Model of Photoinduced Disaccommodation in Oxygen-deficient Yttrium Iron Garnet

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(Received: May 6, 1998 Accepted: August 26, 1998)

A model for disaccommodation in single crystals of yttrium iron garnet (YIG) irradiated with white light is proposed. Only oxygen vacancies are considered to be the origin of triple peaks of disaccommodation, DA, around 130K (DA(I)), 200K (DA(II)) and 300K (DA(III)). Taking account of the number of electrons trapped in oxygen vacancy, mechanisms of DA in the three divisions are explained. The model is confirmed by the irradiation dependence of DA and the thermal hysteresis of DA(I) and DA(II).

Key words: YIG, permeability, oxygen vacancy, photoinduced, disaccommodation

1. Introduction

Photoinduced magnetic effects in Si-doped yttrium iron garnet (YIG:Si) has attracted the attention of researchers since Teal and Temple[1] found for the first time one of these effects, so called the I-effect. These effects can be divided into the I-effect (Si=1 mol% doped YIG) and the II-effect (Si=0.1 mol% doped YIG)[2], 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$^{3+}$ along one of the four cubic directions of octahedral sites, while the II-effect was attributed to the different behaviors of Fe$^{3+}$ close to and far from Si$^{4+}$ ions[3].

On the other hand, the induced preferred directions within the domain wall in soft materials create localized potential minima. This gradual decrease of initial permeability after demagnetization or magnetic slow relaxation of initial permeability is called the disaccommodation (DA)[3]. As these minima become deeper with time, the mobility of the domain wall will decrease. In spinel ferrites, Yanase[4] proposed that the anisotropy arises from a preferential location of vacancies in the lattice, based on the Ohta’s experiment[5]. This model, however, is not enough for explaining the temperature dependence of photoinduced DA in YIG, because it is divided into three parts. In this report, we proposed a new model for the photoinduced DA, by modifying the Ohta and Yanase model.

2. Experimental Results and Discussion

The high purity samples of YIG were used here. In the samples neither Si nor Ca were incorporated intentionally excepting for dopants (Ga 0.31 mol% or Ca 0.001 mol%). In all samples, however, a considerable amount of oxygen vacancies are incorporated, which are spectroscopically estimated to be of the order of 0.001 mol%. A xenon lamp is used as a source of irradiating the samples, since there are no conspicuous differences among the many kinds of light sources such as laser light[6], LED, mercury light, X-ray[7] and or gamma-ray[8] 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[9] which allows one to measure the time dependence of the initial permeability, $\mu'_{0}(t,T)$, at various temperatures $T$ with any arbitrary time intervals $\Delta t = (t_2 - t_1)$ after demagnetization. The experimental results could be represented as an isothermal or isochronal relaxation curves of the magnitude of $\Delta R/\mu'_{0}(t_1,T)$, where $\Delta R = \mu'(t_1,T) - \mu'(t_2, T)$. Here, $t_1 = 50$ sec and $t_2 = 50$ sec after demagnetization. In the measuring temperature range between 77 K and 300 K, photoinduced DA peaks are observed, which are dependent on the measuring time $t_2$; the DA peaks shift to the lower temperature side, whereas of course the height of peaks increases with $t_2$. This indicates a thermally activated process and help deducing the activation energy for DA.
Contrary to the previous report on Si-doped ceramic YIG\(^2\), we observed similar effect in a single crystal in which any trace of Si was not found by spectroscopic method. In the previous paper\(^3\), the monotonic recovery process was reported for warming the sample with \(\mu'\) lowered by photoinduced process in Si-doped polycrystalline YIG. We observed, however, the double or triple concavities in \(\mu' - T\) curve between 77 K and 350 K in our samples\(^6\). In Fig. 1, the solid circles show warming data without irradiation at 77 K during a slow warming in darkness. The open circles show the warming data taken after white light irradiation at 77 K. We note that the magnitudes of the photoinduced DA peaks presented here vary remarkably by \(\sim 100\%\) and the temperature for DA peaks by \(\sim 5\) K, depending on the samples even in the same ingot but highly reproducible from run to run on a given sample. In order to explain these results, we consider these features in connection with an existence of so-called F-center. The basic concept of our explanation is as follows: when the sample cooled in the dark, oxygen vacancies or deep donors capture the double electrons, resulting in a formation of F-centers. Figure 2 displays one of the typical results mentioned above. It should be noted about these figures that the photoinduced DA at the first run disappears in the second run so long as each of the turning temperature \(T\), exceeds above the temperature of each of the peak.

When the trapped electrons are photoexcited from the deep levels to the shallow levels or conduction band, pinning centers for domain walls are created. From an analysis of recovery process, the height of potential barrier can be estimated to be 0.3 eV. The irreversible characteristic is destroyed at room temperature, which is caused by the returning of electrons surmounting the potential barrier to the original state. In this context, an additional DA peak independent of irradiation is observed at around room temperature, so it may be ascribed to phonon-assisted F-center in contrast to a frozen immobile center. As in a previous paper\(^9\), we proposed here also that the peak of DA at the low temperature could be induced by the short range order of mobile oxygen vacancies Vo without trapped electrons. A mobility of Vo can be thought in order of value as \(V_0^i\) (\(i=0,1,e,2,e\)), where \(i\) indicates the number of electrons trapped at the \(V_0\), since they form the discrete and sharp shape as a function of temperature\(^6\). When the sample of YIG showing no photoinduced DA was annealed at 1200 °C in the Ar atmosphere for one day, the photo-induced effect tended to be recovered. These results are interpreted also simply within the context of illustrative band picture shown in Fig. 3. In this figure, the total energy in its ground state, immobile F-center or (Fe\(^{2+}\) - Vo - Fe\(^{2+}\)) is responsible for no DA(a); the interme-
mediate mixed excited states involving of Fe$^{2+}$-center or \{(Fe$^{3+}$-Vo) + Fe$^{3+}$ (c.b)\} for DA(II) and Vo, oxygen vacancy without any trapped electron for DA(I)(b). At higher temperature (c), DA(III) is observed as mentioned above. It is speculated reasonably that the conduction electrons contribute to enhance \(\mu''\).

In conclusion, the triple peaks of DA in irradiated YIG is attributed to oxygen vacancies, and the difference of the peak temperature is considered to arise from the number of electrons trapped in the vacancy.

![Diagram](image)

**Fig.3** Schematic illustration of photoinduced DA processes in oxygen-deficient YIG on a basis of band model.

References