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Etch characteristics of IrMn thin films using an inductively coupled plasma of CH_3OH/Ar

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ABSTRACT

An inductively coupled plasma reactive ion etching of IrMn magnetic thin films patterned with Ti hard mask was studied in a CH_3OH/Ar gas mix. As the CH_3OH concentration increased, the etch rates of IrMn thin films and Ti hard mask decreased, while the etch profiles improved with high degree of anisotropy. The effects of coil rf power, dc-bias voltage to substrate and gas pressure on the etch characteristics were investigated. The etch rate increased and the etch profile improved with increasing coil rf power, dc-bias voltage and decreasing gas pressure. X-ray photoelectron spectroscopy revealed that the chemical reaction between IrMn films and CH_3OH gas occurred, leading to the clean and good etch profile with high degree of anisotropy of 90°.

1. Introduction

Due to the continued growth in communications and information exchanges nowadays, the necessity for non-volatile information storage devices has been growing rapidly. Although the flash memory has dominated the current market with the limited application, the advent of new nonvolatile semiconductor memory (NVSM) has become an urgent demand [1,2]. Magnetic random access memory (MRAM), which can offer fast speed, high density, low operation power and high endurance with nonvolatilty, has been forecasted to be suitable for replacement of numerous volatile and nonvolatile semiconductor memories that are currently in use [2–4].

MRAM based on the integration of magnetic tunnel junction (MTJ) and CMOS has the potential to be competitive with existing semiconductor memories. For the realization of high density MRAM, the etching of MTJ stack which is composed of magnetic materials such as CoFeB, IrMn, and FePt thin films is one of the vital processes to be overcome [5–7]. One of the obstacles for etching magnetic materials is that they rarely react with chemically active species in a plasma. Initially, ion milling was widely applied in the etching of the magnetic materials. However, it was limited by its own weakness such as slow etch rate, sidewall redeposition and etching damage [8–10]. In order to lessen these issues, the high density plasma etching has been recently employed to etch magnetic materials.

Normal reactive ion etching of IrMn thin films was previously investigated using CF_4, O_2 gas to check exchange coupling [11]. However, the investigation on high density plasma etching of IrMn films was not found elsewhere. In this study, inductively coupled plasma reactive ion etching (ICPRIE) of IrMn magnetic thin films have been studied using a CH_3OH/Ar gas mix. In addition, the etch parameters including coil rf power, dc-bias voltage to substrate and gas pressure were systematically explored to examine the etch characteristics of IrMn films.

2. Experimental details

Two types of etch specimens were prepared for the investigation of the etch rate and etch profile. For the samples used to investigate the etch rates of IrMn films and Ti hard mask, dc magnetron sputtering was employed to deposit IrMn thin films on thermally oxidized Si wafers and Ti thin films on Si substrates, respectively. The 3-in diameter targets were used and base pressure of the sputter was $7.8–9.1 \times 10^{-5}$ Pa. After these films were deposited on the substrate, they were patterned by conventional lithography process using an AZ1512 photoresist (PR) of 1200 nm thickness. For the samples that are used for etch profiles of IrMn films with Ti hard mask, IrMn and Ti thin films were successively deposited on Si substrates. Then, Ti films on IrMn films were patterned by lithography, followed by reactive ion etching in a Cl_2/Ar gas mix. Finally, the photoresist masks were removed by wet stripping and O_2 ashing, leaving a patterned Ti mask atop the blanket IrMn film.

IrMn thin films and Ti hard masks were etched using commercial ICPRIE equipment (A-Tech, Korea) that can generate high density plasma. The ICPRIE system consists mainly of a main process chamber and a load lock chamber. The coil installed at the top of the main process chamber was connected to a 13.56 MHz rf power supply to generate high density plasma. A self dc-bias voltage induced by the rf power at 13.56 MHz was capacitively coupled to the substrate susceptor to control the ion energy in the plasma. The main process chamber was evacuated to a base pressure of $2.6–3.9 \times 10^{-4}$ Pa using

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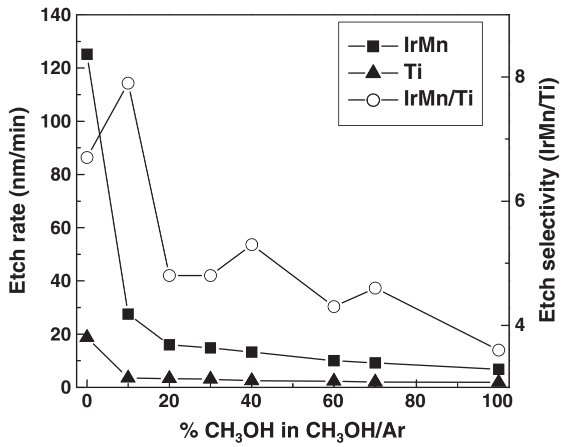

Fig. 1. Etch rate of IrMn and Ti thin films and etch selectivity of IrMn to Ti films at different CH_3OH concentrations. Etch condition: coil rf power of 800 W, dc-bias voltage of 300 V and gas pressure of 0.665 Pa.

a turbomolecular pump. The substrate susceptor was cooled to a constant temperature of 10–12 °C with chilled fluid and the substrate was then cooled with cold helium gas between the substrate and susceptor.

