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Development of the RF indirect-heating LPE furnace and the effect of impurity in YIG film on the MSSW properties

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Abstract We developed a new RF indirect-heating LPE furnace. The thermal gradient of our newly developed furnace is less than that of direct heating, and is as gentle as that of the resistance-heating LPE furnace. With this new furnace, the heating and/or cooling is faster than that of the resisitance-heating furnace. Impurity-doped YIG film was grown from a $PbO-B_2O_3$ based flux on a (111) GGG substrate. To study the effect of the impurities on the MSSW threshold power and the saturation response time, we used two microstrip lines to excite and propagate the MSSW at 1.9 GHz. The MSSW threshold power and saturation response time was found to be related to the ΔH.

Key words Liquid phase epitaxy, RF heating, Impurities doped YIG film, Magnetostatic surface wave, Ferromagnetic resonance linewidth, Threshold power, Saturation response time

1. Introduction

YIG (yttrium iron garnet; $Y_3Fe_5O_{12}$) single crystal film, grown on a GGG (gadolinium gallium garnet; $Gd_3Ga_5O_{12}$) substrate by the LPE (liquid-phase epitaxy) method, is one of the most useful materials for MSW (magnetostatic wave) devices [1, 2]. The device examples using the MSW nonlinear properties are a power limiter and a signal-to-noise ratio enhancer.

Although the microwave and optical properties of YIG are usually modified by using dopants [3, 4], no comprehensive report on the effect of dopants on the MSSW (magnetostatic surface wave) properties of YIG film have been presented to our knowledge. We have, thus, investigated the effect of impurities in YIG film on the MSSW properties.

It takes many times of the crystal growth to do a comprehensive study of the effect the many impurities in YIG films have on the MSSW properties. However, the heating and cooling rate of a conventional resisitance-heating furnace used to grow the YIG films is so slow that repeated efforts are required to prepare doped YIG films.

The first purpose of this study was to develop a new RF indirect-heating LPE furnace and second was to determine the MSSW properties of impurity-doped YIG films.

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2. Experimental Procedure

2.1. The RF indirect-heating LPE method

Figure 1 shows the schematic configuration of our new RF indirect-heating LPE furnace. A characteristic of the developed LPE method is the indirect-heating of the Pt

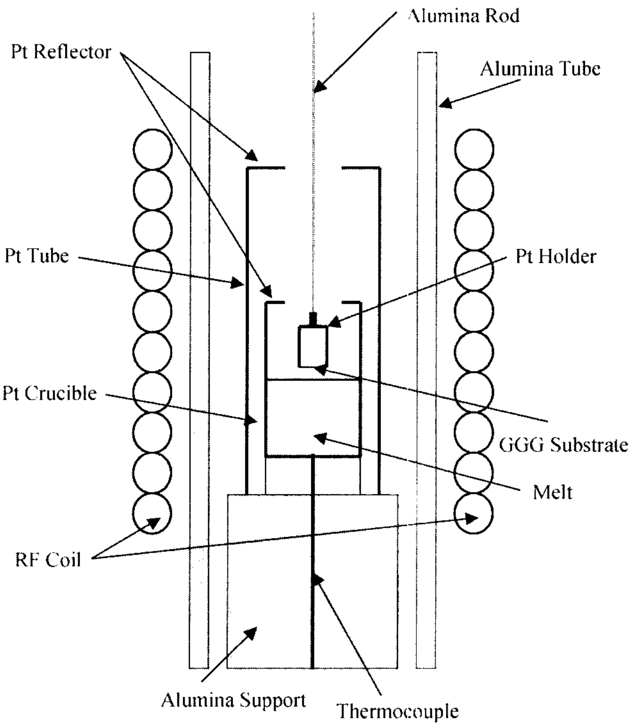

Fig. 1. Schematic configuration of the RF indirect-heating LPE furnace.

