Transactions of the Materials Research Society of Japan 29[4] 1635-1638 (2004)

YIG Ferrite Thin-films Epitaxially Grown by Reactive Sputtering Method

Hirofumi Kuniki, Setsuo Yamamoto, Hiroki Kurisu, Mitsuru Matsuura and Pyungwoo Jang [1]

Faculty of Engineering, Yamaguchi University, 2-16-1, Tokiwadai, Ube, 755-8611, Japan

Fax : 81-836-85-9621, e-mail : yamamoto@yamaguchi-u.ac.jp

[1] Department of physics, Cheongju University, 36, Naedok-Dong, Sangdang-gu, Cheongju, 360-764, Korea

Fax : 82-43-229-8432, e-mail : pwjang@chongju.ac.kr

Amorphous Y-Fe-O thin-films were deposited on GGG (111) substrates using reactive RF magnetron sputtering method with $Y_{2.84}Fe_{5.16}O_{12}$ ferrite sintered target. After that, the thin-films were post-annealed in air at temperatures higher than 650 degrees Celsius for 3 hours to be crystallized. In the XRD diagrams, large diffraction peaks from only YIG ferrite (444) or (888) plane were observed in the samples post-annealed at over 800 degrees Celsius. The half value width ($\Delta\theta_{50}$) in the rocking curve for YIG ferrite (888) was as small as 0.13 degrees. These results proved that the YIG ferrite films have been grown in hetero-epitaxial manner on GGG (111) substrate with high orientation. The YIG ferrite thin-films had reasonable saturation magnetization of 1.6 kG, relatively low coercivity of less than 3 Oe and small ΔH of around 70 Oe. The YIG ferrite thin-films are useful for microwave magnetic devices.

Key words : YIG ferrite, reactive RF magnetron sputtering, amorphous Y-Fe-O, post-annealing, hetero-epitaxial growth

1. INTRODUCTION

Nowadays, YIG (yttrium iron garnet) ferrite bulk materials are widely used in magnetic devices such as isolators and circulators because of their low magnetic loss properties at microwave frequencies. In the near future, YIG ferrite thin-films are expected to be used in low height magnetic devices such as isolators, circulators, MSW filters, waveguides, etc. in the near future.

Usually, YIG ferrite materials used in current isolator / circulator products, etc. are prepared by sintering process, and their height (typically about a half mm) disturb the further to decrease in height and size of devices. If preparation of the ferrite thin-films with good magnetic properties and low loss at microwave frequencies, the reduction of height of magnetic devices will be accelerated.

Liquid phase epitaxy (LPE) methods are commonly employed for deposition of YIG thin-films with several ten to hundred micrometer thickness. Sputtering method is also useful for deposition of YIG epitaxial thin-films. However, high process temperature is needed to obtain crystallized YIG thin-films in these deposition processes. This is a very severe requirement from the viewpoint on mass production of the films.

One of the authors, P.W.Jang, has succeeded in preparation of epitaxially grown YIG ferrite thin-films in combination of sputter-deposition at an ambient temperature and subsequent post-annealing at above 700 degrees Celsius in the air [1]. The sputter-deposited Y-Fe-O films are amorphous and are crystallized by post-annealing treatment [2].

In this paper, the effects of post-annealing condition on structural and magnetic properties of the YIG ferrite thin-films were studied.

2. EXPERIMENTAL

YIG ferrite thin-films were deposited using a RF magnetron sputtering apparatus. Reactive sputtering was performed using $Y_{2.84}Fe_{5.16}O_{12}$ ferrite sintered target in argon and oxygen mixture gas. Total sputter gas pressure and oxygen partial pressure were fixed at 2.5 Pa and

