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Short Communication

Cobalt–titanium multilayer thin films: Effect of thickness of titanium spacer layer on impedance properties

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ABSTRACT

We investigated the impedance parameters of cobalt–titanium (Co–Ti) multilayer thin films deposited on native oxidized Si (100) substrate under ultra-high vacuum (4×10^{-8} mbar) by magnetron sputtering at room temperature. Electrical properties of Co/Ti/Co multilayer films were analyzed depending on the thickness of Ti spacer layer with the impedance spectroscopy as a function of frequency. Co/Ti multilayer films exhibited dielectric relaxation in both real and imaginary part of dielectric constants at the kilohertz frequency region and piezoelectric properties at the megahertz frequency region. We determined that the fabricated multilayer films have complex and super imposed type behavior when DC conductivity is used at lower frequency, resonance event and relaxation properties.

1. Introduction

Thin films have different properties as compared to bulk materials such as optic, electrical and magnetic. The technological improvements always need to be faster, cheaper and more flexible resulting in most of the research focusing on different film structures such as alloy and multilayer films to meet these expectations [1–3]. These structures exhibit new properties when they are compared to the elemental form and single layer form. Especially, multilayer films have gained importance after giant magneto resistance (GMR) effect observed by Fert and Grünberg [4,5]. The structures of multilayer thin films (MTFs) exhibited by GMR effect are fabricated by the consecutive deposition of alternating layers of materials, such as Co, Fe, Ni and permalloys, and they are separated by a nonmagnetic layer. Noble metals like Ag, Au, and Cu are commonly used as the nonmagnetic layer. Some additional nonmagnetic materials such as Cr, Pt, Pd and Ru have also been studied [6]. These kinds of films have been widely used in many areas including data storage media, sensor applications and read head [7]. Besides these applications, multilayer films play a key role in spintronic applications to carry only spin currents, spin Hall Effect and inverse spin Hall Effect [8–11]. Due to the effects of MTFs on magnetic properties, their electrical properties may contribute to the literature and reveal a new area of technological application. Although recent studies about the dielectric properties of multilayered thin films have shown that this type of films can be a promising element for the applications in electronics, till date, there have only been a few studies about the impedance spectroscopy (IS) of multilayer thin films [12,13]. Piezoelectric (PZT) materials show mechanical

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strain when an electric field is applied or these materials can be electrically polarized under the mechanical strain. PZT materials have been used to fabricate different electromechanical devices for minimizing electronic equipment and progressing in the driving circuits [14]. Nowadays, PZT materials have been attracted great attention by researchers because of its wide application area.

In this paper, we investigated the impedance parameters of Co/Ti multilayer Ti (50 Å)/Co (45 Å)/Ti(*x* Å)/Co(40 Å)/Ti (100 Å) films. The dielectric properties of the multilayer films were analyzed depending on Ti spacer layer thickness (7 Å, 10 Å, and 13 Å).

2. Experimental

2.1. Sample preparation

Co/Ti multilayer Ti (50 Å)/Co (45 Å)/Ti(*x* Å)/Co (40 Å)/Ti (100 Å) films were grown on native oxidized Si(100) substrate (the native Si oxide layer; 2–3 nm) at ultra-high vacuum (UHV) condition using the magnetron sputtering system at room temperature. The titanium spacer layer thickness (*x*) was changed from 7 Å to 13 Å by a 3 Å step. The schematic illustration of fabricated MTFs structures are presented in Fig. 1.

Before the substrates were loaded to UHV chamber, they were subjected to cleaning process with ethanol and methanol bath in ultrasonic cleaner. In order to remove surface roughness, the Si substrates were heated up to 600 °C by pyrolytic boron nitride (PBN) heater and were kept at this temperature for 20 min in UHV chamber. The system base pressure was approximately 4×10^{-8} mbar. The pressure was set to $1.2–1.5 \times 10^{-3}$ mbar during the deposition process by high purity argon gas (6 N). The power applied to Co target (RF gun) and Ti targets (DC gun) was 30 W and 25 W, respectively. They cause the deposition rates of 0.3 Å/s for Co and 0.2 Å/s for Ti. The thicknesses of deposited layers were measured by quartz crystal monitoring (QCM).