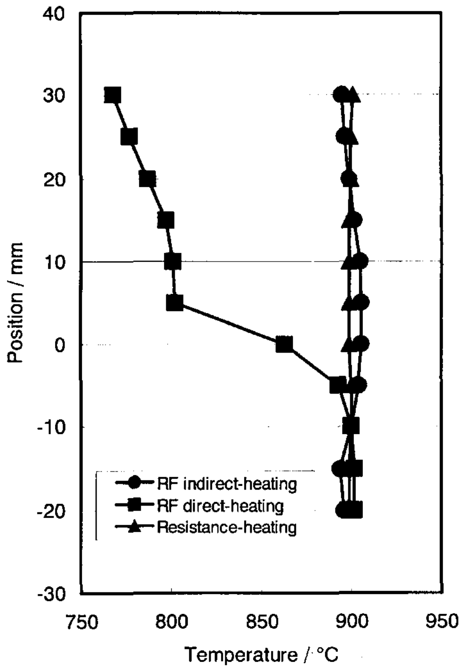

Fig. 2. Temperature distribution in the crucible.

crucible in the Pt tube by RF heating. The temperature distribution in the crucible is shown in Fig. 2. The thermal gradient of the RF indirect-heating LPE furnace is more gentle than that of the RF direct-heating and as gentle as that of the resistance-heating.

2.2. *Crystal growth of the impurities doped YIG film*

Impurity-doped YIG films were grown from a PbO-B_2O_3 based flux on a (111) GGG substrate. Forty-three elements, which were show in Fig. 3, were tried as impurities. Among the impurities, the rare-earth elements were subsitituted 0.13 to 0.39 atom % for Y^{3+} ions and other elements were replaced 0.13 to 0.39 atom % with Fe^{3+} ions in the melt. The growth temperature was 920°C.

2.3. *Characterization*

The thickness was measured by using a light interference method. The ferromagnetic resonance half-line width (ΔH) of the YIG film was measured by using ESR (electron spin resonance) equipment at 9.2 GHz. The ΔH was calculated from the peak-to-peak magnetic field that was applied in the direction parallel to the YIG film. The dopant quantity in the YIG film was estimated by ICP-MS (inductively coupled plasma mass spectrometry), except Si, Zn and Ca, which were estimated by SIMS (secondary ion mass spectrometry).

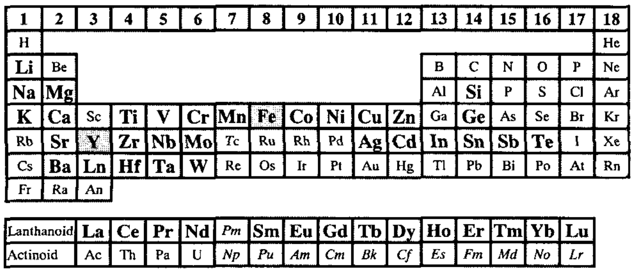

Fig. 3. Forty-three impurity elements of impurity-doped YIG film.

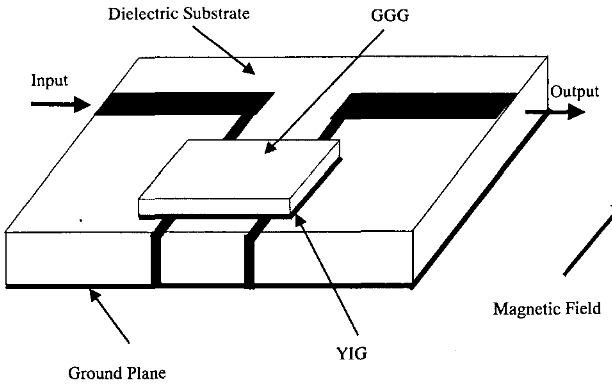

Fig. 4. Schematic view of the MSSW filter.

Figure 4 shows a schematic view of the MSSW filter we used in our experiments. To estimate the effect of the impurities on the threshold power and the saturation response time of an MSSW filter, we used two microstrip lines, 50 μm wide and 4 mm apart, to excite and propagate the MSSW at 1.9 GHz. An external DC magnetizing field was applied in the direction parallel to both the microstrip lines of the transducers and the YIG film during the excitation and propagation of the MSSW. The threshold power of the MSSW filter, which is the input power that the output power becomes fixed at, was measured using a network analyzer (HP 9719C). The saturation response time of the MSSW filter, which is the time before becoming saturated, was measured using an oscilloscope (Sony/Textronix TDS524A). The input signal power was 20 dBm bigger than the threshold power.

