Vacuum 97 (2013) 49–54

Contents lists available at SciVerse ScienceDirect

Vacuum

journal homepage: www.elsevier.com/locate/vacuum

Etch characteristics of CoFeB magnetic thin films using high density plasma of a $H_2O/CH_4/Ar$ gas mixture

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ARTICLE INFO

Article history:
Received 15 January 2013
Received in revised form
16 March 2013
Accepted 27 March 2013

Keywords:
CoFeB magnetic thin films
Magnetic tunnel junction
MRAM
Inductively coupled plasma reactive ion etching
H_2O/CH_4 gas

ABSTRACT

Etch characteristics of CoFeB magnetic thin films patterned with TiN hard masks were investigated using inductively coupled plasma reactive ion etching in H_2O/Ar and H_2O/CH_4 gas mixes. As the H_2O concentration in the H_2O/Ar gas increased, the etch rates of CoFeB and TiN films decreased simultaneously, while the etch selectivity increased and etch profiles improved slightly without any redeposition. The addition of CH_4 to the H_2O gas resulted in an increase in etch selectivity and a higher degree of anisotropy in the etch profile. X-ray photoelectron spectroscopy was performed to understand the etch mechanism in H_2O/CH_4 plasma. A good pattern transfer of CoFeB films masked with TiN films was successfully achieved using the H_2O/CH_4 gas mix.

1. Introduction

Owing to the demand for the transfer of a variety of information and massive data via various electronic devices, development of the next generation of memory devices with high speed and high density is essential. High density dynamic random access memory (DRAM) is currently developed by using cutting edge technologies that function at nanometer dimensions of 30–50 nm. DRAM has many advantages including high density, fast speed, and low power consumption; however, it has the disadvantage of volatility. Therefore, the development of next generation memory devices to meet these demands is prerequisite [1,2].

Among a variety of emerging and nonvolatile candidate memory devices, magnetic random access memory (MRAM) has drawn a great deal of attention because it has many advantages including high density, fast speed, nonvolatility and radiation hardness. MRAM consists of a complementary metal oxide semiconductor field effect transistor and a magnetic tunnel junction (MTJ). MTJ stacks, which correspond to capacitors in DRAM, are important components of MRAM. These stacks are composed of a variety of magnetic thin films, metals and a tunneling barrier layer [2–4].

To fabricate high density MRAM, it is necessary to develop a method of etching the MTJ stacks. The MTJ stacks consist of a few metal films, MgO as a tunneling barrier layer, and magnetic layers such as CoFeB, PtMn, IrMn and FePt thin films. Initially, etching of the magnetic thin films was carried out by ion milling, which employed a physical sputtering etch mechanism, and by reactive ion etching which used a physical and chemical etch mechanism. Magnetic thin films undergo little reaction with chemically active species in plasma; therefore, ion milling has been the main method used for etching of magnetic thin films. However, ion milling has shown several disadvantages including heavy redeposition on the sidewall of the etched patterns and etch damage to the magnetic properties [5–7]. To overcome these issues, inductively coupled plasma reactive ion etching (ICPRIE) was employed to etch the magnetic thin films. Initially, Cl_2, BCl_3, and HBr gases were used for etching; however, they did not produce satisfactory etch results because of the slanted sidewall angles of the etched films (called an etch slope hereafter) and thick redeposition on the sidewall of the films [7–9]. Some studies used a CO/NH_3 gas mixture to etch the magnetic films [10–12], but this process could not be reproduced and the proposed etch mechanism could not be confirmed. Recently, etch studies using CH_3OH to etch magnetic films and MTJ stacks were reported and some progress with good etch profiles was found [13–15].

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0042-207X/$ – see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.vacuum.2013.03.018

In this study, the etch characteristics of CoFeB thin films, which are the key layer in MTJ stacks, were investigated using an ICPRIE in H_2O and H_2O/CH_4 plasmas. The effects of H_2O and CH_4 gases on the etch rate, etch selectivity and etch profiles of CoFeB thin films were examined. In addition, the etch mechanism was explored by using XPS along with the etch characteristics.

2. Experimental details

ICPRIE of CoFeB thin films masked with TiN thin films was carried out using H_2O/Ar and H_2O/CH_4 gas mixes. CoFeB and TiN thin films were prepared on Si substrates by dc magnetron sputtering using 3-in diameter targets at pressures ranging from 7.8 to 9.1×10^{-5} Pa. To study the etch profile, TiN thin films were deposited on CoFeB thin films. These thin films were then patterned by photolithography using a 1.2 μm-thick conventional photoresist. TiN thin films deposited on CoFeB films were etched by reactive ion etching in a Cl_2/C_2F_6/Ar gas after pattering by lithography. The photoresist masks were subsequently removed using a stripping solution and O_2 plasma ashing after the TiN hard mask was etched. The patterned TiN films were left on the CoFeB thin films.

The CoFeB and TiN thin films were etched using ICPRIE equipment (A-Tech, Korea). The ICP coil connected to a 13.56 MHz rf power supply was located on top of the main chamber for generating a high density plasma. The dc-bias voltage induced by another rf power at 13.56 MHz accelerated ions and radicals to the surface of substrates in the plasma. The main chamber was evacuated to a pressure of 1.07×10^{-4} Pa using a turbo molecular pump. The temperature of the susceptor was constantly maintained at 12–15 °C using chilled fluid and the substrate was cooled by cold helium gas filled between the substrate and susceptor. The schematic of the ICPRIE system was shown in Fig. 1.

