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ScienceDirect
Journal of Magnetism and Magnetic Materials 320 (2008) 608–611
Journal of magnetism and magnetic materials
www.elsevier.com/locate/jmmm

Sputtering gases and pressure effects on the microstructure, magnetic properties and recording performance of TbFeCo films

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Received 24 August 2006; received in revised form 24 May 2007
Available online 2 August 2007

Abstract

The MsHc value is considered to be a key factor in high-density recording, and controlling the microstructure on the magnetic underlayer was found to be an effective way of increasing the MsHc of the amorphous TbFeCo magneto-optical (MO) medium. In this paper, we investigate the TbFeCo film's magnetic properties and the effects on the microcolumnar structure, which depends on the sputtering conditions of using various sputtering gases including Ar, Kr, and Xe, and the recording characteristics of TbFeCo memory layers. With heavy sputtering gases such as Kr or Xe, the columnar structure can be prepared in a TbFeCo film at a pressure lower than 1.0 Pa. The columnar structure of a recording layer can be effectively formed thanks to the effects of the magnetic underlayer, which has a fine surface even in the sputtering process in which Xe gas is used. The above applies to the sputtering process in which Ar gas is used. Also, when Xe gas is used in the sputtering process, coercivity Hc is increased through the formation of a well-segregated microcolumnar structure built on domain wall pinning sites, and we obtain a large MsHc and a high squareness ratio of the Kerr-hysteresis loop. Our results indicate that processing a TbFeCo film with heavy sputtering gases is suitable for tiny mark stability because the temperature gradient of Hc is increased. The objective of the low-pressure sputtering process using Xe gas to produce the columnar structure is to achieve ultra-high-density recording with tiny mark stability in the TbFeCo medium. This has been confirmed with magnetic force microscope (MFM) images of stable tiny marks recorded on TbFeCo film.

Keywords: Microstructure; Amorphous thin film; Recording characteristic; Magnetic property; Perpendicular magnetic anisotropy; Coercivity

1. Introduction

Enhanced MsHc, where Ms represents the saturation magnetization and Hc the coercivity, has been identified as a key factor in high-density thermomagnetic recording [1–6]. Further, controlling the microstructure on the magnetic underlayer was found to be an effective method for increasing the MsHc of the amorphous TbFeCo magneto-optical (MO) medium [7,8]. However, the relationship between the characteristics of the microstructure and the magnetic properties of TbFeCo recording films, as well as the effects of sputtering gases in the growth processes and recording performance of TbFeCo films, is not well understood.

This paper describes how the relationship between a TbFeCo film's magnetic properties and its microcolumnar structure depends on the sputtering conditions. We investigate the effects of using various sputtering gases including Ar, Kr, and Xe on the microcolumnar structure of TbFeCo films. The feasibility of linear tiny mark recording on an MO medium with the heavy sputtering gas for ultra-high-density recording is also discussed.

2. Experiment

The sample MO media in the experiment were prepared on a 0.6-mm polycarbonate substrate/SiN (35 nm) enhancement layer/magnetic underlayers of GdFeCoCr/TbFeCoCr (60 nm)/memory layer of TbFeCo (150 nm)/SiN (50 nm) protective layer. These media were designed with a layer structure that acts as a domain wall displacement detection system, which evaluates their static

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doi:10.1016/j.jmmm.2007.07.021

magnetic properties as well as their recording and readout properties [9,10].

Other sample MO media were prepared in order to analyze and evaluate their static magnetic properties with a TbFeCo single layer on a substrate.

The magnetic properties were measured with a vibrating sample magnetometer, a torque magnetometer, and a Kerr magnetometer. The surface and cross-sectional structures of the films were observed using scanning electron microscope (SEM) and an atomic force microscope. The films were also analyzed and observed using secondary ion mass spectrometry (SIMS) analysis and thermal dispersion spectrometry (TDS), and a magnetic force microscope (MFM). The read/write characteristics of the MO medium were measured with a conventional MO head ($\lambda = 660$ nm, NA $= 0.6$) using a magnetic field modulation recording method.

