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Inductively coupled plasma reactive ion etching of IrMn magnetic thin films using a $CH_4/O_2/Ar$ gas

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ABSTRACT

In this study, the etch characteristics of IrMn magnetic thin films patterned with TiN hard mask were investigated using an inductively coupled plasma reactive ion etching in CH_4/Ar and $CH_4/O_2/Ar$ gas mixes. As the CH_4 concentration increased in the CH_4/Ar gas, the etch rates of IrMn and TiN films simultaneously decreased, while the etch selectivity increased and etch profiles improved without any redeposition. The addition of O_2 to the CH_4/Ar gas led to an increase in the etch selectivity and a higher degree of anisotropy in etch profile. The dc-bias voltage and gas pressure were varied to examine and optimize the etching process of IrMn films. Low gas pressure and high dc-bias voltage improved the etch profile, which displayed a high degree of anisotropy. Surface analysis of etched films by X-ray photoelectron spectroscopy was performed to identify the existence of compounds during etching.

1. Introduction

Since the begining of the information-oriented society, the amount of information that each individual needs continues to rapidly increasing along with the advent of various smart devices. In order to meet these demands, there is a need to develop the next generation memory devices with high density and high speed [1,2]. Currently, dynamic random access memory (DRAM) was developed with high density using cutting edge nanotechnology, which involves materials with dimensions between 30 and 50 nm. Despite the great performance of DRAMs, DRAMs have volatile properties and the data is erased when the power is turned off. Magnetic random access memory (MRAM) has also been highlighted as the next generation universal memory. MRAM is composed of a complementary metal oxide semiconductor field effect transistor and a magnetic tunnel junction (MTJ). MTJ stacks which correspond to capacitors in DRAM are the key component of MRAM. It consists of a variety of magnetic thin films, which have the property of tunneling magnetroresistance [2–4].

To achieve high density MRAM, the development of a process to etch the MTJ stacks is a prerequisite. The MTJ stacks are composed of magnetic layers such as IrMn, CoFeB and FePt thin films. At the early stage of etching the magnetic thin films, ion milling, which is a physical sputtering method, has been used because the magnetic thin films hardly react with chemically active species in a plasma. However, ion milling has several disadvantages, including heavy redeposition on the sidewall of the patterns and etching damage to the magnetic properties [5–7]. Many etching studies using an inductively coupled plasma reactive ion etching (ICPRIE) have been previously attempted in Cl_2, BCl_3, HBr gases to address these limitations, [7–9]. These methods have improved the etch profile but issues associated with corrosion, which cause surface corrosion due to remnant corrosive species on the film surface, still need to be addressed. Recently, NH_3/CO and CH_3OH gases have been applied to etch magnetic films and they showed some progress with good etch profiles [10–12].

In this study, the etch characteristics of IrMn thin films, a key layer in MTJ stacks, were investigated using an ICPRIE in CH_4/Ar gas, which are non-corrosive and non-toxic gases. In addition, the etching results and etch mechanism were explored by adding O_2 gas into the CH_4/Ar gas.

2. Experimental details

Two types of etch samples were prepared to investigate the etch rates, etch selectivities and etch profiles. One type was single layers of IrMn and TiN films with a thickness of 100 nm, respectively. These layers were deposited on Si substrates by dc magnetron sputtering using the 3-in diameter targets at pressures ranging from 7.8 to 9.1×10^{-5} Pa. The samples were then patterned by conventional lithography using an AZ1512 photoresist that was 1.2 μm thick. The other type of sample was composed of two layers, IrMn and TiN thin films. The TiN hard masks were deposited on top of the IrMn thin films that were on Si substrates. The TiN films were then patterned by lithography, followed by ICPRIE in a $C_2F_6/Cl_2/Ar$ gas mix. The patterns of the photoresist layers consisted of lines and spaces that were 1, 5, 10, 50, and 100 mm wide. Finally, the photoresist films from the lithography process were stripped by wet stripping

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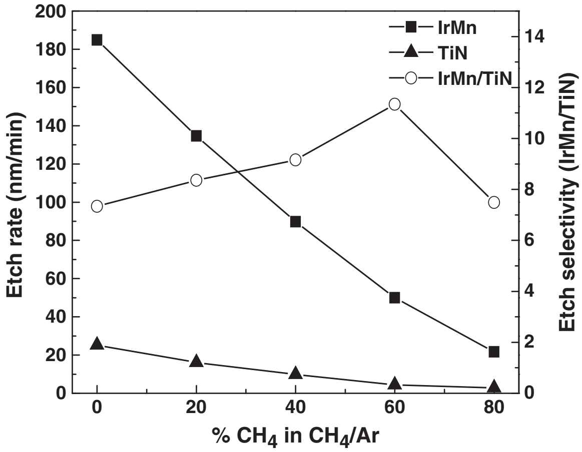

Fig. 1. Etch rate of IrMn and TiN thin films and etch selectivity of IrMn to TiN films at various CH_4 concentrations. Etch condition: Coil rf power of 800 W, dc-bias voltage of 300 V and gas pressure of 0.67 Pa.

and O_2 ashing after etching. The patterned TiN films were left on the IrMn thin films.

