Thermal Hysteresis of Photoinduced Magnetic Effects in Yttrium Iron Garnet with a Small Amount of Oxygen Vacancy

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In single crystals of yttrium iron garnet irradiated with white light at 77 K, a remarkable change was observed in the temperature dependence of complex permeabilities μ' and μ'' . Simultaneously, conspicuous double peaks of DA around 125 K (DA1) and 200 K (DA2) were found to be induced by the irradiation at 77 K, with correlative onset of an irreversible decrease of permeability at low temperature. Besides, the dark DA (DA3) independent of white-light irradiation was observed around the room temperature. The activation energy of DA (1, 2, 3) may be calculated as 0.46, 0.60, and 0.88 eV, respectively.

Key words: photoinduced, oxygen vacancy, disaccommodation, thermal hysteresis, YIG

1. Introduction

Photoinduced magnetic effects in Si-doped yttrium iron garnet (YIG:Si) has attracted the attention of researchers since Teal *et al.*¹⁾ found for the first time one of these effects, so called the I-effect. These effects can be divided into the I-effect (vectorial) and the II-effect (scalar) depending on whether is dominant or not polarization state of free electrons into this insulating system. 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 (Enz-type) was attributed the different behaviors of Fe^{2+} close to and far from Si^{4+} ions.²⁾ On the other hand, disaccommodation (DA, a gradual decrease of initial permeability with time after demagnetization) which is often observed is, phenomenologically, similar to the II-effect.³⁾ DA is, however, so far considered as essentially different from the II-effect, since the former is sensitive but the latter is insensitive to demagnetization. In this report, we observed a thermal hysteresis and the phenomenon of DA can be produced by light irradiation in the high purity crystals of YIG,⁴⁾ indicating of photoinduced formation and relaxation of a potential barrier for photoexcited electron to return to an original state. In general, the excess energy once stored in the crystal by the photoabsorption is released through the emission of enormous number of phonons which give rise to the isomeric reactions, and is expected to show an associated change of μ - T curve.⁵⁾ Therefore, the measurement of the temperature de-

pendence of complex permeabilities μ' and μ'' , and DA of the samples after irradiation at 77 K was measured. The experimental results could be represented as an isothermal or isochronal relaxation curves of the magnitude of DA or $\Delta B/\mu(t, T)$, where $\Delta B = \mu(t_1, T) - \mu(t_2, T)$. At the low temperature, oxygen vacancies V_o behave as a type of charge reservoir which consists of two electrons trapped at the sites (V_o^{2e}) or ($\text{Fe}^{2+} - V_o - \text{Fe}^{2+}$) and light sensitive injector of free electrons into this insulating system.

2. Experimental

These samples of YIG are very pure, with neither Si nor Ca incorporated except for intentional dopants (Ga 0.0625 mol or Ca 0.001 mol). In all samples, however, a considerable oxygen vacancy is incorporated of the order of 0.1 mol% estimated from spectroscopic method. Source of irradiating the samples was a xenon lamp or white light, since no conspicuous differences among the many kinds of light sources such as laser light, mercury light, X-ray⁸⁾ and or gamma-ray⁹⁾ employed in these experiments. The measurement of photoinduced and or usual DA in the dark was carried out using an automated equipment made in our laboratory which allows one to measure the time dependence of the initial permeability, $\mu(t, T)$, at various temperatures T with any arbitrary time intervals $\Delta t = t_2 - t_1$ after demagnetization.

3. Results and Discussion

In order to examine the behavior of μ - T curve after white-light irradiation, the measurement was performed continuously, while the warming process at the rate of 0.5–1.0 K/min was stopped at several temperatures termed as turning temperature T_r (1st run) and again from the temperature T_r quickly cooled to 77 K. Furthermore, the measurement was continued without white-light irradiation with warming the sample at the same raising rate of temperature (2nd run). Figure 1 displays the result mentioned above. It should be noted in these figures that the concaves of μ - T curves at the first run disappear at the second run so long as each of the turning temperature T_r exceeds above the temperature of the DA peak. It is confirmed experimentally that these concaves are due to photoinduced DA as

Fig. 1 Temperature dependence of the complex permeability μ' (upper graph) and μ'' (below) of the samples after light-irradiation (1st run and 2nd run). Measured frequency and field: 0.14 kHz and 1 mOe; rate of temperature increase: 0.5 K/min. Turning temperature: $T_r=190$ K (left two graphs) and 250 K (right two graphs). Here, open circle: 1st run, closed circle: 2nd run.

Fig. 2 Photoinduced disaccommodation spectrum in a YIG single crystal. Here, $t_1=5$ s and $t_2=50$ s. DA(3) is independent of white-light irradiation.

Fig. 3 DA spectrum of a YIG sample around DA(3).

shown in Fig. 2. The basic concept of our explanation is as follows: Cooled in the dark, oxygen vacancies or deep donors capture the double electrons and F^0 -centers are formed. After white-light irradiation, three kinds of oxygen vacancies are possible: no trapped electron (V_o^0), one trapped electron (V_o^e) and two trapped electrons (V_o^{2e}). A mobility of V_o can be considered in order of value as V_o^0 , V_o^e , and V_o^{2e} . In this context, it is assumed that DA(1) is due to the time dependent induced anisotropy from a translation of V_o^0 ,

DA(2) is from V_o^e , and DA(3) is from V_o^{2e} which is independent of irradiation. The photoinduced decreased permeability in YIG returns to the state prior to white-light irradiation, when the sample is brought back to room temperature.²⁾ The irreversible characteristics may be explained by the assumption that these microscopic potential barriers around oxygen vacancy prevent the photoexcited electrons from being recaptured.¹⁰⁾ The irreversible variation in these phenomena is destroyed at room temperature, which is caused by

the returning of electrons surmounting the potential barrier to the original state V_0^{2e} .

After irradiation, the lattice around the defects usually undergoes strong rearrangement (strong lattice relaxation)¹⁰⁾ which may give a contribution to a pinning of domain walls, resulting in a decrease of permeability. In the second run, a part of the diminished permeability above T_r may be recovered as shown in Fig. 1, since amounts of Fe^{2+} contributing to a suppression of μ are reduced due to trapping an electron. In order to obtain the activation energy Q of DA(1), DA(2), and DA(3), we used the following simple relation $t_1/\tau=c$, where τ is the relaxation constant expressed as $\tau=\tau_\infty \exp(Q/kT_p)$, c and k is an arbitrary constant and Boltzmann constant, respectively. An example of these plots of DA(3) is presented in Fig. 3. It is clearly seen that the maximum of DA or T_p is shifted to the lower temperature with t_1 .^{7), 11)} Here, $t_1=5, 10, 20$, and 40 s and $t_2=10, 20, 40$, and 80 s for the calculation of the activation energy.⁷⁾ As the results, we obtained 0.46 eV for DA(1), 0.60 eV for DA(2), and 0.88 eV for DA(3), respectively. These values are so much high that a simple electron hopping model may not be applicable to this case.

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Received Oct. 15, 1996; Accepted Jan. 16, 1997