THERMO MAGNETIC AND ELECTROMAGNETIC PROPERTIES OF RARE EARTH MICROWAVE GARNETS FOR HIGH POWER CIRCULATOR

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Abstract

Iron deficient rare earth microwave garnets have been developed by appropriate molecular engineering and microstructural design by optimization of process parameters. Introduction of fast relaxing Gd^{3+} enables broadening of spin-wave line-width with excellent temperature stability of magnetization and high Curie temperature (>250ºC). Frequency response of permeability spectrum of the sintered Y-Gd-IG system shows suitability of the material for use in below resonance applications at 352 MHz. A prototype stripline ferrite resonator has been designed and simulated using CST Microwave Studio. An excellent result with low insertion loss and high isolation (~28 dB) at 352 MHz has been achieved.

INTRODUCTION

A 100 MeV H^- Proton LINAC has been planned at RRCAT as injector for Spallation Neutron Source. In this system, the installation of a high power circulator is desired between the klystron and the RFQ cavity for the stable operation of the CW klystron and for protection from the reflected power. As Circulator is purely ferrite material oriented design, power threshold of ferrite is an important issue in the design of low loss high power circulators. Low magnetization, high Curie temperature, low temperature coefficient of magnetization and higher spin wave line-width are the important parameters required for the CW ferrite circulators at 350-700 MHz [1-3]. Therefore, tailoring the garnet system with fast relaxing ions could be the best solution to achieve the design goals. In this paper we have discussed the results of Dy^{3+} and Gd^{3+} doped microwave garnet development with optimum magnetic characteristics for high power circulators at 352 MHz. Simulation results of a prototype stripline resonator is also discussed in relation to design optimization of ferrite circulator.

RARE EARTH GARNET DEVELOPMENT

A set of experiments have been designed and conducted with varying process parameters and compositions of mixed garnet systems [$(Y_{3-x-y}Dy_xGd_y)$ $(Fe_{5-\delta})$ O_{12} with x, y = 0 to 2 and δ = 0 to 1] following solid state sintering route. Structural, microstructural and magnetic studies were performed on sintered pellets (∅5 mm x 5 mm). X-ray diffraction studies confirmed cubic garnet phase stabilization in the rare earth garnet systems. After extensive studies, material composition and process parameters (Table 1) have been optimized to achieve desired magnetic characteristics.

Table 1: Optimized composition and process parameters

Composition: $Y_{1.3}Gd_{1.7}Fe_{4.3}O_{12}$; [x= 0, y= 1.7, δ= 0.7]		
Pre-sintering temperature	:	1175°C
Average particle size	:	~ 0.95 μm
Sintering temperature	:	1400°C

Very low temperature coefficient of magnetization with desired $4\pi M_S$ (~950 G) and T_C (>250ºC) values have been achieved in the optimized iron deficient Y-Gd-IG samples**,** as shown in Fig. 1. Scanning electron micrograph (SEM) of the sample, as shown in the inset, shows homogeneous granular microstructure with average grain size of approx. 1.5 μm. Frequency response of permeability spectrum, as measured on co-axial cylindrical (∅7mm x ∅3mm x 15mm) samples using Agilent A714ES RF network analyzer, shows resonance to occur beyond 1 GHz which is much higher than the device operation frequency (352 MHz), thus confirming the suitability of the material for use in below resonance applications at 352 MHz. High density, crack-free large disks (∅100 mm x 5 mm) of Y-Gd-IG have been developed for use in ferrite circulator.

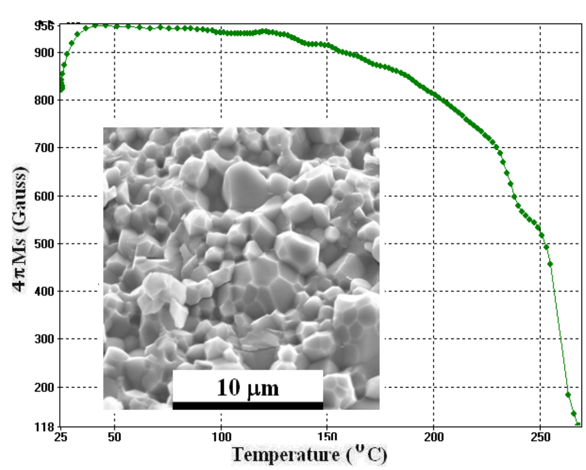

Figure 1: $4\pi M_S$ vs. temp. curve of optimized Y-Gd-IG sample. A SEM image of the sample is shown in the inset.

