samples.

In fig. 3.5(b), I have plotted temperature dependence of resistivity after subtracting \( \rho_0 \) on a log-log plot. We see that the resistivity below 37K for these specimens are also fitted with the equation (3.3a), \( \rho = \rho_0 + AT^n \).

Here, the superscript ‘n’ lies in between 2 and 3. The pure and 10% Ga-intercalated compounds are very close to the T\textsuperscript{3}-behavior but the T\textsuperscript{2}-behavior is dominated in 5% Ga-intercalated polycrystalline sample.
3.4.2 Superconducting Properties

For 10% Ga-intercalation the superconducting transition still exists above 2K - the lowest temperature of our measurement – as shown in fig. 3.5(a). Fig. 3.6(a) and (b) show the superconducting transition of the pure 2H-NbSe2 and 5% Ga-intercalated polycrystalline specimens respectively at different magnetic fields applied perpendicular to the current. The polycrystalline 2H-NbSe2 showed a large positive magnetoresistance compare to the 2H-Ga0.05 NbSe2. The upper critical fields from the resistivity data of these samples are estimated as discussed previously. We are unable to measure the upper critical field for 2H-Ga0.10 NbSe2 polycrystalline sample, because it’s $T_s$ is 2.7K and we can not go down to the lowest temperature beyond 2K in our experimental set up.

Fig. 3.6: $T_s$ at different magnetic fields of (a) 2H-NbSe2 (Polycrystalline) (b) 2H-Ga0.05 NbSe2 (Polycrystalline) specimens.
3.4.3 Seebeck Coefficient

In fig. 3.7, I plotted the Seebeck coefficient of polycrystalline samples of pure and Ga-intercalated 2H-NbSe$_2$ in the temperature range from 16 to 320K. The negative Seebeck coefficient of 2H-NbSe$_2$ increases with the increasing concentration of ‘Ga’ at room temperature. This is understood by the two band model of the diffusion thermopower as explained earlier in which the transfer of charge carriers from valence band to the narrow d-band suppresses the mobility of electrons. On cooling, the Seebeck coefficient of both the Ga-intercalated polycrystalline samples decreases linearly down to about 50K and then shows a steeper drop down to 16K. This dependence is very similar to that for self intercalated 3R-Nb$_{1+x}$S$_2$ and Ga$_{0.10}$NbS$_2$ measured by A. Niazi (Thesis) [24].

![Graph showing Seebeck coefficient vs. temperature for various samples.](image)

Fig. 3.7: Absolute S(T) vs. temperature on pure and Ga-intercalated NbSe$_2$ specimens.
Table – 3.2

<table>
<thead>
<tr>
<th>Compounds name (at 300K)</th>
<th>Symmetry</th>
<th>RRR</th>
<th>$\rho_{300} (\Omega , cm)$</th>
<th>$T_s (K)$</th>
<th>$S_{300} (\mu V / K)$</th>
<th>$T_c (K)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>* NbSe2 4H</td>
<td>4H</td>
<td>21.0</td>
<td>$1.14 \times 10^{-3}$</td>
<td>6.5</td>
<td>-9.16</td>
<td>42</td>
</tr>
<tr>
<td>* NbSe2 2H</td>
<td>2H</td>
<td>66.7</td>
<td>$6.82 \times 10^{-5}$</td>
<td>7.4</td>
<td>-4.08</td>
<td>35</td>
</tr>
<tr>
<td>† NbSe2 2H</td>
<td>2H</td>
<td>13.0</td>
<td>$1.96 \times 10^{-4}$</td>
<td>7.4</td>
<td>-3.70</td>
<td>---</td>
</tr>
<tr>
<td>† Ga$_{0.05}$NbSe2 2H</td>
<td>2H</td>
<td>2.9</td>
<td>$4.18 \times 10^{-4}$</td>
<td>5.6</td>
<td>-6.33</td>
<td>---</td>
</tr>
<tr>
<td>† Ga$_{0.10}$NbSe2 2H</td>
<td>2H</td>
<td>1.5</td>
<td>$1.23 \times 10^{-3}$</td>
<td>2.7</td>
<td>-11.21</td>
<td>---</td>
</tr>
</tbody>
</table>

* = For single crystal Flake
† = For polycrystalline specimen
$T_c (K)$ = CDW transition temperature

3.5 Discussion

From our experimental results, we found that the anomalies related to the CDW transition as seen in the resistivity are very sensitive to the crystalline orientation, since it is absent in the polycrystalline specimen. It is clear that the superconductivity temperature ($T_s$) is less for 4H polymorph, where CDW- $T_c$ is higher. This suppression of $T_s$ seems to be consistent with the effect of pressure on both the transitions as studied by C. W. Chu et al. [5]. To comment about the effect of Ga – intercalation on CDW transition, we have to measure single crystals. However, the superconducting transition temperature $T_s$ decreases as Ga-intercalation increases. The positive transverse and longitudinal magneto-resistance was found for all the samples of pure and Ga-intercalated polycrystalline and single crystal flake specimens by applying external magnetic field up to 6 Tesla.
3.5.1 2H and 4H – polytype:

Polymorphic phase transitions are possible in group-V transition metal dichalcogenides by varying the preparative conditions. We found two polymorphs of NbSe$_2$ -- 2H and 4H with trigonal prismatic coordination of the Nb-atom, when prepared at 750$^\circ$C and 925$^\circ$C respectively. We find anomalies in the resistivity associated with CDW transition at 35K and 42K respectively and a superconducting transition at 7.4K and 6.5K respectively for 2H and 4H polytype. It seems that the bump like anomaly in resistivity due to CDW (as shown in fig. 3.8) is reduced in intense magnetic field. There is, however significant increase in the transverse magnetoresistance just below the CDW transition temperature for both the polymorphs.