2.2. Characterization of electrical properties

To investigate electrical properties of the Co/Ti multilayer thin films, the gold (Au) electrodes were coated by a Leybold Univax 450 thermal evaporation system; base pressure was $\sim 2 \times 10^{-6}$ mbar on both sides of the samples. Dielectric properties of the samples were carried out with HP 4194A Impedance Analyzer. The dielectric constant of multilayer thin films was determined measuring the capacitance of a parallel-plate capacitor method. Fabricated multilayer thin films having three different thicknesses of Ti spacer layer were analyzed by dielectric spectroscopy (DS) to determine their real and imaginary dielectric constant properties.

The frequency dependent impedance and dielectric response were measured in the 1 kHz to 40 MHz range, and the root mean square (RMS) amplitude of the instrument was set to ~500 mV. The samples' frequency dependence of the real and imaginary parts of the dielectric constant was recorded by the automated Novocontrol WinDeta DAQ.

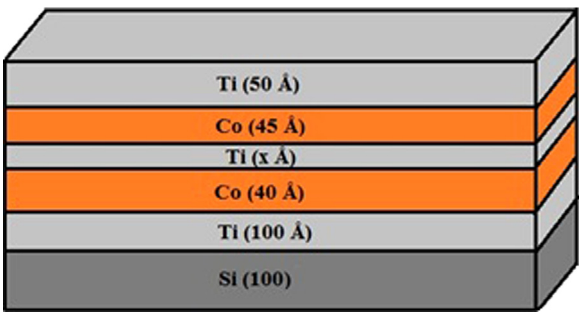

Fig. 1. Schematic illustration of Co–Ti multilayer thin films.

3. Results and discussion

Fig. 2 shows the change in real dielectric constant via frequency between 1 kHz to 40 MHz depending on the thickness of Ti spacer layer (angstrom (Å)) at room temperature. Analysis of the dielectric properties in two frequency regions, between 100 kHz to 6 MHz and higher than 6 MHz, is more suitable for understanding the dielectric behavior of the films. It is clear in Fig. 2 that the real part of dielectric constant of all samples reduced up to 6 MHz. The real part of the dielectric constant was found to be affected by the thickness of Ti spacer layer in multilayer structure. The real part of the dielectric constant between 1 kHz and 6 MHz frequencies increased as Ti spacer layer thickness increased. All samples exhibited dielectric relaxation around 1 MHz. Behavior types of samples demonstrated that relaxation mechanism of samples can be expressed using the method of Cole–Davidson. Moreover, the real part of dielectric constant of samples increased as Ti spacer layer thickness below the 6 MHz frequency region increased (inset Fig. 2).

The increase in dielectric constant thicknesses is, generally, a result of dead layer occurring between the electrode and the thin film [15]. This effect can be explained with defects [16], oxygen atoms can be diffused into the layers or between the layers. Dielectric constants of thin films are expressed as a sum of the interfacial and bulk dielectric constants as given

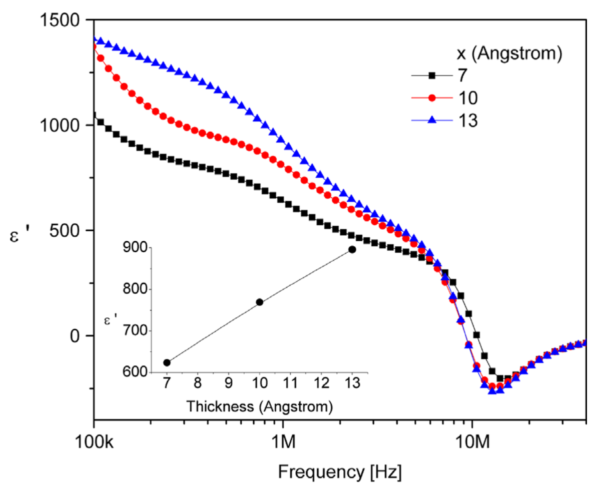

Fig. 2. Real part of dielectric constant variation with frequency for the thin films of different Ti thicknesses.