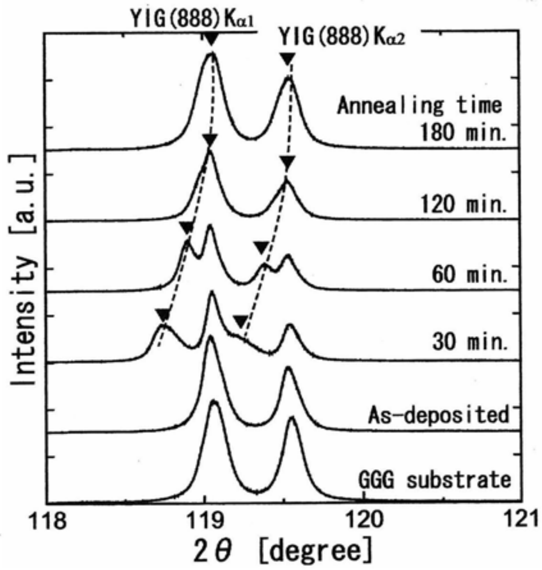

Fig.1 X-ray diffraction peaks from YIG ferrite (888) plane. Upper four lines are for YIG samples annealed at 750 degrees Celsius.

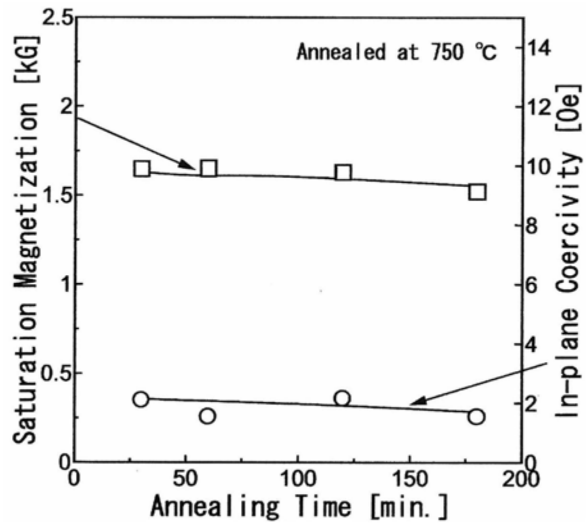

Fig.2 Annealing time dependence of magnetic properties of YIG ferrite thin-films.

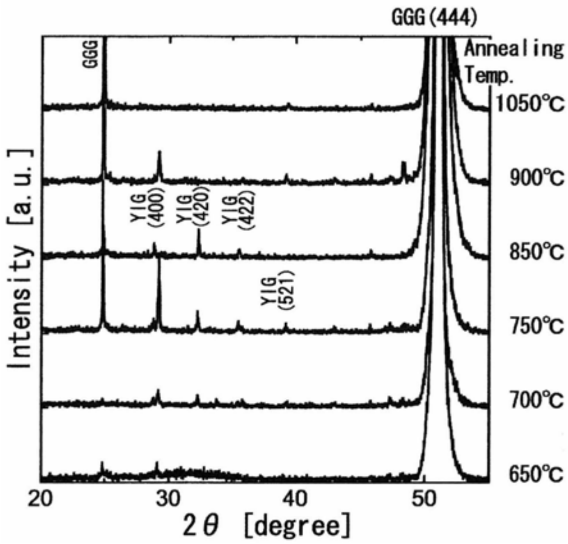

Fig.3 XRD diagrams of YIG ferrite thin-films annealed at various temperature.

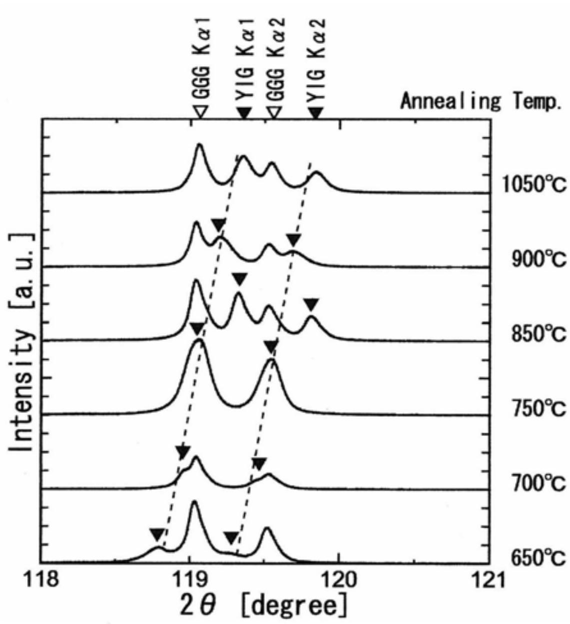

Fig.4 X-ray diffraction peaks from YIG (888) plane. All samples were annealed for 180 minutes.

