Elastic properties of ferromagnetic Mott insulator $YTiO_3$

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Abstract

$YTiO_3$ has attracted interests because of a Mott insulator with a ferromagnetic transition at $T_c \simeq 29$ K. We have measured temperature dependence of elastic moduli for a high-quality single-crystal of $YTiO_3$ around T_c using an ultrasonic technique. It is plausible that the elastic anomaly at T_c arises from a usual magnetostriction effect.

Key words: Elastic moduli; Ultrasound; ferromagnetism; Mott insulator

1. Introduction

Among various kinds of Mott insulators, $YTiO_3$ shows peculiar properties. This compound undergoes a ferromagnetic phase transition around 30 K [1] despite that most of Mott insulators usually possess an antiferromagnetic ground state [2]. If one dopes a carrier into this compound as $Y_{1-x}Ca_xTiO_3$, the electronic property drastically changes from the ferromagnet to paramagnet at $x \approx 0.1$ and then from the insulator to metal at $x \approx 0.4$ [3,4]. Recently, Akimitsu *at al.* reported from polarized neutron experiments that the magnetic form factor of $YTiO_3$ agrees well with the theoretical predictions [5,6], providing a direct evidence for new orbital ordering in the ferromagnetic state of $YTiO_3$ [7]. The observed magnetic form factor was explained by the linear combination of the wave functions $|yz>$ and $|zx>$. This result is one of strong suggestion that the ferromagnetic transition originates from *antiferromagnetic*-type orbital ordering.

An elastic modulus is one of most sensitive quantity to the orbital ordering [8]. One can expect a remarkable elastic anomaly at the ferromagnetic transition temperature T_c if the orbital ordering occurs in concurrence with the ferromagnetic transition. In this work, we have measured various elastic moduli of single-crystalline $YTiO_3$ as a function of temperature T by means of an ultrasonic technique.

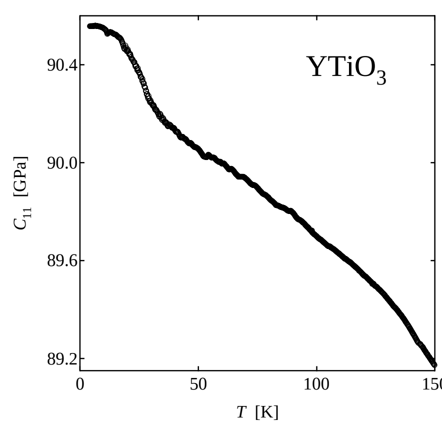

Fig. 1. Temperature dependence of longitudinal elastic stiffness C_{11} in the T-range between 3 and 150 K. An enhancement is observed below the ferromagnetic transition temperature $T_c = 29$ K with decreasing T.

2. Experimental

A change in sound velocity was measured by a phase-comparison type pulse-echo method. The ultrasound with frequency of ≈ 15 MHz was generated and de-

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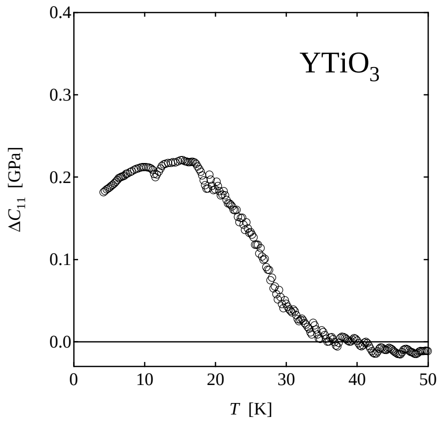

Fig. 2. Temperature dependence of a *magnetic* contribution to the C_{11} modulus, ΔC_{11}, which was evaluated by subtraction of lattice contribution $C_{\rm L}(T)$ from C_{11}.

tected by a pair of $LiNbO_3$ transducers glued onto the polished surfaces of the single crystal with the size of $2.697 \times 3.433 \times 3.024 \mathrm{mm}^3$. The magnitude of elastic moduli C_{ii} was calculated using the relation $C = \rho v^2$, where v is the sound velocity and ρ ($= 5.341 \mathrm{g/cm}^3$ at room temperature [9,10]) is the mass density. Six independent stiffness coefficients were measured for an orthorhombic structure, longitudinal $C_{ii}, i = 1, 2, 3$ and transverse $C_{ii}, i = 4, 5, 6$, since $YTiO_3$ has a $GdFeO_3$-type perovskite structure with the space group $Pnma$ at room temperature. C_{11} to C_{66} are the linear responses to strains ϵ_{xx}, ϵ_{yy}, ϵ_{zz}, ϵ_{yz}, ϵ_{zx} and ϵ_{xy}, respectively.

The single crystal was grown by a floating-zone method using an image furnace with 4 halogen lamps under a reductive atmosphere of Ar and H_2 mixture. Details of sample growth is reported elsewhere [10].

3. Results and Discussion

Plotted in Fig. 1 is temperature dependence of C_{11} between 3 and 150 K. With decreasing temperature, the modulus shows normal enhancement due to anharmonicity in binding potential between atoms and then an abrupt change in slope occurs at $T_{\rm c} = 29$ K. To obtain a *magnetic* contribution to the elastic modulus, we estimated a lattice contribution $C_{\rm L}(T)$ by fitting the data between 30 and 150 K with an equation [11]: $C_{\rm L}(T) = c_0 + c_1 T + c_4 T^4$ with the parameters $c_0 = 90.4038$GPa, $c_1 = -6.6921 \times 10^{-3}$GPa/K and $c_4 = -3.0685 \times 10^{-10}$GPa/K^4. Fig. 2 shows temperature dependence of the *magnetic* contribution ΔC_{11}, which was calculated by subtraction of $C_{\rm L}(T)$ from the experimental data C_{11} presented in Fig. 1. With decreasing temperature, ΔC_{11} shows enhancement blow $T_{\rm c}$ with magnitude of about 0.2 GPa. Such a step-like and scant increase suggests that the anomaly originates from a usual magnetostriction due to coupling linear in the strain but quadratic in the spin orderparameter [12]. Temperature dependence of the *magnetic* contribution to the stiffness for all other modes $C_{ii}, i = 2, 3, 4, 5, 6$ below $T_{\rm c}$ shows similar behavior with scant enhancement with the magnitude of ≈ 0.2 GPa, implying that the orbital ordering may not undergo in concurrence with the ferromagnetic transition. Preliminary data for C_{44}, which is the response to the ϵ_{yz} strain, indicates a lattice anomaly in a temperature range much higher than $T_{\rm c}$ [13].

4. Summary

We have measured elastic moduli of the ferromagnetic Mott insulator $YTiO_3$ around $T_{\rm c}$. The anomaly in C_{ii} at $T_{\rm c}$ can be due to the magnetostriction effect.

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