Fig. 3.8: The resistivity of the single crystal flake specimens of 4H-NbSe$_2$ and 2H-NbSe$_2$ showing a large increase in transverse magnetic field below respective CDW transition.
3.5.2 Upper critical field from Resistivity measurement

The superconducting transition temperatures are found at 7.4K and 6.5K for 2H-NbSe$_2$ and 4H-NbSe$_2$ in our measurement. Previous studies of resistivity, magnetization and specific heat on these polycrystalline materials exhibited type-II superconducting behavior [7, 10, 25]. The superconductivity was measured by passing the current along the planes of the flakes i.e. along a-b planes of the layers. The upper critical field $H_{c2}(T)$ could be estimated from our results using standard procedure. The critical field $H_{c2}(T)$ along the parallel and perpendicular direction of the layers are quite different, as expected for the large anisotropy of the layered compounds. The anisotropy in $H_{c2}$ is about 6.3 and 3 respectively for 4H and 2H flakes. As seen in fig. 3.9, the critical field $H_{c2}$ for in-plane direction has an unusual linear dependence on T, and it extrapolates to a very large value of 31.2 T in case of 4H- NbSe$_2$. This linear dependence has been explained by N. R. Werthamer et al. [26] in the bulk type-II superconductor. The in-plane critical fields of 4H-NbSe$_2$ single crystal flake increases more rapidly compared to 2H-NbSe$_2$ on cooling below $T_s$. This can be explained as the reduction in coherence length of 4H-polymorph along c-axis. The $H_{c2}$ of polycrystalline sample of 2H-NbSe$_2$ is in between the in-plane $H_{c2}$ of two single crystals. This upper critical field is slightly less in 5% Ga-intercalated than 2H-NbSe$_2$ polycrystalline samples.

K. Noto et al. [7] found that $T_s$ enhances with depression of $T_C$ by the application of field. This effect is same as Chu et al. [5] observed in their pressure effect measurement. They calculated the $H_{c2}$ values, having large positive curvature along the layer compare to the other direction.
3.5.3 Magnetoresistivity

We have seen that the magnetoresistance is quite substantial in CDW phase of these compounds. Fig. 3.10(a) showed the Kohlar's plot of the magnetic field dependence measurement for pure NbSe$_2$ at 8K in the configuration of $H \parallel$ and $H \perp$ to the ab-plane. The transverse-resistivity $\Delta \rho / \rho_0$ (i.e. $H \perp$ to layer) increases rapidly with $H / \rho_0$ for single crystals. But along the layer $\Delta \rho / \rho_0$ increases slowly compared to other direction. The $\Delta \rho / \rho_0$ along the layer is very much reduced with increasing magnetic field for 4H-NbSe$_2$ single crystal compare to the 2H polymorph. The transverse-resistivity of the polycrystalline 2H-NbSe$_2$ (i.e. magnetic field applied perpendicular to the flow of current) is very similar with $H \perp$ to the ab-plane of single crystals.
The perpendicular field dependence of the magnetoresistivity on single crystals as well as the polycrystalline pellet smoothly varies as $H^{1.6}$ at low field. Along the layer it varies as $H^{1.2}$ for 2H-NbSe$_2$ and $H^{0.2}$ for 4H-NbSe$_2$. In fig. 3.10(b), the low field magnetoresistivity of NbSe$_2$ are plotted as a function of $H^2$.

![Graphs showing magnetoresistivity variation](image)

Fig. 3.10: (a) Kohlar's plot between $\Delta \rho/\rho_0$ vs. $H/\rho_0$ (b) $\Delta \rho/\rho_0$ vs. $H^2$, for single crystal flake of 4H-NbSe$_2$ and 2H-NbSe$_2$ & Polycrystalline of 2H-NbSe$_2$ at 8K.

### 3.5.4 Thermopower

In 2H-NbSe$_2$, the $S(T)$ varies from negative to positive depending upon the mobility of the narrow d-band charge carriers. The negative thermopower is twice in 4H-NbSe$_2$ compared to 2H-NbSe$_2$ at room temperature is related to the decrease of electron mobility in the narrow d-band due to the stacking sequence of the unit cell. A clear anomaly was found in both the single crystal specimens of NbSe$_2$, which strongly depends on the RRR value. The increase of electron concentrations in the narrow d-band of the Ga-intercalated polycrystalline pellets enhanced the negative thermopower. The behavior of 5 and 10%
Ga-intercalated compounds are very similar to the self-intercalated compounds of 2H-Nb$_{1+x}$S$_2$ and 3R-Ga$_x$NbS$_2$ as previously studied by A. Niazi.

### 3.7 Conclusion

From the above experimental data we conclude that the lattice constant of the Ga-intercalated compounds up to 10% is slightly changed when prepared at 750°C. The c-axis is slightly increased, indicating the Ga atom occupy octahedral sites in Van der Waal’s gap.

The superconducting transition is found for both the polymorphs of 2H and 4H. But the CDW transition is appeared in resistivity and thermopower only on the single crystal flakes which have larger RRR value. Below CDW transition the in-plane magnetoresistance is increasing at same rate whereas longitudinal magnetoresistance reduces in 4H-polymorph.

The intercalation of Ga atom reduces the superconducting transition temperature. The anomaly associated with CDW transition is suppressed in our powder polycrystalline samples due to the small RRR value. To see the effect of ‘Ga’ on CDW transition, one must prepare high quality single crystals.
Reference