0.125 Pa, respectively. RF input power was fixed at 5.1 W/cm^2. The Y-Fe-O films with a thickness of 2.5 - 2.8 μm were deposited directly onto the gallium gadolinium garnet (GGG(111)) substrate with substrate heating at 400 degrees Celsius. The Y-Fe-O films were annealed in air at temperatures from 650 to 1050 degrees Celsius to be crystallized [1,3].

Measurements of magnetic and crystallographic properties and ferromagnetic resonance width (ΔH) of the YIG ferrite thin-films were performed using a vibrating sample magnetometer (VSM), X-ray diffraction (XRD (Cu-Kα)), an electron spin resonance (ESR setup), respectively.

3. RESULTS AND DISCUSSION

Figure 1 shows X-ray diffraction diagrams of YIG ferrite thin-films on GGG substrate. YIG ferrite thin-films were annealed at 750 degrees Celsius for various annealing time. The diffraction peaks are originated from (888) planes of YIG ferrite and GGG substrate. As-deposited sample shows no diffraction peaks from YIG(888) plane because the Y-Fe-O film is amorphous. However, the ferrite thin-films sufficiently crystallized by over 30 minutes annealing. Diffraction peaks from YIG ferrite (888) plane shifted toward higher angle with increasing post-annealing time. At annealing time of 120 min., the diffraction peaks from YIG ferrite (888) overlap with those from GGG (888) substrate showing no lattice mismatch.

Figure 2 shows annealing time dependence of magnetic properties of YIG ferrite thin-films annealed at 750 degrees Celsius. Significant change in saturation magnetization and in-plane coercivity were not observed when the annealing time was changed from 30 to 180 min. This is probably due to the fact that YIG ferrite thin-films are sufficiently crystallized by over 30 minutes post-annealing. Only change in lattice spacing was caused depending on post-annealing time. In the following experiments, annealing time was fixed at 180 minutes.

X-ray diffraction diagrams of YIG ferrite thin-films annealed at various temperature were shown in Fig.3 and Fig.4. Amorphous Y-Fe-O ferrite thin-films were crystallized by post-annealing at over 650 degrees Celsius. X-ray diffraction peaks intensity from YIG ferrite (888) plane shown in Fig.4 were one thousand times as large as that from another planes shown in Fig.3. The YIG ferrite thin-film annealed at 1050 degrees Celsius showed only one peak from (888) plane. Diffraction peaks from YIG ferrite (888) plane shifted toward higher angle as annealing temperature becomes higher. The sample annealed at 750 degrees Celsius had no lattice mismatch with the GGG substrate. Lattice spacing for bulk YIG ferrite (a_0=1.2380 nm) is slightly smaller than that of GGG substrate (a_0=1.2383 nm). The

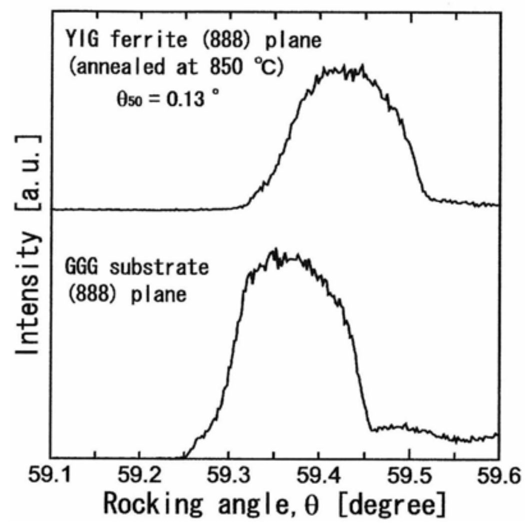

Fig.5 Rocking curves of YIG ferrite thin-film and GGG substrate.

