AD-A093 074 NAVAL SURFACE WEAPONS CENTER SILVER SPRING MD F/G 20/3
MAGNETOSTRICTION OF LAVES PHASE RARE EARTH-NI2 COMPOUNDS,(U)
JUL 80 R ABBUNDI, A E CLARK
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MAGNETOSTRICTION OF LAVES PHASE RARE EARTH-Ni_2 COMPOUNDS

BY R. ABBUNDI, A. E. CLARK

RESEARCH AND TECHNOLOGY DEPARTMENT

1 JULY 1980

NAVAL SURFACE WEAPONS CENTER

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REPORT DOCUMENTATION PAGE

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1. REPORT NUMBER: NSWC/TR-80-303

2. GOVT ACCESSION NO.: AD-A093 074

3. RECIPIENT'S CATALOG NUMBER:

4. TITLE (and Subtitle): MAGNETOSTRICTION OF LAVES PHASE RARE EARTH-Ni_2 COMPOUNDS

5. TYPE OF REPORT & PERIOD COVERED:

6. PERFORMING ORG. REPORT NUMBER:

7. AUTHOR(s): R. Abbundi and A. E. Clark

8. CONTRACT OR GRANT NUMBER(s):

9. PERFORMING ORGANIZATION NAME AND ADDRESS:
Naval Surface Weapons Center
Research & Technology Department
Radiation Division, Solid State Branch R45
White Oak, Silver Spring, Maryland 20910

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: 61153N; RR 02-206; RR 02-206-01; R45AC

11. CONTROLLING OFFICE NAME AND ADDRESS:

12. REPORT DATE: 1 July 1980

13. NUMBER OF PAGES: 20

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office):

15. SECURITY CLASS. (of this report): UNCLASSIFIED

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE:

16. DISTRIBUTION STATEMENT (of this Report):

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report):

18. SUPPLEMENTARY NOTES:

To be published in IEEE *Transactions on Magnetics*

19. KEY WORDS (Continue on reverse side if necessary and identify by block number):

Magnetostriction
Rare Earth-Intermetallic Compounds
Rare Earth-Ni Compounds

20. ABSTRACT (Continue on reverse side if necessary and identify by block number):

The magnetostriction of the RNi_2 compounds (R = Tb,Dy,Ho,Er and Tm) was measured as a function of applied field from T = 5 K to above the Curie temperatures. A direct comparison is made between these results and the huge magnetostriction observed at cryogenic temperatures in the RFe_2 and RCo_2 compounds. The largest magnetostriction in the RNi_2 series occurs in $TbNi_2$. At T = 5 K the magnetostriction is fairly well saturated and results in a value of $\lambda_\parallel - \lambda_\perp = 2270 \times 10^{-6}$ at H = 25 kOe, while extrapolation to infinite field yields 2340×10^{-6}. $DyNi_2$ also displays a tendency to saturate at the higher fields

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) at lower temperatures with $\lambda_{\parallel} - \lambda_{\perp} = -765 \times 10^{-6}$ at 25 kOe and -840 ppm at H = ∞. The compounds $HoNi_2$, $ErNi_2$ and $TmNi_2$ all exhibit large strains at T = 5 K although fail to saturate with available fields. At 25 kOe the magnetostriction for these compounds was found to be -586×10^{-6}, -415×10^{-6} and -552×10^{-6} respectively.

FOREWORD

The magnetostriction study reported here is part of a research program undertaken to determine the nature of the magnetostriction in the rare earth-intermetallic compounds. In this paper is detailed the temperature dependence of the magnetostriction for a series of rare earth-Ni_2 compounds. Studies were made as a function of applied field from T = 5 K to temperatures above the Curie points.

The largest magnetostriction in the RNi_2 series occurs in $TbNi_2$. At T = 5 K the magnetostriction is fairly well saturated and results in a value of $\lambda_{\parallel} - \lambda_{\perp} = 2270 \times 10^{-6}$ at H = 25 kOe, while extrapolation to infinite field yields 2340×10^{-6}. $DyNi_2$ also displays a tendency to saturate at the higher fields at lower temperature with $\lambda_{\parallel} - \lambda_{\perp} = -765 \times 10^{-6}$ at 25 kOe and -840 ppm at $H = \infty$. The compounds $HoNi_2$, $ErNi_2$, and $TmNi_2$ all exhibit large strains at T = 5 K although fail to saturate with available fields. At 25 kOe the magnetostriction for these compounds was found to be -386×10^{-6}, -415×10^{-6} and -552×10^{-6} respectively.