SIMULATION AND DESIGN OPTIMIZATION OF RESONATOR

Design and optimization of the strip line circulator has been performed using CST Microwave Studio high frequency simulation software. Various geometries of circulator have been simulated for achieving the design parameter at desired frequency of 352 MHz. Transient solver of the microwave studio with adaptive mesh refinement and Gaussian profile of signal excitation has been used for the simulation. Ferrite disks has been used as the resonator structure with lande-g factor 2, resonance line width of 50 Oe, $4\pi M_S$ of 950 Oe and other typical magnetic properties. S parameters observed at ~ 352 MHz are as shown in Fig. 2. Peak of the curve S_{21} clearly indicates coupling of most of the input signal to port-2 while valley in the curve S_{31} indicates coupling of very small signal into port 3 (isolated port). Also reflection back to the excitation port is very small (curve S_{11}).

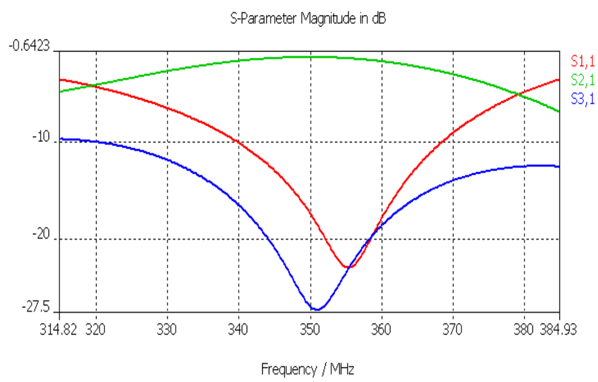

Figure 2: S-parameters of simulated strip line circulator

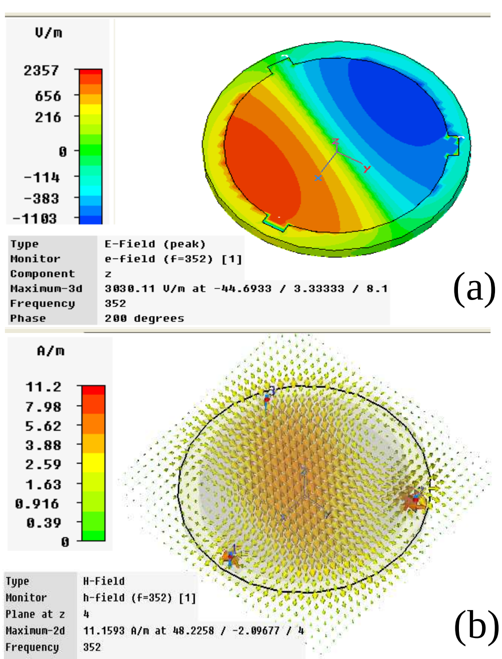

Figure 3: (a) E-Field (scalar) and (b) H-Field (vector) monitor at 352 MHz

Electric-field monitor, as shown in Fig 3(a), shows that electric field in vicinity of port 3 is very small. Magnetic-field monitor (Fig 3b) shows slight clockwise rotation of the magnetic field pattern in resonator as compared to that coupled by port 1. This is due to the permeability tensor of the ferrite disk material caused by magnetic biasing. Very good isolation (at isolated port 3) of 27.5 dB has been observed at 352 MHz. Also reflection (at excitation port 1) is observed to be 23 dB and coupling (to the coupled port 2) observed is about 0.5 dB.

Following simulation results, a prototype stripline resonator with permanent magnet biasing has been designed and tested for operation below resonant mode using ∅100 mm Y-Gd-IG disks, as shown in Fig. 4.

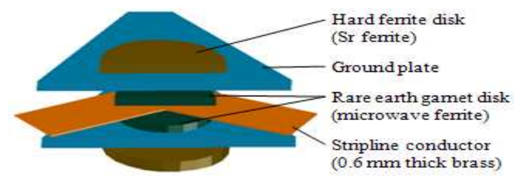

Figure 4: Assembly of a stripline ferrite resonator

CONCLUSIONS

Thermomagnetic and electromagnetic characteristics of rare earth garnets have been optimized for use in high power circulators at 352 MHz. Extremely low temperature coefficient of magnetization with optimum $4\pi M_S$ (~950 G) and high T_C (>250ºC) values have been achieved by introducing fast relaxing Gd3+ ions in the iron deficient garnet $(Y_{1.3}Gd_{1.7})(Fe_{4.3})O12$ system. Using this microwave garnet, a prototype resonator in stripline geometry has been developed for testing and optimization of the circulator design. The prototype ferrite resonator has been tested using RF Network Analyser at frequencies from 100 to 500 MHz. An excellent result with low insertion loss and high isolation (>26 dB) has been obtained at the centre frequency of about 352 MHz, which is in close agreement with the simulation results (Isolation ~28 dB, Reflection ~23 dB and Coupling ~0.5 dB) obtained using CST microwave studio.

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