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## Oriented Y-type hexaferrites for ferrite device

M. Obol,<sup>a)</sup> X. Zuo, and C. Vittoria

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We have developed a technique to orient particles of Y-type hexaferrite in which the  $c$  axis of the particles is oriented perpendicular to a plane. Disks of oriented  $\text{Ba}_2\text{MnZnFe}_{12}\text{O}_{22}$  particles were characterized in static and dynamic field excitations and exhibited the following properties:  $4\pi M_s = 2300$  G,  $H_a = 9500$  G,  $4\pi M_{\text{eff}} = 4\pi M_s + H_a = 11800$  G, and  $H_c = 60$  Oe. The ferrimagnetic resonance linewidth at 27 GHz measured to be 350 Oe and the  $g$  factor approximately equal to 2. The magnetic parameters of the oriented particles were very similar to the bulk parameters previously published. © 2002 American Institute of Physics. [DOI: 10.1063/1.1446113]

### I. INTRODUCTION

There is a need to operate microwave ferrite devices at high frequencies in small biasing magnetic fields.<sup>1</sup> Cubic ferrites of the spinel and garnet types require magnetic fields at any frequency but more so as the frequency is increased. The introduction of permanent magnets in ferrite microwave devices implies large size. Whereas most microwave devices reduce in size as the frequency of operation is increased, the required permanent magnets increase in size. Currently, the trend is toward miniature circuitry at any frequency, efficient and cost effective microwave circuits. Clearly, something needs to be done about reducing the size of ferrite microwave devices, especially at high frequencies. We propose the use of Y-type hexagonal ferrites to replace spinel and garnet ferrites in microwave devices. Hexaferrites of the Y type are self-biased, because the intrinsic magnetic anisotropy field is uniaxial in symmetry with easy axis of magnetization contained in a plane normal to the  $c$  axis direction. This means that if one were to orient the  $c$  axis of all the Y-type hexaferrite particles in the same direction, there is a preferential plane in which the saturation magnetization is aligned and that plane can be chosen to be the plane of the microwave circuit. However, the process of orienting the particles must be cost effective and efficient, for example. The resulting properties of oriented particles should mimic the properties of single crystal slabs of the Y type. In this work, we describe the sintering process and the orienting of Y-type ferrite particles with  $c$  axis normal to a common plane. X-ray, vibrating sample magnetization (VSM), and ferromagnetic resonance (FMR) measurements of oriented particles showed that their magnetic properties are compatible with single crystal materials of the Y-type hexaferrite.

### II. PREPARATION TECHNIQUE

In order to produce single phase of  $\text{Ba}_2\text{Fe}_{12}\text{MnZnO}_{22}$  (Ref. 2) particles our starting oxide powder materials were chosen in the following amounts:  $\text{BaCO}_3$  (3.947 g),  $\text{MnO}$  (0.482 g),  $\text{ZnO}$  (1.480 g), and  $\text{Fe}_2\text{O}_3$  (9.464 g). The oxides were grinded until the particles size was reduced to 4–5  $\mu\text{m}$ . The admixed particles were calcified four times at

1100 °C for 3 h. The purpose of calcification was to remove unwanted gaseous components. The admixed powder was then pressed into disks and sintered at 1250 °C for 3 h. After sintering the disk was characterized by VSM technique in order to ascertain their magnetism. Typically, at this point the saturation magnetization was measured to be about 2300 G. The sintered ferrite disk was grinded again in order to reduce the particle size down to 2  $\mu\text{m}$  or less. The particles were then placed together with pure water inside a cylinder in a mechanical press arrangement, a permanent magnet of 6.5 kOe was placed on a rotating platform such that the direction of the applied field was in the radial direction. The applied pressure on the die was typically 500 psi. The oriented particles were pressed into a disk shape and were postannealed at 1200 °C. VSM measurement showed that the saturated magnetization was the same as the nonoriented sintered ferrite slab, but  $H_c$  (coercive field) increased from 6 to 16 Oe. For comparison, x-ray diffraction data were obtained for both the oriented Y-type polycrystal and single crystal materials. Indeed, the two x-ray patterns compared very well and confirmed the single phase nature of the oriented particles. X-ray diffraction patterns of polycrystal and single crystal are shown in Fig. 1. The solid line shows the x-ray diffraction pattern of the sintered polycrystal at 1250 °C; the dots show the single crystal material.