In this study, the etch characteristics of CoFeB thin films were investigated using an ICPRIE in H_2O/Ar and H_2O/CH_4 gas mixes. The etch rates, etch selectivities and etch profiles of CoFeB thin films were examined by varying the H_2O and CH_4 concentrations in H_2O/Ar and H_2O/CH_4 gas mixes. The surface profiler (Tencor P-1) and field emission scanning electron microscopy (FESEM; Hitachi 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 a source of Al Kα and X-ray beam energy of 1486.6 eV was employed to assess the etch mechanism of CoFeB thin films by detecting the presence of chemical compounds on the etched surfaces of the films.

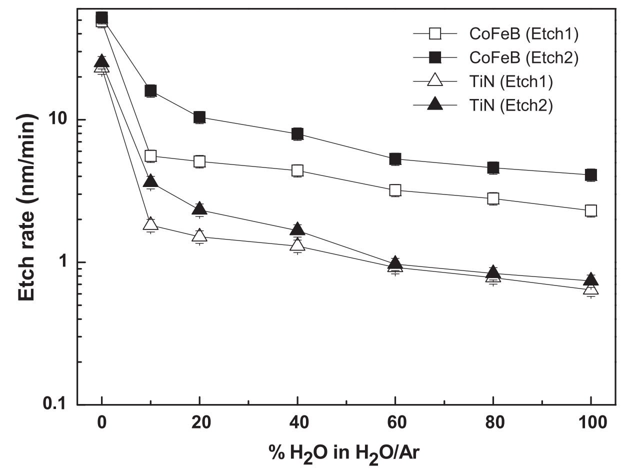

Fig. 2. Etch rates of CoFeB and TiN thin films at different H_2O concentrations; Etch condition 1: ICP rf power of 800 W, dc-bias voltage of 300 V, and gas pressure of 0.67 Pa, Etch condition 2: ICP rf power of 900 W, dc-bias voltage of 400 V, and gas pressure of 0.13 Pa.

3. Results and discussion

The main objective of this study was to develop a prospective gas for etching of CoFeB thin films. To prevent corrosion of CoFeB magnetic films by corrosive etch gases such as Cl_2, BCl_3 and HBr, and to reduce the heavy redeposition on the sidewall of the etched films by CH_3OH and CH_4 [16,17], H_2O gas was used for etching. Fig. 2 shows the etch rates of CoFeB and TiN thin films in H_2O/Ar gas containing various H_2O concentrations. The etching was carried out under two different etch conditions; etch condition 1 (etch 1), which was an ICP rf power of 800 W, dc-bias to substrate of 300 V and gas pressure of 0.67 Pa; and etch condition 2 (etch 2), which consisted of an ICP rf power of 900 W, dc-bias to substrate of 400 V and gas pressure of 0.13 Pa. The etch rates of CoFeB and TiN thin films decreased remarkably as the H_2O concentration increased for both etch conditions. The etch rates under etch condition 2 were

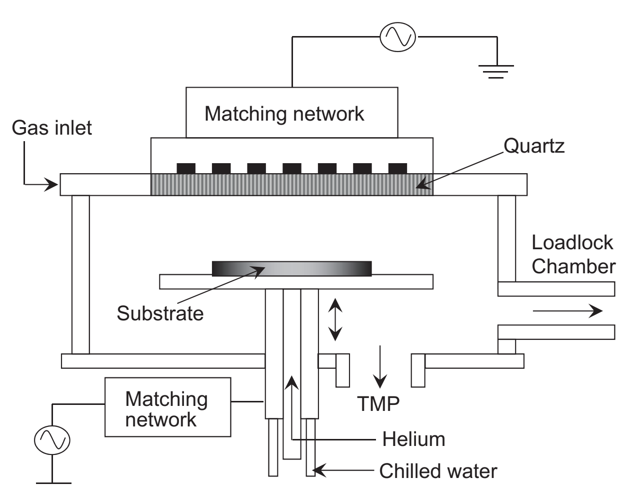

Fig. 1. Schematic of the ICPRIE system.

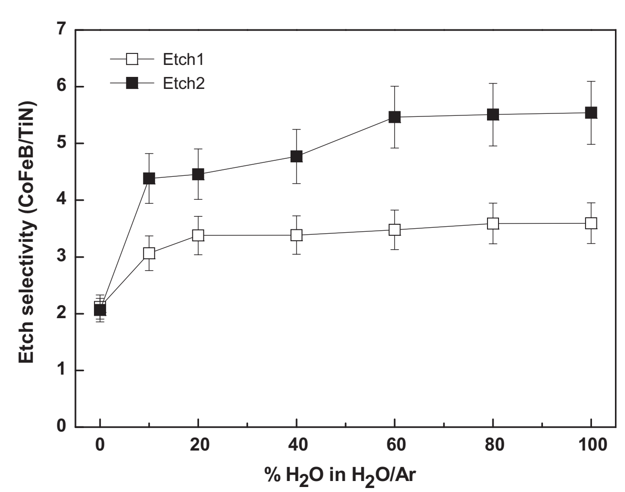

Fig. 3. Etch selectivity of CoFeB to TiN films at different H_2O concentrations.