The study was carried out in the Solid State Branch of the Radiation Division as part of the research program on magnetostrictive material. The research was sponsored by the Office of Naval Research (PO-4-0081, NR 039-110) and the NSWC Independent Research Program (IR-011).

B. F. DESAVAGE
By direction

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INTRODUCTION

Intermetallic compounds of the rare earths with the 3d transition metals of Fe, Co and Ni have been the subject of extensive investigations at many laboratories. Many interesting effects have been observed in ultrasonic and magnetostriction measurements in the cubic Laves phase RTM_2 compounds, where large changes in the elastic moduli as well as huge magnetostriction constants occur.[1-7] In this work we report on the magnetostriction of the RNi_2 compounds (R = Tb, Dy, Ho, Er and Tm).

Bulk magnetization measurements[8] on the RNi_2 series have shown that the Curie temperatures are in the cryogenic region with $T_c < 90$ K. Both YNi_2 and $LuNi_2$ were found to exhibit only a Pauli paramagnetic behavior down to 4.2 K. Thus it appears that Ni possesses no moment of its own in these compounds. This behavior is unlike that observed in the RFe_2 and RCo_2 compounds. In the case of the RFe_2 series the 3d transition element when combined with the heavy lanthanide elements Tb through Tm possesses a moment of approximately 1.6 μ_B/Fe atom, with only a relatively small variation dependent upon the rare earth.[9,10] In the RCo_2 compounds the Co moment is approximately 1 μ_B/Co atom.[11] The magnetization results[8] further showed that $GdNi_2$ at T = 0 possesses a saturation moment of 7.1 μ_B, very nearly equal to the gJ value of the rare earth. However, the moments of the remaining RNi_2 compounds are substantially reduced from their theoretical gJ values. This discrepancy has been attributed to crystal field effects on the rare earth which partially quench the orbital angular momentum.[12]

Mössbauer effect measurements[13] on the RNi_2 compounds have shown that the easy axis of magnetization follows the same sequence as that observed for both the RFe_2[14] and RCo_2[15] series. $DyNi_2$ and $HoNi_2$ magnetize along a [100] direction, while $TbNi_2$ and $ErNi_2$ along a [111] direction. Although no results were reported on $TmNi_2$, it is assumed that $TmNi_2$ has its easy axis of magnetization along a [111] direction, similar to $TmFe_2$.[16]

The magnetostriction measurements were performed as a function of field from T = 5 K to above the Curie temperatures. These results can be directly compared with the huge magnetostriction which has been found at cryogenic temperatures in both the RFe_2[3-5] and RCo_2[6,7] series.

EXPERIMENTAL RESULTS

The highly anisotropic 4f electron charge cloud of the Tb^{3+} ion produces enormous magneto-strains in $TbFe_2$[3] and $TbCo_2$.[6,7] The high Curie temperature of $TbFe_2$ (T_c = 710 K) allows this huge magnetostriction of $\lambda_{111}(0\ K) = 4400 \times 10^{-6}$ at T = 0 to remain large at room temperature, where $\lambda_{111}(300\ K) = 2500 \times 10^{-6}$. This strain is the largest room temperature magnetostriction of any known material. In $TbCo_2$ a similarly huge rhombohedral distortion develops below T_c = 240 K, also reaching 4400×10^{-6} at 4.2 K.

Gignoux et al.[7] state that $TbNi_2$, however, behaves quite differently. Rhombohedral distortions (λ_{111}), measured by x-ray diffraction, were found to be ≈ 0. They state that this small value is consistent with a smaller molecular field than found in either $TbFe_2$ or $TbCo_2$ resulting in a smaller value of $\langle O_2^0 \rangle$. Our results on the magnetostriction of $TbNi_2$ do not confirm this low measured value. Instead, we find that the strain in $TbNi_2$ is about 50% of that in $TbFe_2$ and $TbCo_2$. Figure 1 shows the magnetostriction at T = 5 K as a function of applied field for $TbNi_2$ and $DyNi_2$. The temperature dependence of the magnetostriction at H = 25 kOe for $TbNi_2$ and $DyNi_2$ is shown in Figure 2. At T = 5 K the magnetostriction of $TbNi_2$ is fairly well saturated and results in a value of $\lambda_{\parallel} - \lambda_{\perp} = 2270 \times 10^{-6}$ at H = 25 kOe, while extrapolation to infinite field yields 2340×10^{-6}.