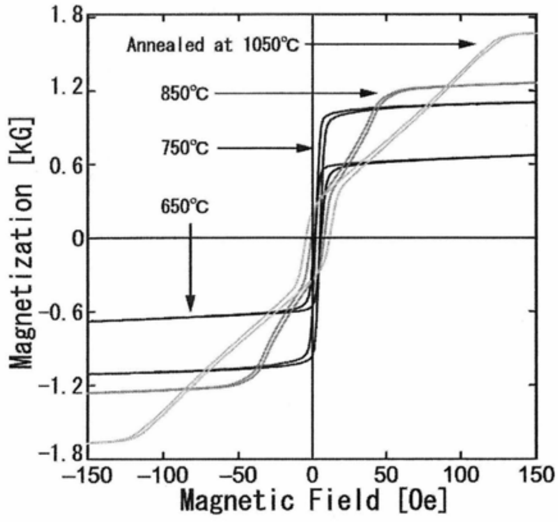

Fig.7 In-plane M-H loops of YIG ferrite thin-films annealed at 650, 750, 850 and 1050°C.

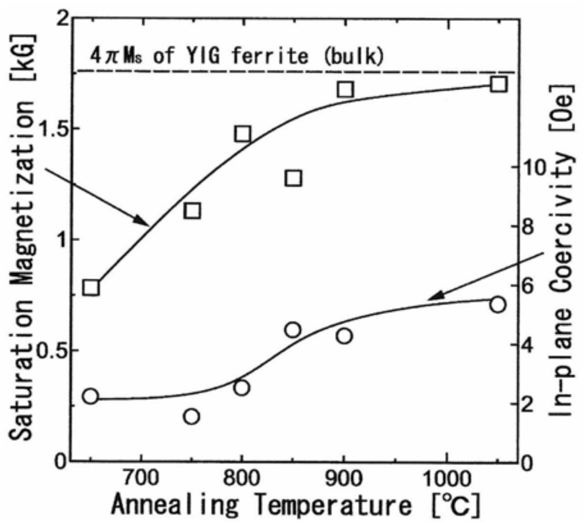

Fig.6 Annealing temperature dependence of magnetic properties of YIG ferrite thin-films.

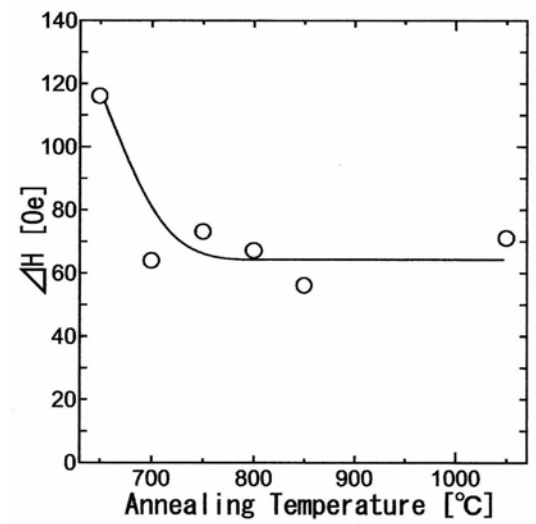

Fig.8 Annealing temperature dependence of ΔH of YIG ferrite thin-films.

lattice spacing for YIG ferrite thin-film deposited on GGG substrate was larger than that of the bulk YIG ferrite because of the influence of the substrate. High temperature annealing treatment made the lattice spacing for YIG ferrite thin-film close to that for bulk YIG ferrite.

Figure 5 shows rocking curves of the YIG ferrite thin-film annealed at 850 degrees Celsius and the GGG substrate. The half value width ($\Delta\theta_{50}$) in the rocking curve for YIG ferrite (888) was only 0.13 degrees and coincided with that of GGG substrate. This value is limited by the XRD slit resolution. These results proved that the films have been grown in hetero-epitaxial manner on GGG (111) substrate with high orientation.

