Magnetically induced Lattice Dynamics in a Magnetoelectric Antiferromagnet Cr_2O_3

T. Nishimoto, T. Moriyasu, and T. Kohmoto
Graduate School of Science, Kobe University, Kobe 657-8501, Japan
kohmoto@kobe-u.ac.jp

Abstract: We studied the optically induced lattice dynamics in a magnetoelectric antiferromagnet Cr_2O_3 by polarization spectroscopy. The observed divergence behavior of the relaxation rate at the Néel temperature suggests the correlation between lattice and spin fluctuations.
OCIS codes: (160.3820) Magneto-optical materials; (260.1440) Birefringence

1. Introduction

In recent years, various types of multiferroic materials have been discovered, in which magnetic order and ferroelectricity coexist. Many of them are antiferromagnets with spiral spin structures, and their giant magnetoelectric effects have been attracting attention.

Chromium oxide Cr_2O_3 is known to show the linear magnetoelectric effect [1], in which electric polarization is induced in proportion to an applied magnelic field and magnetization is induced in proportion to an applied electric field. Although the linear magnetoelectric effect was first observed in Cr_2O_3 a half century ago [2,3], recently the room temperature magnetoelectric effect has been attracting attention again [4,5].

In this report, we studied the optically induced lattice dynamics in a Cr_2O_3 single crystal by using a transient birefringence measurement with the pump-probe technique.

2. Sample and experiment

Cr_2O_3 has a corundum structure with a 3-fold symmetry axis. Cr^{3+} ions align along the symmetry axis and are surrounded by distorted octahedra of O^{2-} ions. The spins on Cr^{3+} ions shows an antiferromagnetic order below the Néel temperature $T_N \cong 307$ K.

A lattice distortion is generated by a linearly polarized pump pulse (805 nm, 0.2 ps). The induced anisotropy of the refractive index, or linear brirefringence, is detected by a polarimeter with a quarter-wave plate as the change in the polarization of a linearly polarized probe beam (900 nm, 0.2 ps). The polarization plane of the probe beam is tilted by 45° from that of the pump beam, and the ellipticity of the transmitted probe beam caused by the birefringence is monitored. The thickness of the sample is 0.25mm.

3. Result and descussion

The optically induced lattice distortion signal observed in the picosecond region is shown in Fig. 1. Oscillation components of ~0.1 and ~0.3 THz are found in the lattice distortion signals at low temperatures. These componets disappear above 50K.

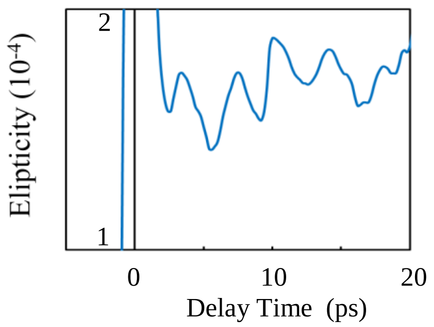

Fig. 1. Optically induced lattice distortion signal in the picosecond region observed at 7 K.

The optically induced lattice distortion signals observed in the nanosecond and subnanosecond regions are shown in Fig. 2. The decay curve of the lattice distortion is expressed well by a single exponential. The temperature dependence of the relaxation rate $1/\tau$ obtained from the observed lattice distortion signals is shown in Fig. 3. As the temperature increases, its relaxation rate shows a divergence behavior towards the Néel temperature. The solid line in Fig. 3 represents the relation $1/\tau = (T_N - T)^{-n}$ with n~0.6.

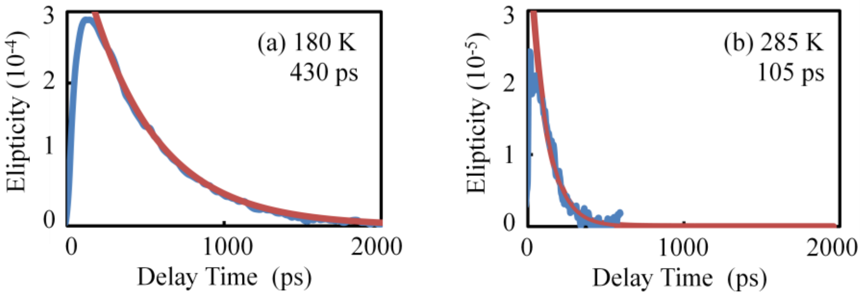

Fig. 2. Optically induced lattice distortion signal in the nanosecond and subnanosecond region observed at (a) 180 and (b) 285 K.

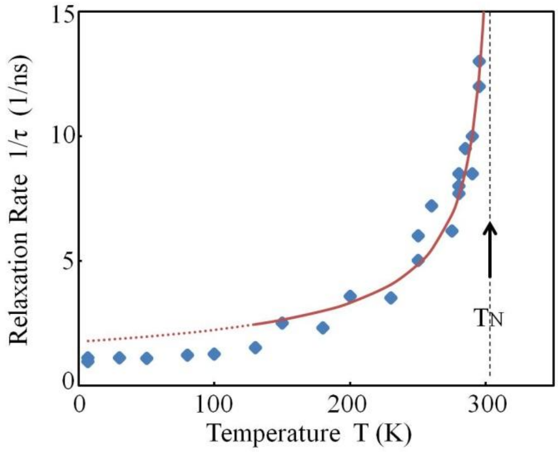

Fig. 3. Temperature dependence of the relaxation rate of the lattice distortion signal.

In the ferroelectrics of the displacement type, oscillations of soft phonon modes appear. In the ferroelectrics of the order-disorder type, the relaxation rate is expected to decrease at the transition temperature (critical slowing down). However, the relaxation rate observed in Cr_2O_3 increases at T_N. The experimental result in Fig. 3 shows the lattice fluctuation also increases at T_N where the spin fluctuation increases and suggests the correlation between lattice fluctuation and spin fluctuation. The observed dynamics is considered to be a phenomenon peculiar to magnetoelectric materials and may be called a dynamic magnetoelectric effect.

4. References

[1] I. E. Dzyaloshinskii, “On the magneto-electric effect in antiferromagnets,” Zh. Exp. Teor. Fiz. 37, 881-882 (1959) [Sov. Phys. JETP **10**, 628-629 (1959)].

[2] D. N. Astrov, “The magnetoelectric effect in antiferromagnetics,” Zh. Exp. Teor. Fiz. 38, 984-985 (1960) [Sov. Phys. JETP 11, 708-709 (1960).

[3] G. T. Rado and V. J. Folen, “Observation of the Magnetically Induced Magnetoelectric Effect and Evidence for Antiferromagnetic Domains,” Phys. Rev. Lett. 7, 310 (1961).

[4] A. Iyama and T. Kimura, “Magnetoelectric hysteresis loops in Cr_2O_3 at room temperature,” Phys. Rev. B **87**, 180408(R) (2013).

[5] T. Satoh, B. B. V. Aken, N. P. Duong, T. Lottermoser, and M. Fiebig, “Ultrafast spin and lattice dynamics in antiferromagnetic Cr_2O_3” Phys. Rev. B **75**, 155406, (2007).