Southern Illinois University Carbondale
OpenSIUC

Publications | Department of Physics

4-1999

Magnetic Properties of RTSb3

Michael Leonard
Southern Illinois University Carbondale

Shibaji Saha
Southern Illinois University Carbondale

Naushad Ali
Southern Illinois University Carbondale

Follow this and additional works at: http://opensiuc.lib.siu.edu/phys_pubs
© 1999 American Institute of Physics
Published in *Journal of Applied Physics*, Vol. 85 No. 8 (1999) at doi: 10.1063/1.370472

Recommended Citation
Leonard, Michael, Saha, Shibaji and Ali, Naushad. "Magnetic Properties of RTSb3." (Apr 1999).

This Article is brought to you for free and open access by the Department of Physics at OpenSIUC. It has been accepted for inclusion in Publications by an authorized administrator of OpenSIUC. For more information, please contact opensiuc@lib.siu.edu.

Magnetic properties of $RTSb_3$

Michael Leonard, Shibaji Saha, and Naushad Ali[a)]
Department of Physics and Molecular Science Program, Southern Illinois University at Carbondale, Carbondale, Illinois 62901

Magnetization, electrical resistivity, and thermal expansion measurements have been performed on polycrystalline $RTSb_3$ (R=La, Ce, Pr, Nd, Gd, Tb, and Dy; T=Cr, V) samples in order to study their magnetic properties. Depending on the rare-earth element, $RTSb_3$ has been found to have either a purely ferromagnetic (or antiferromagnetic) phase or combination of antiferromagnetic (lower-temperature) and ferromagnetic (higher-temperature) phases. The antiferromagnetic order evolves from the ferromagnetic order as a result of the competition between R^{3+} and Cr^{3+} ions. As R is changed from La to Dy, the antiferromagnetic ordering of the R^{3+} ions becomes more prominent and predominate over the ferromagnetic ordering of Cr^{3+} for R=Gd, Tb, and Dy. Thermal expansion measurements show that the antiferromagnetic transition accompanies a drop in the sample dimension. The order of the ferromagnetic transition is found to be of the second order.
© *1999 American Institute of Physics.* [S0021-8979(99)58008-0]

INTRODUCTION

The intermetallic alloys formed by combining the magnetic properties of the $4f$ metals (large magnetocrystalline anisotropy, R) and the $3d$ metals (large exchange coupling, T) in $RTSb_3$ present an interesting class of magnetic material both for the study of their basic magnetic behavior and for their possible applications. It is mentioned that the rare-earth metal is useful in stabilizing low-dimension features such as layers or chains[1] (seen in $CeCrSb_3$). Successive layering of such compound allows for the control of the magnetic aspect through interlayer coupling.

Previous results on the magnetic properties of the $RTSb_3$ system with T=Cr and V show that the Cr atoms which order ferromagnetically, correspond to two unpaired spins, whereas the V has one uncompensated spin.[2] The lowered Curie temperatures for $RTSb_3$ (T=Cr) are attributed to the R–T coupling where R orders antiferromagnetically. In the same way as the atomic radius decreases from La to Lu, it was found that substitution of heavier rare earths for La in $LaTSb_3$ causes the structure of the compound to contract.[1] The contraction of the structure is accompanied by changes in the magnetic properties of the system. This led us to extend the study of the magnetic properties of $RTSb_3$ with R=La, Ce, Pr, Nd, Gd, Tb, and Dy.

EXPERIMENTAL DETAILS

Polycrystalline $RTSb_3$ samples were synthesized by are melting of the proper amounts of the constituent elements in an Ar atmosphere. An excess amount (10%) of Sb was added to compensate for its weight loss during melting. The purities of the elements were 99.9% for all the rare-earth elements, 99.99% for Cr, 99.9% for V, and 99.999% for Sb. Samples were annealed in an evacuated quartz tube at 600 °C for two days and at 800 °C for eight days. Magnetization measurements were carried out by means of a superconducting quantum interference device magnetometer (Quantum Design, CA) over the temperature range of 5–400 K and in an applied magnetic field up to 5.5 T. Thermal expansion measurements were made using a capacitance dilatometer over the temperature range of 4.2–200 K. Electrical resistivity measurements were done using the standard four-probe method over the temperature range of 5–300 K.

