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ETCHING CHARACTERISTICS OF MAGNETIC THIN FILMS BY ION BEAM TECHNIQUE

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Abstract - The etching characteristics of magnetic thin films of permalloy and Fe-based alloys are investigated. The thin films are fabricated by rf magnetron sputtering and the substrates used are silicon and glass. Etching is done by ion beam technique and the main process parameters investigated are beam voltage, beam current and accelerating voltage. The etch rate of the magnetic films is proportional to the beam current, but it is not directly related to the accelerating voltage and beam voltage. The dependence of etch rate on the process parameters can be explained by ion current density. It is found that the ion beam etching is effective in obtaining well-developed micro-patterns on the permalloy and Fe-based magnetic thin films.

I. INTRODUCTION

The miniaturization of electromagnetic devices has been one of important goals in the related industries and, in order to achieve the goal, great efforts have been directed to develop integrated circuit technology. However, although a remarkable development has been achieved in the field of semiconductors, the miniaturization technology for magnetic devices is far behind the integrated technology for semiconductors, causing an obstacle to the production of integrated electromagnetic devices. With this situation in mind, thin film magnetic devices have drawn much attention [1-5]. The fabrication of magnetic devices may involve the two main steps; (1) fabrication technology for high-quality magnetic thin films and (2) the photolithography technology for the micropattern formation. While the former is considerably established particularly in the field of recording media and magnetic recording heads, the latter is not. It is therefore important to develop microfabrication technology of thin magnetic films.

Recently, ion beam etching has been used in the fabrication of thin film devices owing to the progress in the production of ion beam source and it has the merits of low substrate temperature, low possibility of impurities and defects inclusion into the film, and the use of wide varieties of substrates, etc.

The main aim of the present work is to establish the basic etching technology of magnetic thin films by ion beam technique and, in an effort to achieve the goal, the effects of the process parameters such as the accelerating voltage, beam voltage and beam current on the etching rate and surface morphology of permalloy and Fe-based thin magnetic films are investigated.

II. EXPERIMENTAL PROCEDURE

Both permalloy and $Fe_{74}Zr_8C_6N_{12}$ (Fe-based) films were fabricated onto Corning glasses and silicon wafers (1 cm × 1 cm) by r.f. magnetron sputtering. The films were then cleaned by using an ultrasonic cleaner in acetone, ethanol and deionized water. The line width in the photo mask for micropattern formation was 60 μm and AZ-1512 was used for photochemist. The process of micropattern formation was as follows. The magnetic film was spin-coated about 1.2 μm thick with AZ-1512 at the revolution of 4000 rpm. After soft baking at 95℃ for 30 min, UV light exposure and developing process were performed and then hard baking was carried out at 115℃ for 45 min. The etching was performed by using an ion beam apparatus (MPS-3000PBN, Ion Tech Co.) under Ar atmosphere. The ion source-substrate distance was 12 cm and the accelerated ion flux was aimed at normal incidence. The main factors affecting the etching rate and surface morphology of the films are considered to be the amount of accelerated ion flux and the kinetic energy of the ion, which can be controlled by the accelerating voltage, beam voltage, and beam current, etc. A Langmuir probe, which was located near to the substrate, was used to measure the current density of accelerated ions. The duration of etching was 20~30 min. The morphology of etched samples was examined by a long scan profiler and a scanning electron microscope (SEM).

III. RESULTS AND DISCUSSION

Fig. 1 shows the variations of etching rate of permalloy and Fe-Zr-C-N thin films with the accelerating voltage at the beam currents of 60, 100, and 150 mA. The beam voltage was held constant at 600 V. The etching rate of Ni-rich permalloy ($Ni_{80}Fe_{20}$) is higher than that of the Fe-rich film ($Fe_{74}Zr_{8}C_{6}N_{12}$.). This can be understood from different etching rates of constituent elements, as given in Table I for some elements [6]; the etching rates of pure Ni and Fe are 530 and 350 Å/min, respectively. It is also noted that the etching rate is nearly independent of the accelerating voltage when the beam current is low but, at high beam currents, it decreases with the accelerating voltage, which is particularly true for the permalloy film.

