Photoinduced Disaccommodation Spectrum in Ca(0.001 mol)-doped Yttrium Iron Garnet

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A remarkable photoinduced disaccommodation (DA) of magnetic permeability μ is observed in yttrium iron garnet (YIG) single crystal with very low contents of Ca: these double peaks of DA are around 125 K (0.46 eV) and 200 K (0.60 eV) with correlative onset of the irreversible decrease of real part of permeability μ' insensitive to demagnetization at lower temperature than 250 K. In addition, we observed the lowest temperature peak of DA is strongly frequency dependent and at 1 kHz it is cancelled by the accommodation (A) phenomenon. For these observations, we propose that the pinning center may be due to a photoinduced structure change around oxygen defects.

Keywords: photoinduced, disaccommodation, accommodation, frequency dependent, yttrium iron garnet, oxygen vacancy.

1. Introduction

Photoinduced magnetic effect is a very interesting problem, related to magnetic after effect and potential for an application in photo-memory and evaluation of vacancy-type defects of materials. These effects can be divided into the I-effect (Si~0.1 mol doped YIG) and the II-effect (Si~0.01 mol doped YIG)¹⁾, depending on whether is dominant or not the polarization state of light for the observation. The origin of I-effect was explained as a redistribution of uniaxial anisotropy of Fe^{2+} along one of the four cubic directions of octahedral sites, while the II-effect was attributed to the different behaviors of Fe^{2+} close to and far from Si^{4+} ions. On the other hand, the induced preferred directions within the domain wall in soft

materials create localized potential minima. As these minima become deeper with time, the mobility of the domain wall will decrease. The gradual decrease of μ' after demagnetization or magnetic slow relaxation of μ' is called the disaccommodation (DA)²⁾. On the other hand, photoinduced DA is termed as PDA. In this report, we present the observation of PDA, in not Si- but Ca-doped YIG and a clue to explain why it is possible for the single or double peaks of PDA to exist in YIG single crystal based on the photoinduced accommodation, A. These effects are completely reversible by the irradiation-annealing cycle.

2. Experimental

The high purity samples of YIG were fabricated from a floating zone method, except for intentional dopants Ga^{3+} :0.0625 replaced by Fe^{3+} and Ca^{2+} :0.001 by Y^{3+} which is expected to increase the penetration depth of light. In the sample, however, a considerable oxygen vacancy is incorporated of the order of 0.001 mol estimated from spectroscopic method. In this experiment, two samples (A) and (B) are used, both of which have 4 mm in the outer diameter and 2 mm in the inner diameter cut from the same ingot of YIG single crystal. Source of irradiating the samples was visible light from a xenon lamp, since no conspicuous differences of the characteristics among the many other kinds of light sources, but the most effective wavelength of light in these phenomena is about 1 μm . The measurements of PDA, photoinduced accommodation and or usual DA in the dark were carried out, using an automated equipment which allows one to measure the time

dependence of $\mu'(t_1, T)$, at various temperatures T with any arbitrary time intervals $\Delta t = (t_2 - t_1)$ after demagnetization. The experimental results could be represented relaxation curves of the magnitude of $\Delta R / \mu'(t_1, T)$, where $\Delta R = \mu'(t_1, T) - \mu'(t_2, T)$. Here, $t_1 = 2$ sec and $t_2 = 2^n$ ($n=2, 3, \dots, 7$) sec for a sample (A) and $t_1 = 5$ sec and $t_2 = 50$ sec for a sample (B) after demagnetization (see the appendix).

3. Experimental results and discussion

3.1. Photoinduced irreversible decrease of μ'

First, we observed the photoinduced irreversible decrease of μ' (termed as PID) in these samples (A) and (B). The effect in the sample (A) in Fig.1 is not due to DA, since it cannot be returned back to the original state before irradiation or being insensitive to demagnetization (not shown in the figure)¹⁾. This shows the light intensity dependence of PID in YIG (sample A). Measuring frequency is 140 Hz. It is natural to observe for the response time to become reduced with the light intensity. Next, measuring field intensity and frequency dependence of the PID were studied and are shown in Fig.2 and Fig.3, respectively. In general, the spectrum of μ' of YIG is characterized by two distinct regions of dispersion. The lower one less than 100 kHz results from the relaxation of domain wall contribution, while the dispersion at higher than 100 MHz is due to the magnetic resonance in an effective field by anisotropy and internal demagnetizing fields²⁾.

Fig.1 Time dependence of photoinduced irreversible decrease in permeability μ' (PID) in YIG (sample A). Measuring field and frequency are 3 mOe and 140 Hz, respectively.

