Physical Properties Study of the CeOsGa$_4$ Compound

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A polycrystalline sample of CeOsGa$_4$ was prepared by arc-melting stoichiometric quantities of high purity elements of 4N and greater, in an arc furnace. The data was confirmed to crystallize in an orthorhombic structure, with a space group $Pnma$ (Number 51). Measurements of the magnetic susceptibility showed a distinct anomaly around $T_p = 3.8$ K, while the high temperature data (above 100 K) obeys Curie-Weiss law. The calculated effective moment of 2.44 $\mu_B$, was obtained, which was a bit less than the theoretical moment for a Ce$^{3+}$ ion of 2.54 $\mu_B$. Magnetization data at $T = 2$ K depicts that CeOsGa$_4$ does not saturate up to applied magnetic field of 7 T, while the data measured at 9 K indicates that the compound is purely paramagnetic at that temperature. The low temperature specific heat data is characterized by an anomaly at $T_p = 3.8$ K confirming the $\chi(T)$ data. Electrical resistivity shows a metallic behaviour at high temperatures with a deviation at low temperatures, signalling the cooperative behaviour which results to ordering. In this work we present the initial studies of the physical properties measurements performed on this compound.

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1. Introduction

The study of gallium (Ga) rich compounds has drawn some attention due to the complexities related to the crystal structures in these compounds. Amongst the first reported Ga-rich compounds are RE$_2$Co$_5$Ga$_9$ (RE: Y, Ho) [1], RE$_2$T$_3$Ga$_9$ (RE: Y, Sm, Gd-Yb; T: Rh, Ir) [2]. The structures of these members in these families of gallium-rich lanthanide (Yb$_2$Ru$_2$Ga$_{10}$ and Lu$_2$Ru$_2$Ga$_{10}$) vary from tetragonal structure, with space group $P4/mnm$ where gallium atoms form a two dimensional infinite double layer that extends orthogonally to the entire axis of the structure [3]. Other stoichiometries such as LnRu$_2$Ga$_8$ (Ln = La – Nd) were found to crystallize in an orthorhombic CaCo$_2$Al$_5$-type structure, exhibiting the space group, $Pbam$, and also orthorhombic structures belonging to $Cmcm$ space group [4].

Here we report on the physical properties of a polycrystalline CeOsGa$_4$ compound. This compound was confirmed to crystallize in an orthorhombic structure belonging to the space group $Pnma$ [5]. The structure exhibits two types of two dimensionally alternating layers that are slightly puckered, having OsGa$_3$ layer sandwiched between CeGa layers.

2. Experimental procedure

Polycrystalline sample of the CeOsGa$_4$ compound was prepared by arc-melting high-purity elemental constituent elements on a water-cooled copper plate under ultra-high pure argon atmosphere. Metals of the following purity in wt% were used: Ce, 99.99%; Os, 99.95% and Ga, 99.999%. The button was turned over and remelted several times to ensure good homogeneity of the sample. The calculated mass loss after final melting was less than 1%. The sample was characterised by powder x-ray diffraction (XRD) at room temperature using a Rigaku powder diffractometer with a CuK$_\alpha$ radiation ($\lambda = 1.540698$ Å).

Magnetic susceptibility measurements of the polycrystalline sample was carried out using Quantum Design MPMS — a superconducting quantum interface device magnetometer, in the temperature range 380–2 K. Magnetization in applied fields up to 7 T was also measured in three different isotherms. Specific heat measurements were measured in the temperature range 275–2 K, using Physical Properties Measuring System (PPMS) from San Diego. Electrical resistivity was carried out using DC option in PPMS, in temperature ranges between 300 K and 2 K.

3. Results and discussion

3.1 Magnetic susceptibility

Figure 1 depicts the inverse magnetic susceptibility, $\chi^{-1}(T)$ data measured in the field of 0.05 T in temperature range of 2 K till 380 K. The high temperature data (> 100 K) obey Curie Weiss (CW) relationship following the relation:

$$\chi^{-1}(T) = \frac{3k_B(T - \theta_p)}{N_A \mu_{eff}^2},$$

(1)

where $k_B$ is the Boltzmann constant, $\theta_p$ is the paramagnetic Curie temperature, $N_A$ is the Avogadro number and $\mu_{eff}$ is the effective magnetic moment. The least square (LSQ) fit of $\chi^{-1}(T)$ data is shown in the main panel of the figure using a red line.

The fit yields the values of the effective magnetic moment, $\mu_{eff} = 2.44(2)$ $\mu_B$ and $\theta_p = 6.5(2)$ K. The fitted value of $\mu_{eff}$ is close to the expected value of the free Ce$^{3+}$ ion for $g[(j + 1)/2] = 2.54$ $\mu_B$, although the slight

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(398)
reduction in the effective moment can be ascribed to few possibilities which include the presence of the crystal electric field (CEF) effects.

Specific heat

Specific heat measured is shown in Fig. 3. The data monotonously decreases down to low temperatures and a peak is observed at \(T_o = 3.8\) K. The estimation of the location of this anomaly was taken from the maximum peak as indicated by an arrow on the inset of Fig. 3(a). The location of this peak corresponds well with the data obtained in magnetic susceptibility. This data reaches the Dulong-Petit value at 149.652 J/mol K, reached at about 150 K, and it is less than the maximum specific heat obtained at room temperature, which is 170 J/mol K.

Fig. 3(b) shows the \(C_p/T\) vs \(T^2\) curve, with the Sommerfeld coefficient (\(\gamma\)) fit for the data just above the ordering temperature. The red line is the fit according to the expression:

\[
\frac{C_p}{T} = \gamma + \beta T^2,
\]

where \(\gamma\) is the Sommerfeld coefficient and \(\beta\) is the constant associated with Debye temperature, \(\theta_D\). The calculated Debye temperature was found to be 226(1) J/mol K, while the obtained Sommerfeld coefficient, \(\gamma = 0.098(2)\) J/mol K².

Electrical resistivity

The electrical resistivity, \(\rho(T)\) measured in zero applied magnetic field is displayed in Fig. 4. The data is characterised by a metallic behaviour at high temperatures where deviations around \(T_o\) are observed with the
decrease in temperatures. The drop in $\rho(T)$ is ascribed to the scatter on the long-range ordered magnetic moments. The inset shows the low temperatures where position of the ordering temperature is expected. The arrow points at temperature that corresponds to anomaly that exhibited ordering temperature in $C_p(T)$ and $\chi(T)$ data.

4. Conclusion

The physical properties of CeOsGa$_4$ were studied through magnetic studies ($\chi(T)$, $M(B)$), specific heat and electrical resistivity, $\rho(T)$. An antiferromagnetic anomaly was observed at $T \approx 3.8$ K. The compound shows signs of ferromagnetism at high applied magnetic field. This finding is further investigated and will be reported elsewhere.

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References