$DyNi_2$ also displays a tendency to saturate with $\lambda_{\parallel} - \lambda_{\perp} = -765 \times 10^{-6}$ at 25 kOe. The magnitude of this strain while comparable to that observed in $DyCo_2$[6] implies a substantially larger $|\lambda_{100}|$ than was found in $DyFe_2$, where $|\lambda_{100}|$ remained small through the entire temperature range.[3]

The field dependence of the magnetostriction at T = 5 K for $HoNi_2$, $ErNi_2$ and $TmNi_2$ is shown in Figure 3. A peak in the magnetostriction of $HoNi_2$ was observed near H = 5kOe. We attribute this behavior to the large magnetocrystalline anisotropy which characterizes the RTM_2 compounds.[7,9,17-20] In the case of $HoNi_2$, as the field is increased above 5kOe, the moments are tilted away from their highly magnetostrictive easy [100] axes, decreasing the net strain. This behavior is only observed at the lower temperatures. For T > 11 K the rapid decrease in anisotropy with increasing temperature results in the usual behavior of increasing $|\lambda|$ with increasing field. The magnitude of the peak strain in $HoNi_2$ at T = 5 K of -533 ppm is comparable to λ_{100} measured in $HoFe_2$ where $\lambda_{100}(0\ K) = -745$ ppm.[5] The temperature dependence of the magnetostriction at H = 25 kOe for $HoNi_2$ is shown in Figure 4.

The large anisotropy in these materials is again reflected in the failure of $ErNi_2$ to reach saturation at 5 K, as shown in Figure 3. However, the magnetostriction is still large with $\lambda_{\parallel} - \lambda_{\perp} = -415 \times 10^{-6}$ at H = 25 kOe. Figure 5 shows the temperature dependence of the strain at 25 kOe, from 5 K to above the Curie temperature.

A comparison of the field dependence of the magnetostriction at 5 K between $TmNi_2$ (see Figure 3) and the other compounds shows a substantially different behavior. The magnetostriction is far from saturation. Farrell and Wallace, in their bulk magnetization measurements,[8] report that $TmNi_2$ may not be ferromagnetic at T = 2 K. They could not determine whether $TmNi_2$ was displaying VanVleck paramagnetism or the onset of ferromagnetism. However, in view of those findings, it appears that, at least at 5 K, $TmNi_2$ is not ferromagnetic and thus that accounts for the absence of any spontaneous magnetostriction at this temperature. Nevertheless at H = 25 kOe the strain is becoming quite large with $\lambda_{\parallel} - \lambda_{\perp} = -552 \times 10^{-6}$. In theory the saturation magnetostriction of $TmNi_2$ should be of comparable magnitude to that found in $TbNi_2$. The temperature dependence of the magnetostriction for $TmNi_2$ at 25 kOe is shown in Figure 6.

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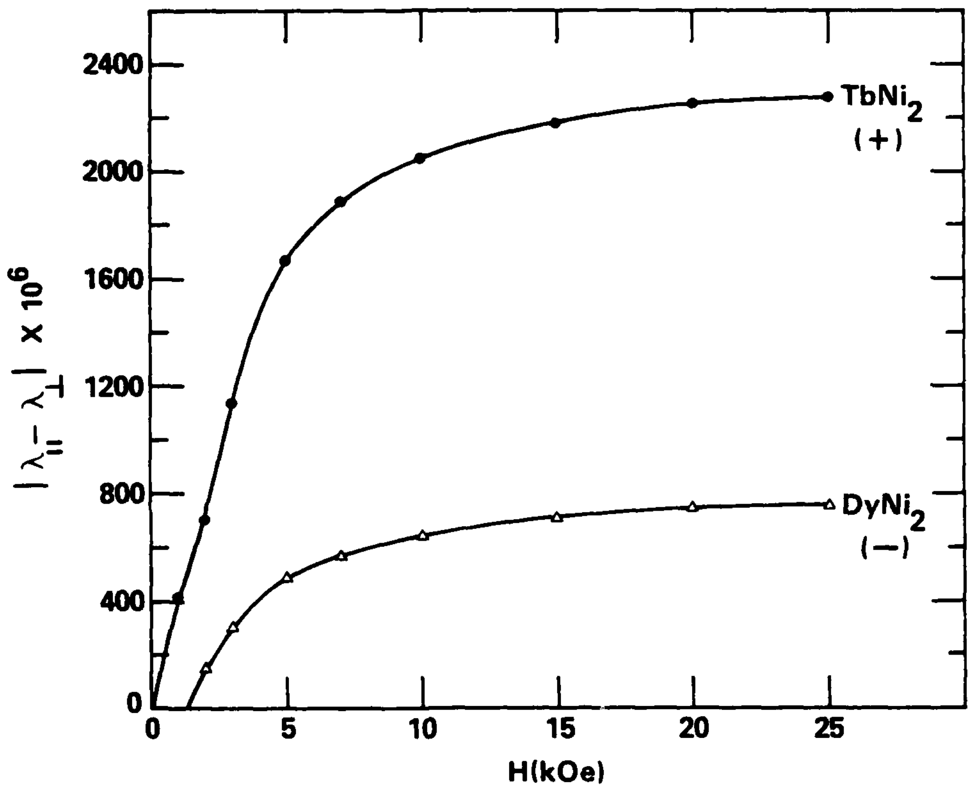