The IrMn and TiN films were etched using ICPRIE equipment (A-Tech, Republic of Korea). The ICP coil for generating a high density plasma was located on the top of the main chamber and connected to a 13.56 MHz rf power supply. The dc-bias voltage was induced by the other rf power at 13.56 MHz accelerated ions and radicals to the surface of substrates in the plasma. The main chamber was evacuated down to a pressure of 1.07×10^{-4} Pa using a turbo molecular pump. The temperature of the susceptor was constantly maintained using chilled fluid at 12–15 °C and the substrate was cooled by cold helium gas filled between the substrate and susceptor.

In this study, the etch characteristics of IrMn thin films were investigated using an ICPRIE in CH_4/Ar and CH_4/O_2/Ar gas mixes. The etch rates and etch profiles of IrMn thin films were examined by varying the CH_4 and O_2 concentrations in CH_4/Ar and CH_4/O_2/Ar gas mixes and the dc-bias voltage and gas pressure. The surface profiler (Tencor P-1) and field emission scanning electron microscopy (FESEM; S-4300) with an operating voltage of 20 kV were used to measure the etch rate of the films and etch profiles, respectively. X-ray photoelectron spectroscopy (XPS: ThermoScientific K-Alpha) with X-ray source of Alα and X-ray beam energy of 12 kV was employed to assess the etch mechanism of IrMn thin films by detecting the presence of chemical compounds on the etched surfaces of the films. Optical emission spectroscopy (OES) was also used to measure the levels of active species in the plasma.

3. Results and discussion

To determine the optimal concentration of CH_4 in the CH_4/Ar gas mix, IrMn magnetic thin films patterned with photoresist masks were etched using various concentrations of the CH_4 gas. A coil rf power of 800 W, dc bias voltage of 300 V and gas pressure of 0.67 Pa were chosen as the standard etching conditions. Fig. 1 shows the etch rates of IrMn and TiN thin films at various CH_4 concentrations in the CH_4/Ar gas mix. The etch rates of IrMn thin films remarkably decreased from 1850 Å/min in pure Ar to 220 Å/min in 80% CH_4/Ar. The etch rates of TiN hard masks also decreased from 250 Å/min in pure Ar to 30 Å/min in 80% CH_4/Ar gas. The etch selectivity of the IrMn thin films to the TiN hard masks slightly increased with an increase in CH_4 concentration. The decrease in etch rates with an increase in CH_4 concentration was attributed to a decrease in the energetic Ar ions due to a reduction of Ar gas, which physically etches the film surface.

The etch selectivity increased when the CH_4 concentration was increased up to 60% and then slightly decreased as more CH_4 gas was added to Ar. This occurred because the decrease in the etch rate of TiN hard mask was larger than that of the IrMn films. In addition, the formation of polymer films containing C and H in high CH_4 concentrations exceeding 60% resulted in a decrease in the etch rate of the films because these formed polymers interrupted ion bombardment and/or any chemical reactions between the radicals and the films surface.

FESEM micrographs of the etched samples in various CH_4 concentrations are presented in Fig. 2. Thick redeposition on the sidewall of IrMn thin film etched in pure Ar was observed (Fig. 2 (a)). This

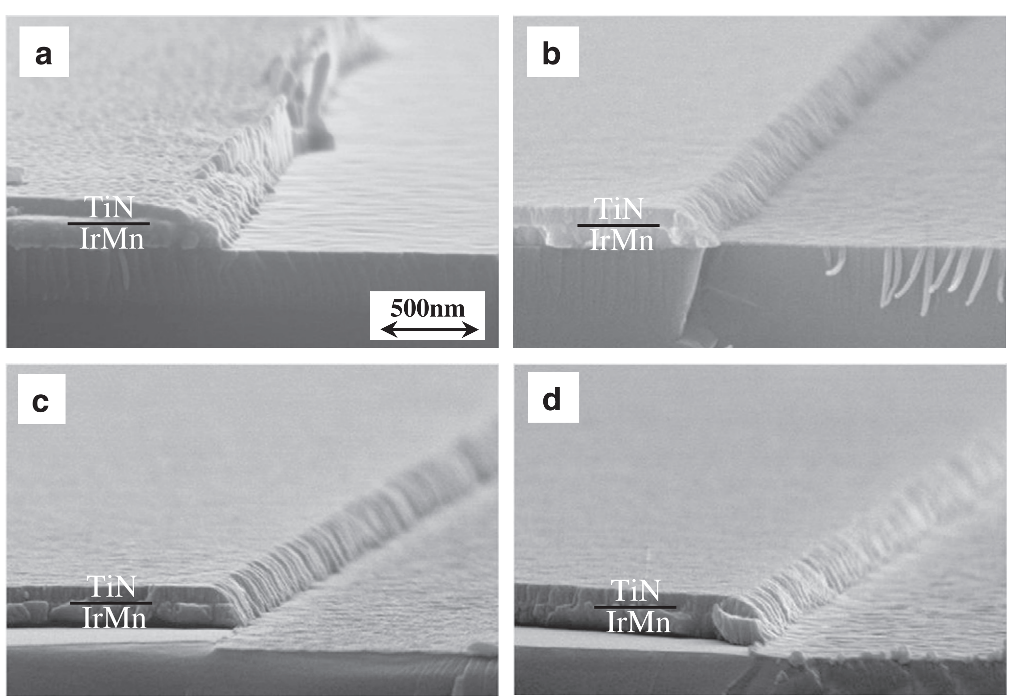

Fig. 2. FESEM of IrMn thin films etched under varying CH_4 concentrations. (a) pure Ar, (b) 20% CH_4/Ar, (c) 40% CH_4/Ar and (d) 60% CH_4/Ar.