3. Results and Discussion

3.1. *Growth rate*

Figure 5 shows the growth rate of the impurity-doped YIG, except for the rare-earth doped YIG film. The growth rate of the YIG film was varied by the kind of the dopant but no trend was observed. On the other hand, the rare-earth doped YIG films exhibited almost

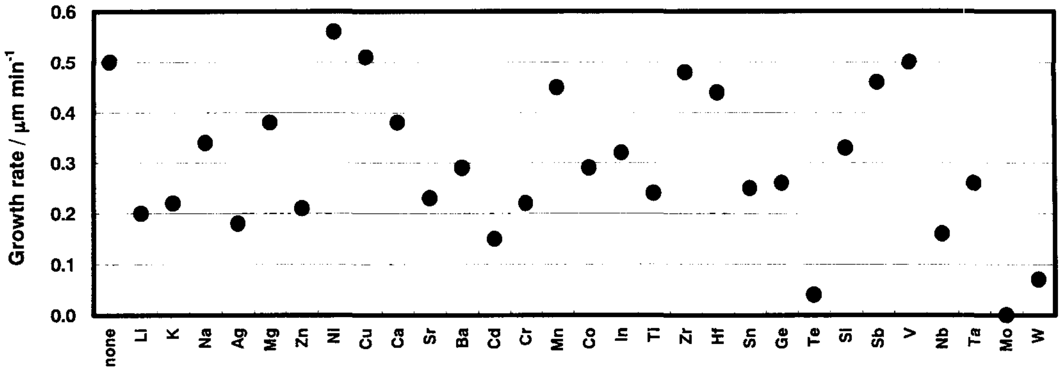

Fig. 5. Growth rate of the impurity-doped YIG except for the rare-earth doped YIG film grown by the RF indirect-heating LPE method.

the same growth rate compared with pure YIG. We believe that the effects of the non-rare-earth impurity on the growth rate are varied by the liquid temperature.

3.2. *Relative distribution coefficient of impurity*

The relative distribution coefficient of the non-rare-earth impurity against the Fe for the YIG film are shown in Fig. 6 and that of the rare-earth impurity against the Y are shown in Fig. 7. Li, K, Na, Ag, Mo, W, Ba, Te and V were almost never replaced with Fe. We think that the univalent as Li, K, Na, Ag and the hexavalent as Mo, W hardly formed a solid solution with YIG, and Ba, Te, V acted on the flux. The relative distribution coefficients of La and Ce for Y were less than the other rare-earth impurities. It is thought that La and Ce form a solid solution with YIG because the ionic radius of La^{3+} is bigger than that of Y^{3+}, and Ce is the tetravalent.

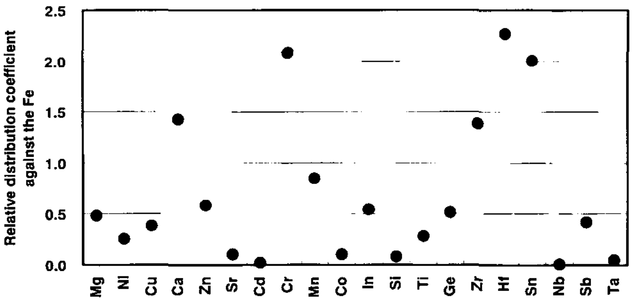

Fig. 6. Relative distribution coefficient against the Fe of the non-rare-earth impurity for the YIG film.

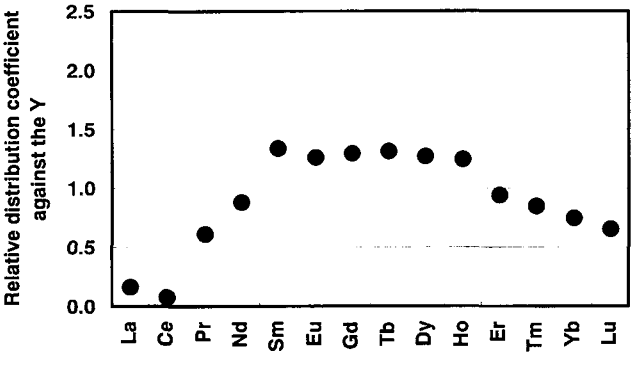

Fig. 7. Relative distribution coefficient against the Y of the rare-earth impurity for the YIG film.