FIGURE 1 MAGNETOSTRICTION AT T=5K AS A FUNCTION OF APPLIED FIELD FOR $TbNi_2$ AND $DyNi_2$. THE MAGNETOSTRICTION OF $TbNi_2$ IS POSITIVE (+), WHILE $DyNi_2$ IS NEGATIVE (−).

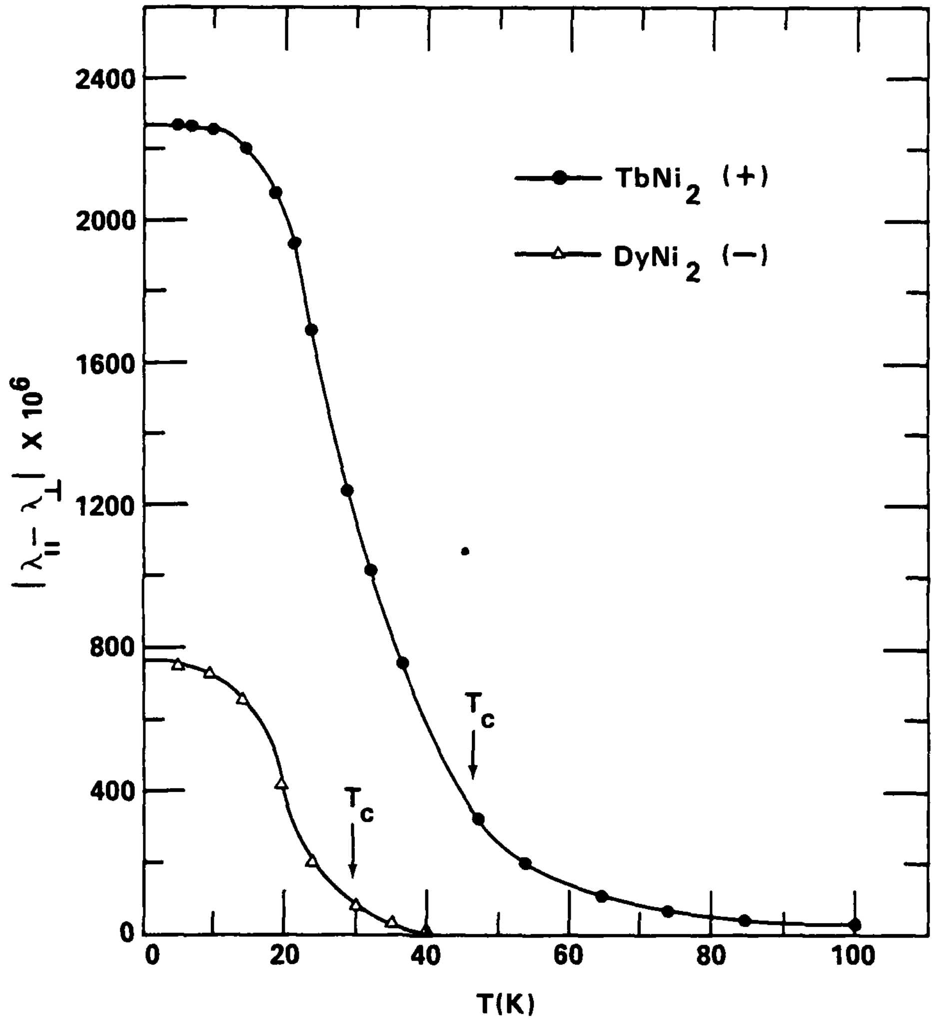

FIGURE 2 TEMPERATURE DEPENDENCE OF THE MAGNETOSTRICTION AT H=25kOe FOR $TbNi_2$ AND $DyNi_2$. THE CURIE TEMPERATURES WERE TAKEN FROM BULK MAGNETIZATION MEASUREMENTS (REF. 8).