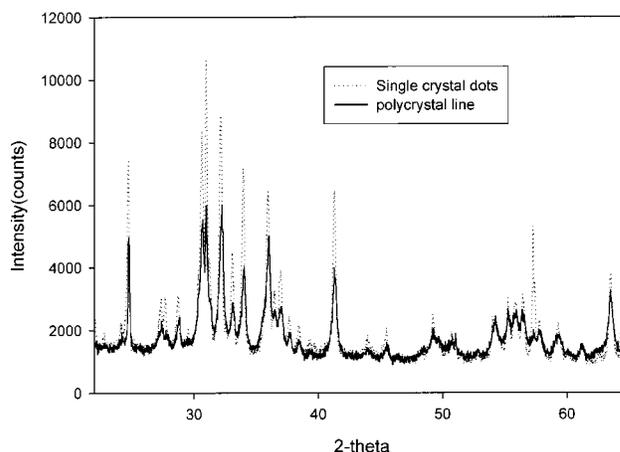


FIG. 1. X-ray diffraction data for single crystal and polycrystal phase structure.

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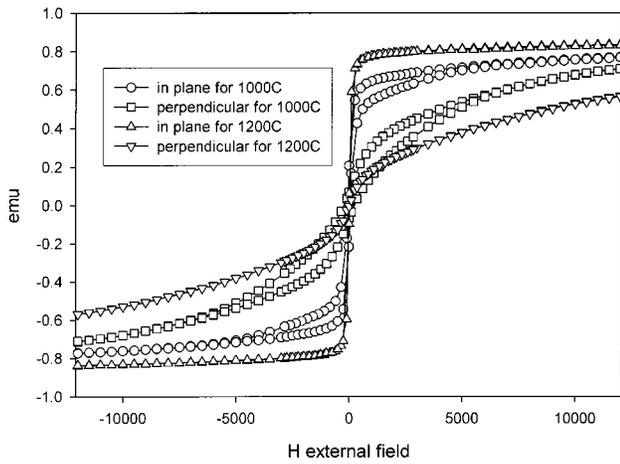


FIG. 2. VSM data of oriented disk at different temperatures, where H is in Oe.

### III. MAGNETIC MEASUREMENTS

#### A. Static field measurements (VSM)

We measured the coercive field,  $H_c$ , saturation magnetization,  $4\pi M_s$ , and magnetic anisotropy field,  $H_a$ , by the VSM technique. After orienting the particles in a disk shape, we postannealed the disks from 600 to 1250 °C. At each annealing temperature we measured  $H_c$ ,  $H_a$ , and  $4\pi M_s$ . The value of  $4\pi M_s = 2300$  Oe and  $H_a = 9500$  Oe remained the same at all annealing temperatures, but  $H_c$  varied with temperatures. Figure 2 shows VSM measurements for  $T_a = 1000, 1100,$  and  $1200$  °C, where the external field is applied parallel and perpendicular to the disk plane. Orientation of the  $c$  axis of the particles was on the average perpendicular to the disk plane and was not affected by the annealing process even up to 1250 °C. Disks annealed at 1000 °C exhibited the highest remanence and full saturation was attained for fields as low as 100 Oe. The remanence at 1000 °C was 27.5% and  $H_c = 60$  Oe (Fig. 2). The VSM data are shown for two different postannealed temperatures. Figure 3 shows a plot of  $H_c$  versus annealing temperature and  $H_c$  reaches a maximum for  $T_a = 900$  °C, and a minimum at 1250 (Fig. 3).