Table 1 Ion beam etching rate of some materials. The experimental conditions are: Ar gas at 500 eV; normal incidence; beam current density of 1 mA/cm^2.

Material	Etch rate (Å/min)	Material	Etch rate (Å/min)
Al	640	Al_2O_3	83
Si	370	GaAs(100)	650
Fe	350	GaAs(110)	1600
Co	450	$LiNbO_3$	390
Ni	530	$Ni_{80}Fe_{20}$	500
Cu	880	Photoresist (AZ1350)	200

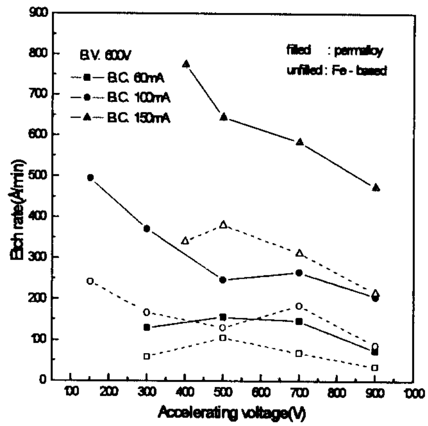


Fig. 1 Etching rate of the permalloy and the Fe-based films as a function of the accelerating voltage at the constant beam voltage of 600 V.

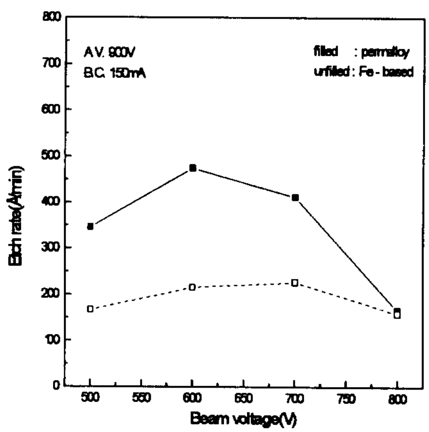


Fig. 2 Etching rate of the permalloy and the Fe-based films as a function of the beam voltage when the beam current is 150 mA and the accelerating voltage is 900 V.

The dependence of etching rate on the beam voltage is shown in Fig. 2. The results are obtained at the beam current of 150 mA and the accelerating voltage of 900 V. The etching rate shows a maximum at the beam voltages of 600 - 700 V. Since the kinetic energy of Ar ion is proportional to the beam voltage, these results indicate that the etching rate is not directly related to the kinetic energy of accelerated Ar ion.

Fig. 3 shows the variation of the etching rate with the beam current. The accelerating voltage is

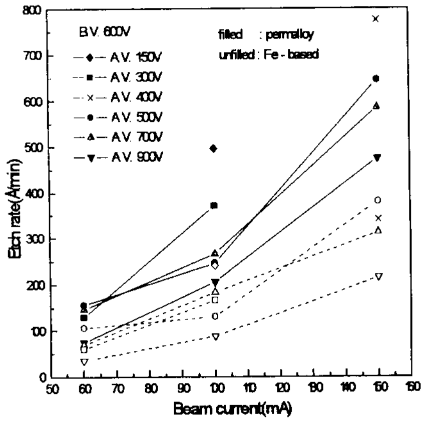


Fig. 3 Etching rate of the permalloy and the Fe-based films as a function of the beam current at the beam voltage of 600 V.

varied widely from 150 to 900 V but the beam voltage is fixed at 600 V. The etching rate of the permalloy film is nearly twice as high as that of the Fe-based film and the etching rate of both the magnetic thin films increase monotonically with the beam current.