RESULTS AND DISCUSSIONS

Figure 1 shows the magnetization behavior of the $RCrSb_3$ (with R=La, Ce, Pr, Nd, Gd, and Tb) compounds as a function of temperature. Unless specified, all samples were cooled in zero applied magnetic field from room temperature and magnetization measurements were done in an applied field of 0.01 T while raising the temperature. Figure 1(a) shows that $LaCrSb_3$ is ferromagnetic with a Curie temperature of 144 K. The transition temperature was determined from the first derivative of M vs T data. The T_c found by Hartjes *et al.*[2] for $LaCrSb_3$ is 125 K, which was determined from the lowest point of the $1/\chi$ vs T plot. In Fig. 1(b) $CeCrSb_3$ shows ferromagnetic ordering with $T_c=140$ K. This is much higher than that found by Hartjes *et al.*[2] The inset shows the magnetization data of $CeCrSb_3$ at 1 T. It shows that there is another ordering below 30 K. Interestingly, the $PrCrSb_3$ sample [Fig. 1(c)] shows antiferromagnetism below 16 K while it is ferromagnetic at higher temperatures with $T_c=142$ K. A comparison of the low-temperature ordering in $CeCrSb_3$ [the inset of Fig. 1(b)] with the low-temperature antiferromagnetic ordering in $PrCrSb_3$ suggests that in $CeCrSb_3$ there is an onset of an antiferromagnetic phase at low temperature. Temperature-dependent magnetization of the $NdCrSb_3$ [Fig. 1(d)] sample is similar to that of $PrCrSb_3$. For $NdCrSb_3$, transition temperatures of $T_N=18$ K and $T_c=141$ K were found. The overall magnetic behavior of the samples presented in Figs. 1(a), 1(b), 1(c), and 1(d) agree with those found by Hartjes *et al.*[2]

We now turn our attention to new systems in the $RTSb_3$ series, namely, $GdCrSb_3$, $TbCrb_3$, $DyCrb_3$, and $DyVSb_3$.

a)Electronic mail: nali@physics.siu.edu

 © 1999 American Institute of Physics

Downloaded 04 Jan 2012 to 131.230.71.39. Redistribution subject to AIP license or copyright; see http://jap.aip.org/about/rights_and_permissions

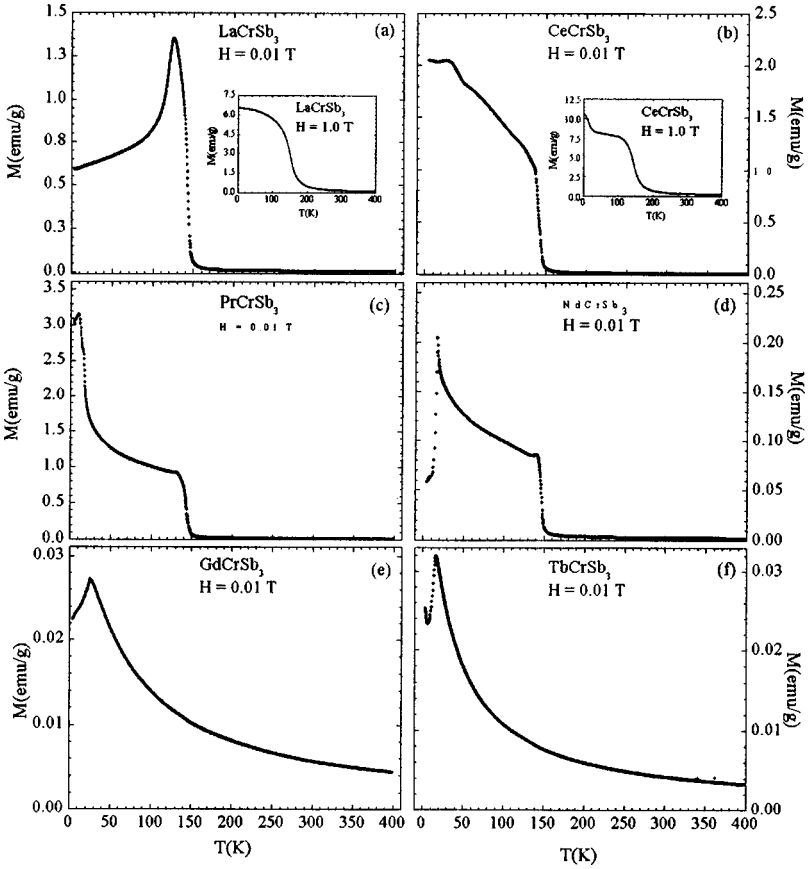

FIG. 1. Magnetization as a function of temperature of $RCrSb_3$ samples: (a) M vs T of $LaCrSb_3$ at 0.01 T; the inset shows the data taken at 1 T. (b) M vs T of $CeCrSb_3$ at 0.01 T; the inset shows the data taken at 1 T. (c) M vs T of $PrCrSb_3$ at 0.01 T; the inset shows the data taken at 1 T. (d) M vs T of $NdCrSb_3$ at 0.01 T. (e) M vs T of $GdCrSb_3$ at 0.01 T. (f) M vs T of $TbCrSb_3$ at 0.01 T.

