PROPERTIES OF THE DYSPROSIUM-GADOLINIUM GALLIUM GARNET SYSTEM

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Abstract

Single crystals of a number of compositions of the dysprosium-gadolinium gallium garnet system were grown by the Czochralski technique. Precision lattice parameters were measured by X-ray diffraction powder methods and compositions were determined by X-ray fluorescence analysis. The precision lattice constants of the end members differ from published values and the collected data shows that the system obeys Vegard's Law. Other physical properties are presented and compared with requirements for substrates used in the chemical vapor deposition of magnetic garnet films.

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Introduction

Single crystalline nonmagnetic rare-earth garnets have become important as substrates for the heteroepitaxial growth of films of magnetic garnets. The magnetic garnets in thin-film form of special recent interest are those in which cylindrical magnetic "bubble" domains can be produced. For films grown by chemical vapor deposition, the uniaxial anisotropy required for the formation of bubble domains is derived from strain induced in the film by structural mismatch between the film and substrate (1). This strain may be caused by the difference in interatomic lattice spacings of the film and substrate or by the difference in thermal expansions of the film and substrate on cooling to room temperature from the film deposition-temperature (2).

Attention has been directed primarily to the lattice spacing as a means of obtaining a mismatch that is suitable for producing the desired uniaxial anisotropy while avoiding stresses great enough to rupture the film. To a large extent, the control of mismatch is accomplished by employing substrates with selected lattice constants. Since garnets of individual rare earths, such as gadolinium gallium garnet (Gd$_3$Ga$_5$O$_{12}$ or GdGG) or dysprosium gallium garnet (Dy$_3$Ga$_5$O$_{12}$ or DyGG), have only discrete values of lattice constants, it is necessary to look to the mixed rare-earth garnets to obtain a continuous spectrum of lattice parameters. The dysprosium-gadolinium gallium garnet system (Dy$_x$Gd$_{1-x}$Ga$_5$O$_{12}$ or Dy:GdGG), with complete solid solution between the end members GdGG and DyGG, is the system treated in this paper. Crystal growth, crystal quality, lattice parameter measurement, composition determination, and several physical properties of garnets in this system will be discussed.

Crystal Growth

Nonmagnetic garnet crystals were grown by the Czochralski technique in an A. D. Little Multipurpose Crystal Growth Furnace. Induction heating of the melt was accomplished by use of a 25 kw, 450 kHz rf generator coupled to an iridium crucible. The 1.25 inch-diameter and 1.25 inch-tall crucible was surrounded by bubble zirconia insulation which was contained in a larger fused-silica vessel. Temperature sensing was achieved by a sapphire light pipe that abutted the bottom of the iridium crucible and focused the radiation onto a Honeywell Radiamatic head. This sensor was used in conjunction with a Leeds and Northrup Speedomax H proportional controller.

The starting materials were 99.99 percent pure rare-earth oxide powders from Research Chemicals Co., Phoenix, Arizona and 99.99 percent pure gallium oxide (Ga$_2$O$_3$) powder from Alusuisse Co., Ft. Lee, New Jersey. Oriented garnet wafers were used as seed crystals. Crystals were grown along <100>, <110> or <111> directions at 0.125 inches per hour and rotated at five revolutions per minute. A typical crystal is shown in Figure 1.

Growth of these rare-earth gallium garnets is complicated by the fact that they must be grown in an atmosphere containing oxygen because Ga$_2$O$_3$ decomposes at the elevated temperatures employed (1700 to 1800°C) into a volatile suboxide, Ga$_2$O, and oxygen (3). Attempts to grow rare-earth gallium garnets in a neutral atmosphere such as argon or nitrogen cause white fumes of Ga$_2$O to rise from the melt. A white powder, identified as Ga$_2$O$_3$, deposits on the