3.3. *MSSW properties of the YIG film*

The MSSW threshold power and the saturation response time of the impurity-doped YIG film is shown in Fig. 8. And the ΔH of the impurity-doped YIG films is shown in Fig. 9. The MSSW threshold power of YIG films doped by Tb, Dy and Ho were increased more than that

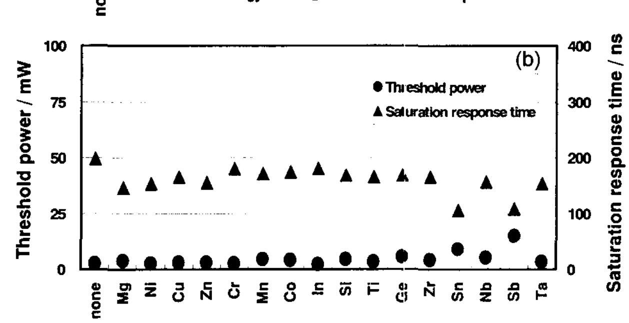

Fig. 8. MSSW threshold power and saturation response time of the impurity-doped YIG film: (a) rare-earth doped YIG film, (b) non-rare-earth doped YIG film.

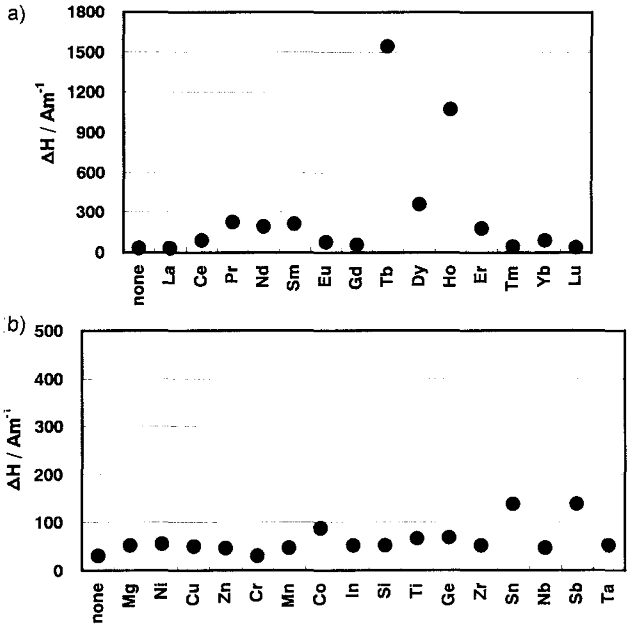

Fig. 9. ΔH of the impurity-doped YIG film: (a) rare-earth doped YIG film, (b) non-rare-earth doped YIG film.

of the other rare-earths. And the MSSW threshold power of YIG films doped by Sb and Sn were increased more than the other non-rare-earth impurities. The MSSW saturation response time of YIG films doped by Tb, Dy and Ho were too short to measure. And the MSSW saturation response time of YIG film with Sb and Sn were less than that of the another non-rare-earth impurities.

Figure 10 shows the dependence of the MSSW threshold power and the saturation response time on the ΔH. The greater the ΔH, the greater the MSSW threshold power and the less the MSSW saturation response time was. We think that the MSSW threshold power and saturation response time are related to the ΔH. In a word, the MSSW properties are controlled by the loss of microwaves.

4. Conclusions

We developed a new RF indirect-heating LPE furnace where the heating and cooling velocities are faster than those obtainable with the conventional method. Impurity-doped YIG films by were grown using our furnace. The growth rate of the YIG film was varied by the kind of non-rare-earth dopant used and no trend was observed. However, the growth rate of the rare-earth doped YIG film did not change. The MSSW threshold power and saturation response time was found to be related to the ΔH.

We found a relationship between type of impurity in the YIG film and the MSSW properties. Our results should provide a wealth of information that will be useful in the design of MSW devices.

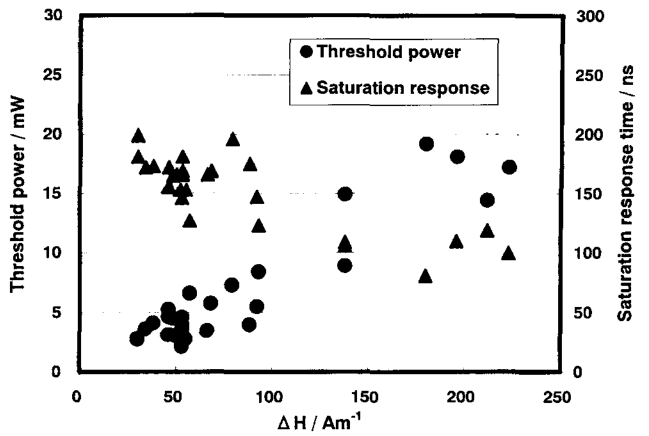

Fig. 10. Dependence of the MSSW threshold power and saturation response time on the ΔH.

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