The ion beam etching is done mainly by the energy transfer between accelerated Ar ions and surface atoms. In order to explain the present results, it will be necessary to measure the current density of accelerated Ar ion near the substrate. In this work the current density is measured by using a Langmuir probe as was mentioned in the Sec. II. Fig. 4(a) shows the variations of the ion current density with the accelerating voltage, at the beam voltage of 600 V and the beam currents of 60, 100 and 150 mA. At low beam currents, the ion current density does not change with the accelerating voltage. At the high beam current of 150 mA, however, the ion current density, however, shows a tendency of decreasing with the accelerating voltage. This is similar to the variation of etching rate with accelerating voltage shown in Fig. 1. Fig. 4(b) shows the dependence of the ion current density on the beam voltage. The ion current density does not change consistently with the beam voltage, which is directly linked with the dependence of etching rate on the beam voltage.

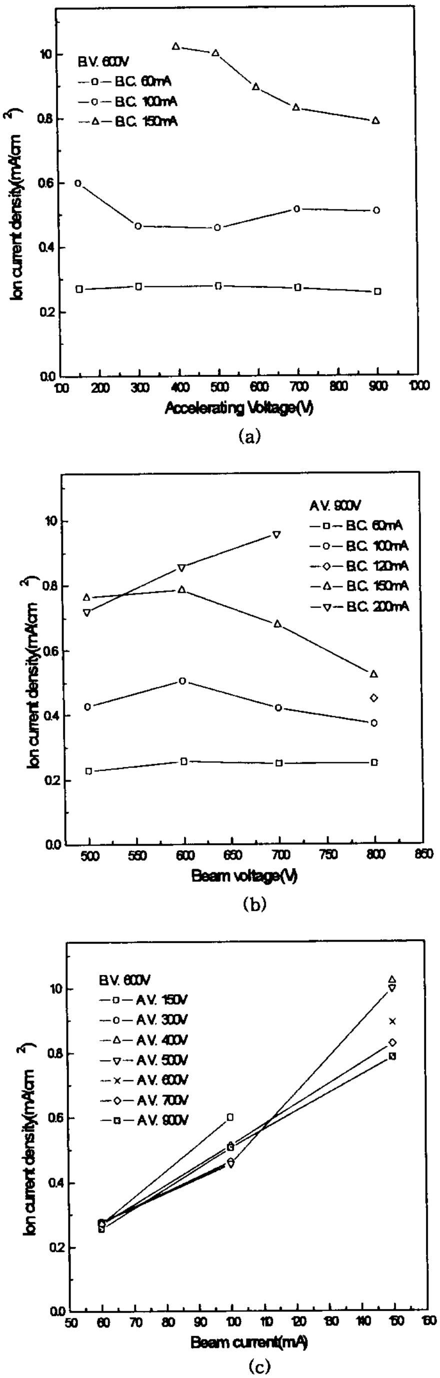
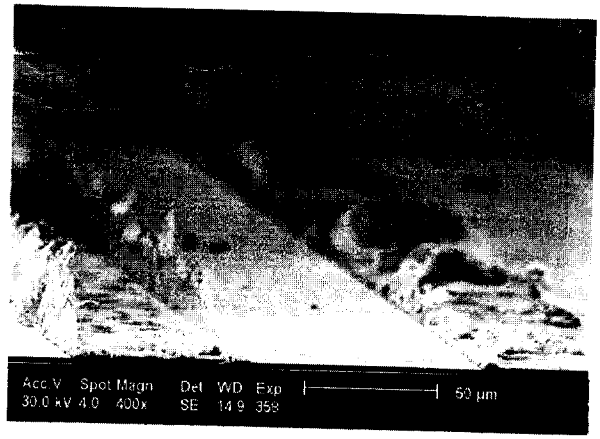