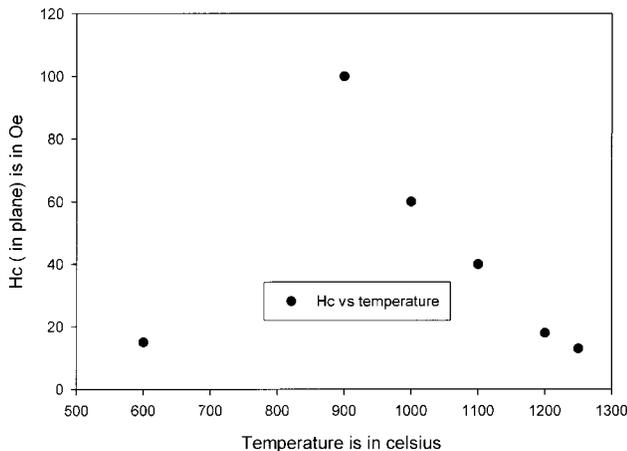


FIG. 3. Data for  $H_c$  (coercive field) at different annealed temperature.

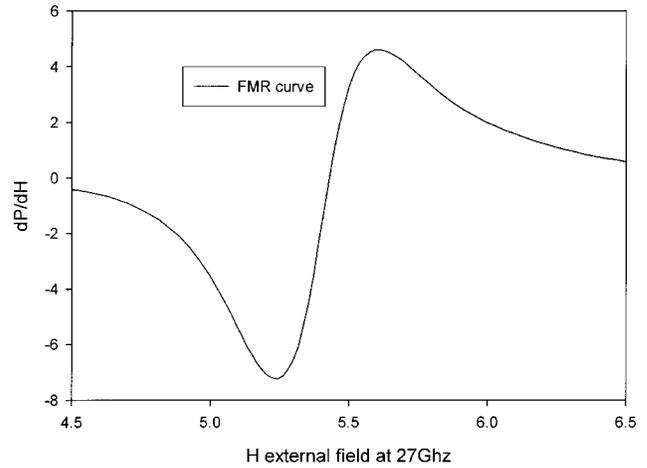


FIG. 4. Data for FMR where  $dP/dH$  differential power measurement vs H(kOe) external field.

#### B. Microwave measurement (FMR)

We measured the (FMR) field and linewidth on a number of samples of  $0.2 \times 2 \times 2$  mm<sup>3</sup> cut from disks with  $c$ -axis orientation perpendicular to the slab plane. The rectangular slabs were placed at a shorted end of a waveguide structure. The external field was applied perpendicular to the  $c$  axis, but in the plane of the slab. Magnetic field modulation techniques were used to measure the FMR field and linewidth. We measured  $\Delta H = 350$  Oe at 27 GHz; see Fig. 4. This result is compared with the FMR linewidth measurement of 100 Oe on single crystal slabs at the same frequency.<sup>3</sup> The deduced value of  $H_a$  from FMR field measurements was 9500 Oe yielding an effective saturation magnetization of  $4\pi M_{\text{eff}} = 4\pi M_s + H_a = 11\,800$  G. Increased value of  $4\pi M_{\text{eff}}$  results in “pushing” the frequency of operation of ferrite devices to higher frequencies. This should be compared with a value of 1750 G for YIG.<sup>4</sup>

### IV. DISCUSSION AND CONCLUSION

We developed a technique to orient hexaferrite particles of the Y type, specifically particles of  $\text{Ba}_2\text{Fe}_{12}\text{MnZnO}_{22}$ . However, special care must be exercised in the orientation procedure. Particles larger than 3  $\mu\text{m}$  do not orient easily with the  $c$ -axis normal to the slab plane. Particles of that size may contain more than one crystallite; hence, diluting or reducing alignment torque required to orient the particles. We have determined particles in the range of 1–2  $\mu\text{m}$  are most suitable for orientation, implying that the size of a single crystallite may be in that order of magnitude. The magnetic properties of the oriented particles are very similar to the single crystal properties except for the linewidth. We believe that the FMR linewidth can be improved if the particle size can be further reduced to, perhaps, less than 1  $\mu\text{m}$ . Smaller particles will reduce voids and therefore, nonuniform distribution of the internal field. Future studies should concentrate on the means to reduce the FMR linewidth of oriented particles of hexaferrites of the Y type.

## ACKNOWLEDGMENT

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