In Fig. 1(e), $GdCrSb_3$ shows an antiferromagnetic ordering with $T_N = 26$ K. $GdCrb_3$ does not show the ferromagnetic ordering found in all the $RCrSb_3$ for R lighter than Gd. $TbCrSb_3$ shows a clear antiferromagnetic phase with $T_N = 17$ K [Fig. 1(f)]. It is known that the ferromagnetic ordering in $LaCrSb_3$ is due to the ordering of the Cr atoms. According to Czachor,[3] the antiferromagnetic order in $RCrSb_3$ compounds is due to the antiferromagnetic ordering of the R^{3+} ions. In the present study, the evolution of an antiferromagnetic order from ferromagnetic order in $RCrSb_3$ as we changed R from La to Dy, is most likely due to favorable antiferromagnetic ordering of the R^{3+} ions over the ferromagnetic order of the Cr atoms. This, most likely, has a connection with the changes in the lattice parameters due to the lanthanide contraction.

Magnetization data of $DyCrSb_3$ are plotted in Fig. 2(a). It shows that $DyCrSb_3$ orders antiferromagnetically below 12 K. Field-dependent magnetization data in the antiferromagnetic phase are plotted in Fig. 2(c) for $DyCrSb_3$. It clearly shows that the sample is antiferromagnetic below 12 K; more importantly, the sample transforms to a ferromagnetic phase with higher field showing a metamagnetic behavior of the sample. The critical field is found to be $H_C = 1.9$ T at 5 K. The critical fields have been determined from several field-dependent magnetization measurements at different constant temperatures. An $H-T$ phase diagram is shown in the inset of Fig. 2(c). Hartjes *et al.*[2] also found a metamagnetic transition in $PrVSb_3$ and $NdVSb_3$. Since $DyCrSb_3$ showed metamagnetism, we also studied $DyVSb_3$. Figure 2(b) shows the magnetization of $DyVSb_3$ as a function of temperature. It is antiferromagnetic with $T_N = 12$ K. Figure 2(d) shows the magnetization as a function of applied field at 5, 7, and 8 K where it is clear that $DyVSb_3$ also shows metamagnetic behavior. The inset of Fig. 2(d) shows the $H-T$ phase diagram for $DyVSb_3$.

Thermal expansion measurements were done on selected samples to determine the order of the ferromagnetic transitions and also to investigate any dramatic dimensional

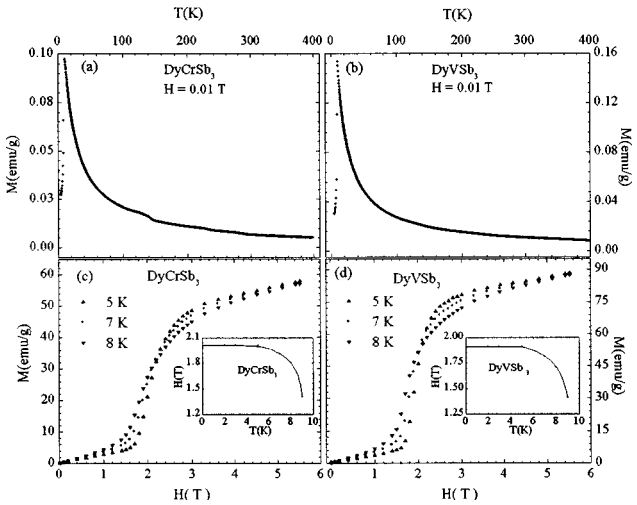

FIG. 2. Magnetization of $DyCrSb_3$ (a) and $DyVSb_3$ (b) samples as a function of temperature at an applied field of 0.01 T. Magnetization as a function of applied field at different constant temperatures of $DyCrSb_3$ (c) and $DyVSb_3$ (d) samples; the insets show the $H-T$ phase diagrams.