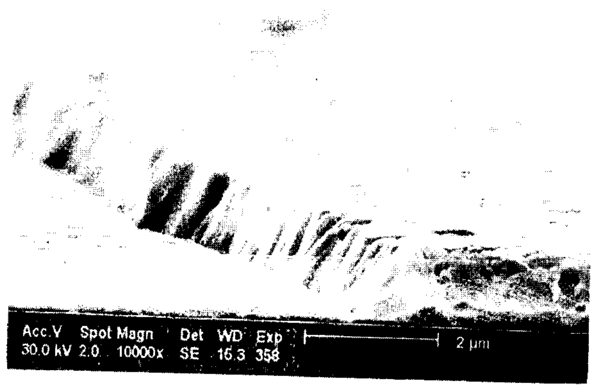
Fig. 4 The variations of ion current densities depending on (a) accelerating voltage, (b) beam voltage, (c) beam current

Fig. 4(c) shows the variation of the ion current density with the beam current. The ion current density is proportional to the beam current, which is consistent to the dependence of etching rate on the beam current shown in Fig. 3. Resultantly, the ion current density is directly related to the etching rate of the magnetic thin films. In addition, the beam current is more proportional to ion current density than to the accelerating voltage and beam voltage. Since these process parameters of accelerating voltage, beam voltage and beam current are correlated with each other, the maximum ion current density and hence the etching rate can be achieved at a proper combination of these process parameters.

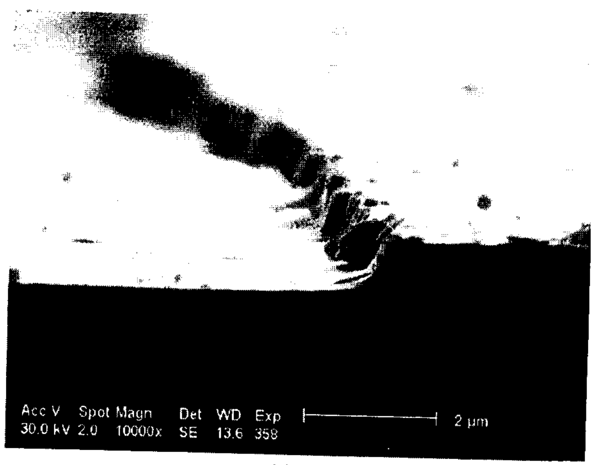
The surface morphology of the magnetic films, before and after ion beam etching, has been investigated by using a SEM. Figs. 5(a), (b), and (c) show etched morphologies of the permalloy film before and after removing the photoresist film and of the Fe-based film after the removal of photoresist, respectively. As shown in Fig. 5(a), the photoresist film is damaged extensively during the ion beam etching, which can be understood from the etching rate of photoresist film in Table I. Since the accelerated Ar ions strike against both the photoresist and the magnetic film, the photoresist film may be damaged excessively by the kinetic energy transfer and the temperature increase at the film surface. After the ion beam etching and striping of photoresist film, the micro patterns on both the permalloy and the Fe-based films are well developed. The crooked edge in the line pattern may be caused by the imprecise mask.



(a)



(b)



(c)

Fig. 5 Scanning electron micrographs of etched magnetic films; (a) before and (b) after the stripping of photoresist film on permalloy film, and (c) after the stripping of photoresist film on Fe-based film.

IV. CONCLUSIONS

Both the permalloy ($Ni_{80}Fe_{20}$) and the Fe-based $Fe_{74}Zr_8C_6N_{12}$ thin films have been etched by ion beam technique and the etching characteristics as a function of process parameters have been examined. The results are summarized as follows:

(1) By varying the process parameters, the etching rate of the permalloy and the Fe-based films change from 75 to 780 Å/min and from 35 to 340

Å/min, respectively.

(2) The etching rate of the two magnetic films is proportional to the beam current, but it is not related directly to the accelerating voltage and the beam voltage.

(3) The dependence of etching rate on process parameters can be explained by the measurement of ion current density at the substrate.

(4) Well-developed micro-patterns are achieved on both the permalloy and the Fe-based films by ion beam technique.

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