Figure 6 shows annealing temperature dependence of magnetic properties of YIG ferrite thin-films. As-deposited sample showed nonmagnetic behavior even when magnetic field of 15 kOe was applied. Saturation magnetization of the YIG ferrite thin-films increased with increasing annealing temperature. The thin-film annealed at 1050 degrees Celsius showed saturation magnetization of 1.7 kG which is almost same as YIG bulk. In-plane coercivity gradually increased with rising annealing temperature.

Figure 7 shows M-H loops of YIG ferrite thin-films annealed at 650, 750, 850 and 1050 degrees Celsius. YIG ferrite thin-films annealed at 650 and 750 degrees Celsius showed very soft magnetic properties. However, the M-H loops of the samples annealed at over 850 degrees Celsius show peculiar shape which is seen for the film with perpendicular magnetic anisotropy. As can be seen from Fig.4, the YIG film annealed at over 850 degrees Celsius were subjected to tensile stress from GGG (111) substrate. The perpendicular magnetic anisotropy was induced by the stress.

When the YIG ferrite thin-films are used in microwave magnetic devices, ferromagnetic resonance width, ΔH, is a very important index because it relates to magnetic loss at high frequency. Annealing temperature dependence of ΔH of the YIG ferrite thin-films is shown in Fig.8. ΔH decreased with increasing annealing temperature and leveled off at 70 Oe at 700 degrees Celsius and above. The ΔH value of the YIG bulk ferrite used in current circulator and isolator products was 50-60 Oe [4]. The YIG ferrite thin-films are promising to be used in new type low height isolators or circulators which the authors designed [5].

4. CONCLUSIONS

YIG ferrite thin-films prepared by combination of sputter-deposition and subsequent post-annealing have been grown in hetero-epitaxial manner on GGG (111) substrate with high orientation. The YIG ferrite thin-films post-annealed at 1050 degrees Celsius had saturation magnetization of 1.6 kG, low coercivity of less than 3 Oe and small ΔH of 70 Oe. The YIG ferrite thin-films are useful for microwave magnetic devices.

This work was financially supported by Ministry of Economy, Trade and Industry, Ministry of Education, and Culture, Sports, Science and Technology. The authors would like to thank Professor Yoshihisa Nakamura, director of RIEC, Tohoku University, and Emeritus Professor Masahiko Naoe of Tokyo Institute of Technology for their useful advice and encouragement.

REFERENCES

[1] P. W. Jang and J. Y. Kim, "New Growth Method of Solid Phase Epitaxy in Sputtered YIG Films," IEEE Trans. on Magn., Vol.37, No.4, pp.2438-2440 (2001).

[2] Myung-Beom Park, Byung Jin Kim and Nam-Hee Cho, "Chemical Composition, Microstructure and Magnetic Characteristics of Yttrium Iron Garnet (YIG, Ce:YIG) Thin Films Grown by RF Magnetron Sputter Technique," IEEE Trans. on Magn., Vol.35, No.5, pp.3049-3051 (1999).

[3] Manabu Gomi, Kensuke Satoh and Masanori Abe, "Giant Faraday Rotation of Ce-Substituted YIG Films Epitaxially Grown by RF Sputtering," Jpn. J. Appl. Phys., Vol.27, No.8, pp.L1536-L1538 (1988).

[4] Trans-Tech, catalogue: "Products for RF/Microwave Applications", (2003) 66-67.

[5] K. Oshiro, S. Yamamoto, H. Kurisu and M. Matsuura, "Low height circulator using microstrip line," ISAM2, Symposium B-9, The 8th IUMRS International Conference on Advanced Materials (IUMRS-ICAM 2003), B9-10-O08, Yokohama, Japan, (Oct.8-13, 2003).

(Received October 8, 2003; Accepted February 19, 2004)