Fig.2 Time dependence of the permeability μ' (PID) as a function of magnetic field in YIG (sample A). Measuring frequency is 140 Hz.

In our experiments taking into consideration of the strong frequency dependent PDA, the low frequency region must be, furthermore, divided into the regions lower and higher than 1 kHz.

Fig.3 Time dependence of photoinduced irreversible decrease in permeability μ' (PID) in YIG (sample A). Measuring frequency is 0.14 kHz.

An explanation for PID has been mentioned in the introduction. But it is possible that another model could exist in our previous paper³⁾: photoinduced atomic rearrangements or charge change around vacancy triggered by an electronic excitation in the crystals, within a domain wall may lead to the formation of a stabilization potential acting as pinning center. Photoinduced migration is known in the F-center of an ionic crystal, where self-trapped excitons mediate such a process⁴⁾. These processes can be represented by a configurational coordinate diagram such as that shown in Fig.4. Although the diagram is schematic, the features essential to PID are present, especially the metastability at low temperature in a distorted configuration.

Fig.4 Configurational coordinate diagram for the explanation of photoinduced decrease of μ' (PID).

3.2 Photoinduced DA (PDA) in YIG

Within the measuring temperature range between 77 K and 300 K, photoinduced DA peaks are observed, these of which shift to the lower temperature side, of course the height of peaks increases with t_2 . This indicates a

Fig. 5 Temperature dependence of photoinduced DA(PDA)(sample A). L_i indicates the inductance (arbitrary unit) of i sec after demagnetization. Measuring frequency and field; 0.14 kHz and 3 mOe, respectively.

thermally activated process and help deducing the activation energy Q for DA. In both of the samples(A) and (B) of YIG irradiated with an intense visible light at 77 K and then in the dark, conspicuous double peaks of DA around 125K (DA(I)) and 220 K (DA(II)) are seen in Fig.5. The magnitudes of these peaks are found to be strongly dependent of the measuring field. From the dependence of these peaks on the measuring time interval, activation energies Q are estimated to be 0.46 eV for DA(I) and 0.60 eV for DA(II) as shown in Fig.6. This figure shows the measuring field dependence of PDA.

Fig.6 Magnetic field variation of the photoinduced DA (PDA) vs temperature of YIG (sample B). Measuring frequency is 0.14 kHz.

In addition, we observed the third peak (DAIII, 0.88 eV) around the room temperature, independent of irradiation around the room temperature in some samples. The peak shows strongly the sample-dependence although the peak is perfectly reproducible for a given sample. An explanation for a PDA is also presented, including a migration of oxygen vacancy, since some kinds of carriers such as electron and vacancy must themselves to form an induced anisotropy and stabilize the magnetic domain wall so that the total energy takes the minimum. In a previous paper⁶⁾, we proposed that DAI is due to a time dependent induced anisotropy from a translation of oxygen vacancy V_o without trapped electron, DAII is from V_o with one trapped electron and DAIII is V_o with trapped two electrons, taking into consideration of the mobility of V_o . This explanation is, however, not unique but the alternatives are numerous⁷⁾.

Fig.7 Phototoinduced DA (PDA)vs Temperature vs Frequency

3.3 Photoinduced accommodation in YIG

Figure 7 shows the frequency dependence of PDA in sample (B). It should be noted that the height of DA I is reduced; at 560 Hz DAI disappears completely and at 1 kHz negative DAI, that is accom-modation(A) grows with the measuring frequency.

Appendix

The normalized DA amplitudes of μ' (t, T) measured between t_1 and t_2 is expressed as $\Delta\mu' (t_1, t_2, T) = \mu' (t_1, T) - \mu' (t_2, T)$ (A1) and if the simple exponential time dependence is assumed,

$$\Delta\mu' (t_1, t_2, T) = \exp(-t_1/\tau) - \exp(-t_2/\tau) \quad (A2),$$

where the relaxation time τ is given by Arrhenius equations $\tau = \tau_0 \exp[Q/kT]$ with the pre-exponential τ_0 and the activation energy Q .

The relaxation time τ at the temperature $T_{\max}$ of the DA peak is given by the differentiation of (A2) with respect to T . Thus we have^{9,10)}

$$\tau(T_{\max}) = (t_2 - t_1) / \ln(t_2/t_1) \quad (A4).$$

The temperature dependence of τ can be determined, for an example, by a variation of t_2 at the fixed t_1 , so the activation energy Q can be obtained.

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