3. Results and discussion

3.1. Magnetic film properties depend on sputtering gases process

Fig. 1 shows the temperature dependence of MsHc for different sputtering gases. The figure shows a TbFeCo memory layer sputtered at a pressure of 0.7 Pa with different sputtering gases, including (a) Ar, (b) Kr, and (c) Xe. The layer structure of the medium in this experiment has the same composition deposited on the substrate, i.e. an SiN layer, magnetic underlayers of GdFeCoCr/TbFeCoCr, a TbFeCo memory layer, and finally an SiN layer. The layers of the MO medium in this experiment have the following composition: a first magnetic underlayer acting as the displacement layer, then a second magnetic underlayer acting as the switching layer, and finally a memory layer. The memory layer of the amorphous TbFeCo film has a compensation temperature of 155 °C and a Curie temperature of 305 °C. The MsHc value for sample films is increased depending on the molecular weight of the sputtering gas. As much as 1.8×10^6 erg/cm^3 of MsHc can be obtained in a memory layer sputtering from Xe gas by sputtering from an alloy target.

Fig. 2 shows the deposition rate for the TbFeCo film, which is dependent on sputtering pressures with different

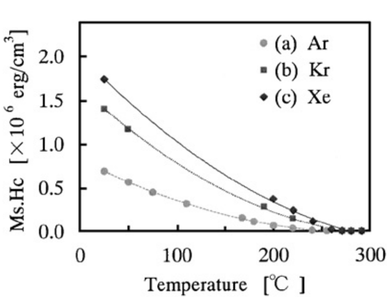

Fig. 1. Temperature dependence of the MsHc of TbFeCo films for different sputtering gases: (a) Ar, (b) Kr, and (c) Xe.

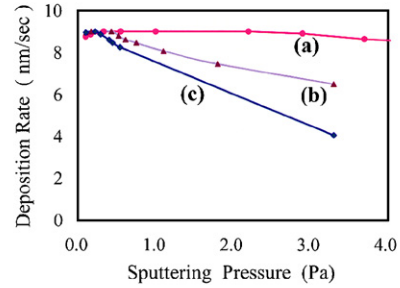

Fig. 2. Deposition rate dependence on the sputtering conditions for different sputtering gases including (a) Ar, (b) Kr, and (c) Xe.

sputtering gases, including (a) Ar, (b) Kr, and (c) Xe. The deposition rate of film using Ar gas does not change over a wide range of sputtering pressures. The deposition rate of film using Kr gas begins to decrease at 1.2 Pa, and the film using Xe gas begins to decrease at 0.7 Pa. It appears that the sputtering TbFeCo particles increase and are scattered by the heavy sputtering gases. Consequently, the deposition rate of the film decreases depending on the mean free path of sputtering particles in the vacuum process chamber. It seems that both the energy flux of Tb and Fe sputtering particles and the deposition rate of film using 3.5 Pa of Ar gas is nearly equal to conditions at 1.2 Pa using Kr gas and at 0.7 Pa using Xe gas.

Fig. 3 shows SEM images of cross-sections of the MO medium. The layer structure of the medium in this experiment is the same as that when magnetic underlayers of GdFeCoCr/TbFeCoCr (60 nm) are used. The memory layer in each sample is sputtered under different conditions using the same TbFeCo alloy target with the same sputtering power of 1 kW: an Ar pressure of 3.5 Pa (a), a Kr pressure of 1.2 Pa (b), and an Xe pressure of 0.7 Pa (c).

The amorphous TbFeCo film sample (a) is a segregated columnar structure cross-section, including a small broken structure under an Ar pressure of 3.5 Pa. Sample (b) shows the inter-granular structure including grains of the film cross-section under a Kr pressure of 1.2 Pa. Sample (c) shows the well-segregated columnar structure with a nearly fixed width when the Xe pressure is 0.7 Pa. The figure shows that it is possible to create a columnar structure using a Xe pressure less than 1.0 Pa on the underlayers with a target in-face type DC magnetron sputtering system. The sputtering condition with low migration energy is the dominant factor in the scattering with heavy gas to make the microcolumnar structure, which is easy to make by lowering the sputtering pressure.

The microstructure of magnetic film forming varies depending on the film growth process conditions, especially the sputtering gas types and pressures and the underlayer structures. The sputtering particle energy was reduced through the interaction of the sputtering gas type and pressure. This concurs with the results of the simulation experiments for the particle energy in a sputtering chamber. In particular, when Xe gas is used, the sputtering particle energy reduction is more effective even at a low