In this study, a CH_3OH/Ar gas mix was used as an etch gas and Ti thin films were employed as a hard mask. The etch rates and etch profiles of the IrMn films and Ti hard masks were examined under varying CH_3OH gas concentration. In addition, the effects of the etch parameters such as coil rf power, dc-bias voltage to substrate and gas pressure on the etch rate and etch profile were investigated. A surface profilometer (Tencor P-1) was used to measure the film thickness for the etch rate. The etch profiles were observed by field emission scanning electron microscopy (FESEM). The surface chemistry of the etched films was examined by using X-ray photoelectron spectroscopy (XPS) to elucidate the etch mechanism of IrMn thin films in a CH_3OH/Ar gas chemistry.

3. Results and discussion

IrMn thin films patterned with the photoresist masks were etched under varying CH_3OH concentration to determine the optimal gas concentration in a CH_3OH/Ar gas mix. Fig. 1 shows the variation of etch rates of IrMn films and Ti hard mask at different CH_3OH concentrations. The etch conditions were fixed at a coil rf power of 800 W, dc-bias voltage to substrate of 300 V, and gas pressure of 0.665 Pa. The etch rates of IrMn films greatly decreased from 125 nm/min in pure Ar to 7 nm/min in 100% CH_3OH. The etch rate of Ti hard mask also decreased from 19 nm/min in pure Ar to 2 nm/min in 100% CH_3OH. Therefore, the etch selectivity of IrMn films to Ti hard mask showed the similar decreasing tendency from 6.7 (in pure Ar) to 3.6 (in 100% CH_3OH) as the CH_3OH gas was added to Ar gas. The decrease in etch rate with increasing CH_3OH concentration was attributed to the reduction of ion bombardment onto the specimen due to the decrease of argon ions and/or the hindrance of a passivation layer containing hydroxyl radical or hydrogen in a CH_3OH plasma. It is considered that the etching of IrMn thin films does not obey the mechanism of reactive ion etching.

The FESEM micrographs of IrMn films etched under varying CH_3OH concentration were shown in Fig. 2. Thick redeposition was formed on the sidewall of IrMn pattern etched in pure Ar which was shown in Fig. 2(a). This result was believed due to the physical bombardment on the film surface by energetic Ar ions without any chemical reactions. The etch profile of IrMn films in 10% CH_3OH/Ar gas still showed a little redeposition along the sidewall of the pattern. However, the redeposition on the sidewall of patterns etched in 30% CH_3OH/gas was not observed. As the CH_3OH concentration increased to 30%, the etch profiles of IrMn films improved with high degree of anisotropy. In 70% CH_3OH/Ar gas, the sidewall angle of the etched pattern (hereafter, called an etch slope) was almost 90° without any redepositions or residues. These results indicate that clean and vertical etch profiles can be achieved in CH_3OH concentration over 30% at the above etching conditions. Generally, the surface reaction by an etch chemistry, the redeposition rate at the sidewall, and shrinkage of mask dimension are the main factors which have a great influence on the etch slope [12]. In etching of IrMn thin films using CH_3OH gas,

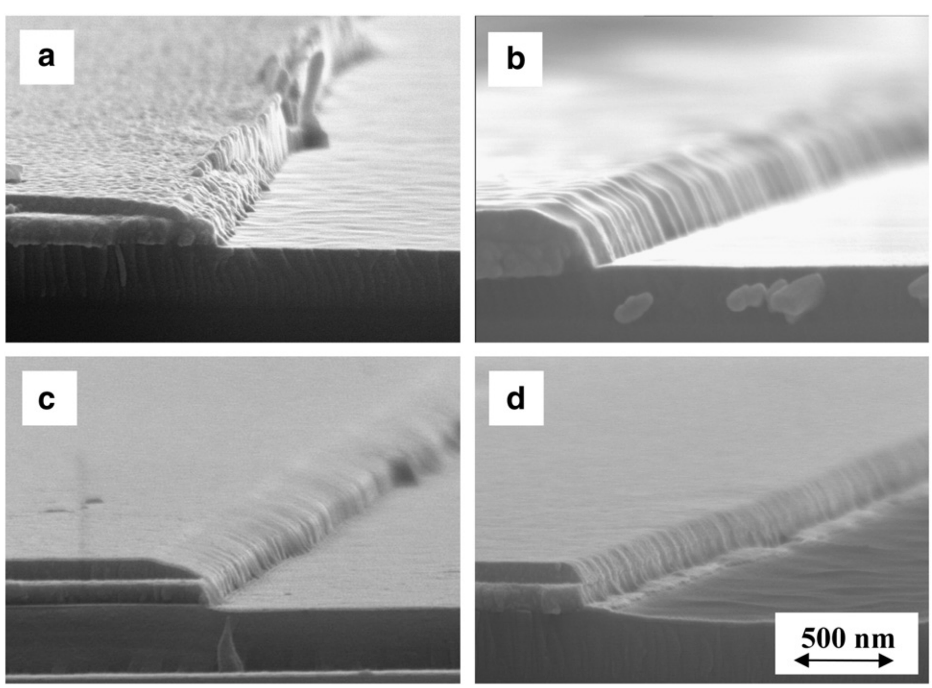

Fig. 2. FESEM micrographs of IrMn thin films etched under different CH_3OH concentrations. (a) pure Ar, (b) 10% CH_3OH/Ar, (c) 30% CH_3OH/Ar, and (d) 70% CH_3OH/Ar.