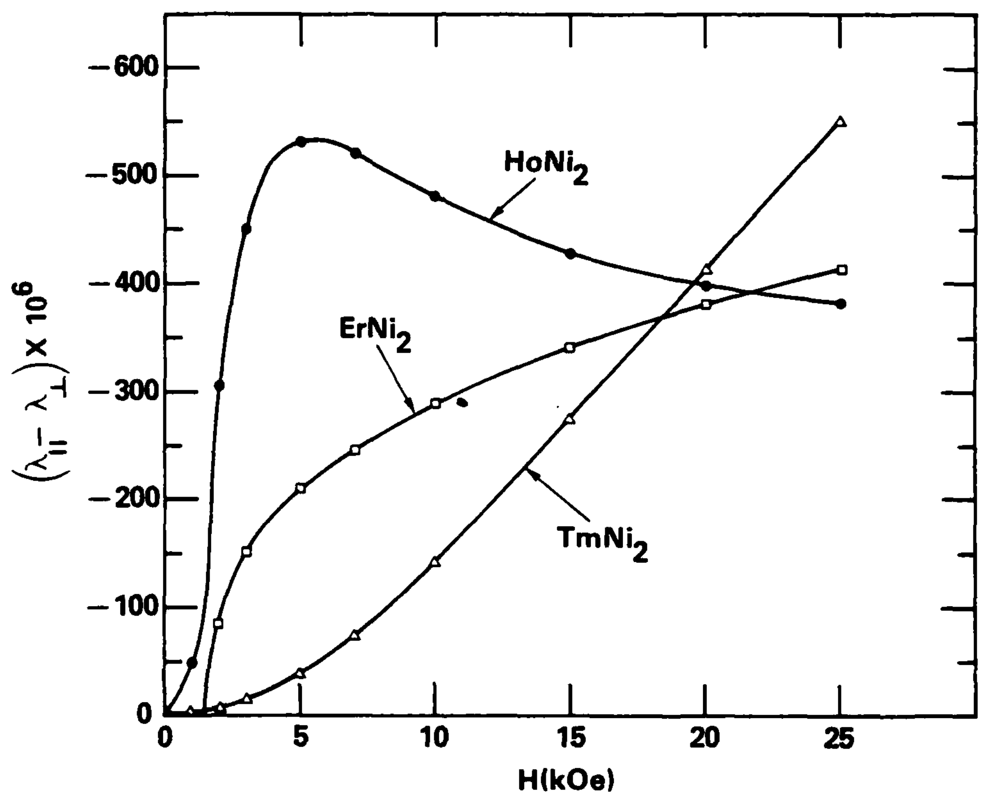

FIGURE 3 MAGNETOSTRICTION AT T=5K AS A FUNCTION OF APPLIED FIELD FOR $HoNi_2$, $ErNi_2$ AND $TmNi_2$.

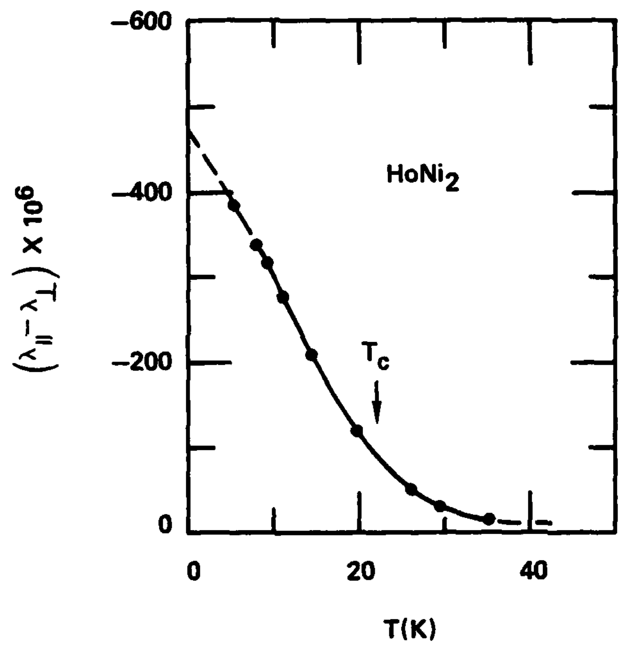

FIGURE 4 TEMPERATURE DEPENDENCE OF THE MAGNETOSTRICTION AT H=25kOe FOR $HoNi_2$. THE CURIE TEMPERATURE WAS TAKEN FROM BULK MAGNETIZATION MEASUREMENTS (REF. 8).