Downloaded 04 Jan 2012 to 131.230.71.39. Redistribution subject to AIP license or copyright; see http://jap.aip.org/about/rights_and_permissions

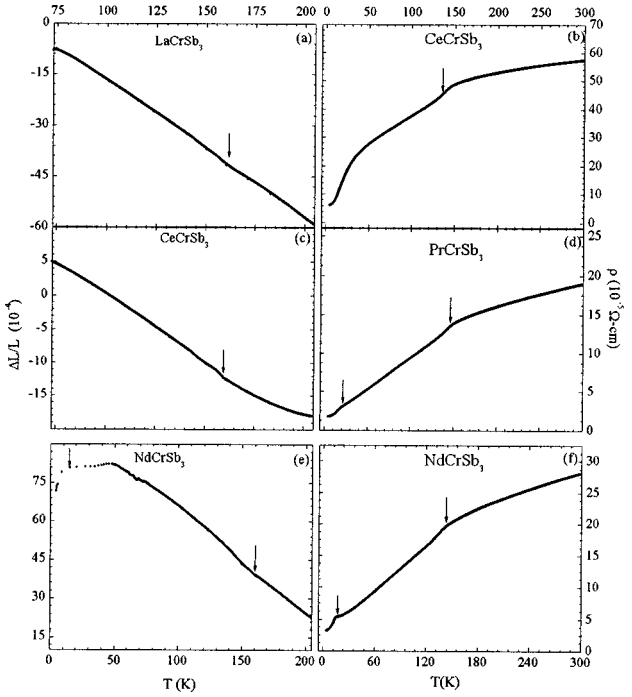

FIG. 3. Respective relative thermal expansivity $\Delta l/l$ of $RCrSb_3$ (R=La, Ce, Nd) are given in (a), (c), and (e) as a function of temperature. Electrical resistivity of $RCrSb_3$ (R=Ce, Pr, Nd) are shown in (b), (d), and (f), respectively, as a function of temperature.

changes associated with the magnetic transitions. Thermal expansion data for $LaCrSb_3$, $CeCrSb_3$, and $NdCrSb_3$ are given in Figs. 3(a), 3(c), and 3(e), respectively. In the data for $LaCrSb_3$, a slope change occurs near the ferromagnetic transition which suggests a second-order transition. In the $CeCrSb_3$ sample a slope change occurs near the ferromagnetic transition, which again suggests a second-order transition. A drop in sample dimension appears, near $T_N = 18$ K, the antiferromagnetic transition of $NdCrSb_3$, at higher temperatures, the data suggests a second-order ferromagnetic transition at $T_c = 141$ K.

Electrical resistance measurements on selected samples of $RCrSb_3$ were made to identify features in resistance which would correlate with the transitions observed in the magnetization measurements. Resistivity data on $CeCrsb_3$, $PrCrSb_3$, and $NdCrSb_3$ are shown in Figs. 3(b), 3(d), and 3(f), respectively. All samples show metallic character. In $CeCrSb_3$ the transition marked by an arrow corresponds to the ferromagnetic transition observed in the magnetization data. The two transitions found in the resistivity data of both $PrCrSb_3$ and $NdCrSb_3$ correspond to the antiferromagnetic and ferromagnetic transitions in the magnetization data.

SUMMARY

Magnetization, thermal expansion, and electrical resistivity measurements have been made on $RTSb_3$ samples. $RCrSb_3$ samples show ferromagnetic order for R=La; antiferromagnetic and ferromagnetic orders for R=Ce, Pr, and Nd, and antiferromagnetic order for R=Gd, Tb, and Dy. The variety of magnetic order clearly depends on the size of the rare-earth elements. A drop in the sample dimension is found to occur near the Néel temperatures. The ferromagnetic transitions in $RCrSb_3$ are found to be second order. Transitions in electrical resistivity data corresponded to those in magnetization data.

ACKNOWLEDGMENT

This work was supported in part by a grant from Consortium for Advanced Radiation Source, University of Chicago, Chicago, IL.

[1] M. Ferguson *et al.*, J. Alloys Compd. **249**, 191 (1997).
[2] K. Hartjes *et al.*, J. Magn. Magn. Mater. **173**, 109 (1997).
[3] A. Czachor, J. Magn. Magn. Mater. **139**, 355 (1995).

Downloaded 04 Jan 2012 to 131.230.71.39. Redistribution subject to AIP license or copyright; see http://jap.aip.org/about/rights_and_permissions