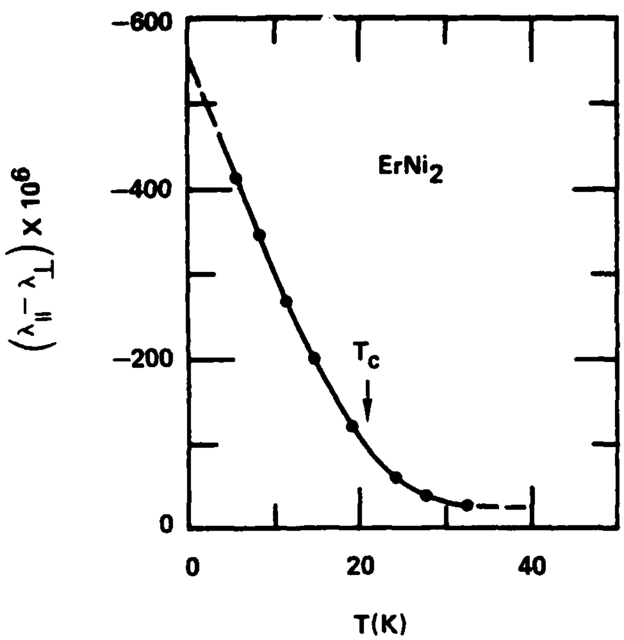

FIGURE 5 TEMPERATURE DEPENDENCE OF THE MAGNETOSTRICTION AT H=25kOe FOR $ErNi_2$. THE CURIE TEMPERATURE WAS TAKEN FROM BULK MAGNETIZATION MEASUREMENTS (REF. 8).

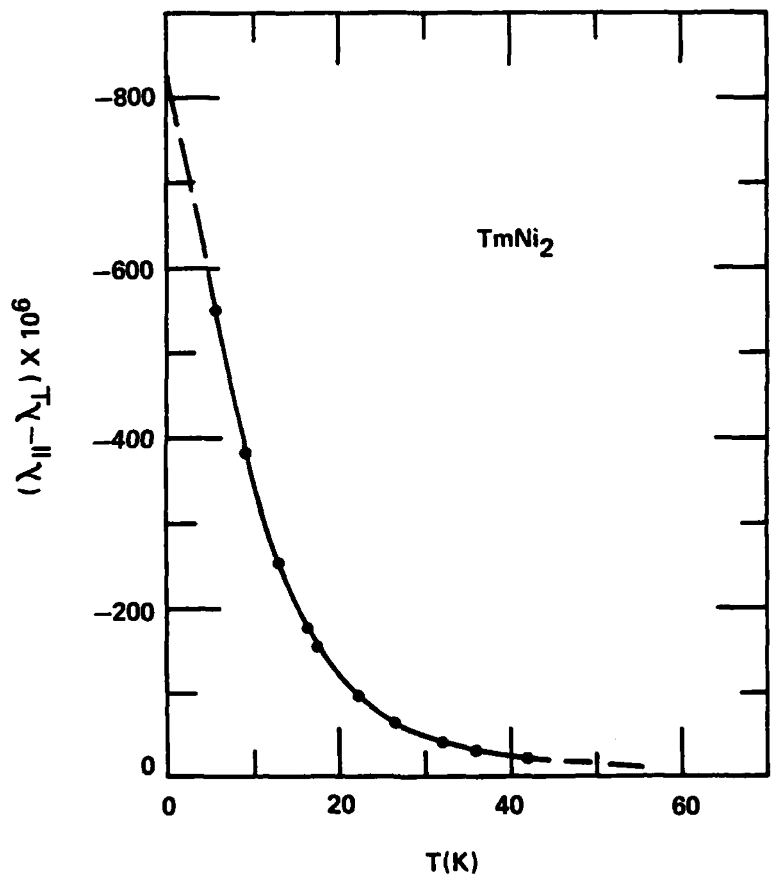

FIGURE 6 TEMPERATURE DEPENDENCE OF THE MAGNETOSTRICTION AT H=25kOe FOR $TmNi_2$.

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