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Reactive Ion Etching of NiFe Film with Organic Resist Mask and Metal Mask by Inductively Coupled Plasma

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Etching of NiFe films covered with an organic photo-resist or Ti was successfully performed by an inductively coupled plasma-reactive ion etching (ICP-RIE) system using $CHF_3/O_2/NH_3$ discharges exchanging CHF_3 for CH_4 gas gradually. Experimental results showed that the organic photo-resist mask can be applied to the NiFe etching. In the case of the Ti metal mask, it was found that the etching-selectivity Ti against NiFe was significantly varied from 7.3 to ~0 by changing $CHF_3/CH_4/O_2/NH_3$ to $CH_4/O_2/NH_3$ discharges used in the ICP-RIE system. These results show that the present RIE of NiFe was dominated by a chemical reaction rather than a physical sputtering.

Keywords : etching, reactive ion etching, RIE, plasma, NiFe, magnetic film

1. Introduction

The size of magnetic storage devises has been become smaller rapidly. Micro-and nanofabrications of magnetic thin films have been important for practical application of advanced magnetic devices such as magnetic random access memory (MRAM). Micro-fabrication of magnetic materials was widely performed by ion milling. This process has some problems that shape, homogeneity and selectivity would not be controlled fully. For those reasons the conventional reactive ion etching using Cl_2-based discharge has been applied to the etching process of magnetic materials [1]. However one can not get rid of a degradation of the resultant structure due to residual chlorine and non-volatile products in the Cl_2-based process. Also the RIE process for etching of NiFe and other magnetic materials were carried out under the CO/NH_3 discharges [2-4]. It was indicated that producing volatile metal carbonyl proceed with the etching of NiFe.

In this study, we etched NiFe films covered with an organic photo-resist and Ti by the ICP-RIE system using $CHF_3/O_2/NH_3$ discharges exchanging CHF_3 for CH_4 gas gradually. In the case of the Ti mask, the relative etch rate of Ti against NiFe showed broad variation by changing $CHF_3/CH_4/O_2/NH_3$ to $CH_4/O_2/NH_3$ discharges. From the experimental results, we deliberate the effect of F-and C-related chemical reaction on the NiFe surface based.

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2. Experiment

The etching was performed in the ICP-RIE system (RIE-101iPH, Samco Inc.) using $CHF_3/O_2/NH_3$ discharges exchanging CHF_3 for CH_4 gas gradually. The total gas flow of CH_4 and CHF_3 was held constant. The NiFe films were fabricated onto Si (100) substrates by a sputtering system. These films were partially covered with an organic photo-resist and Ti to determine the etch rate of NiFe. The masks of the photo-resist and Ti were lithographically patterned. The gas flow of O_2 was used in 10 SCCM or 5 SCCM with the organic etch-mask. ICP source power set at of 300 W and 500 W as the plasma source. The lower RF source power, that is 150 W, was selected to investigate the role of the chemical reaction rather than that of the physical sputtering. The etching was carried out under the low pressure of 0.8 Pa. The features of NiFe were observed by field emission scanning electron microscopy (FESEM). The etching depth of the NiFe was measured with a stylus profilometry.

3. Results and Discussion

The etching of NiFe covered with the organic photo-resist was performed in ICP-RIE system using $CHF_3/O_2/NH_3$ discharges exchanging CHF_3 for CH_4 gas gradually. Fig. 1 shows the etch rate of NiFe as a function of the ratio of CH_4 gas. The ICP source power and the O_2 gas flow carried out in the etching was changed as 300 W and 10 SCCM, 300 W and 5 SCCM, 500 W and 10 SCCM. In the all plasma conditions, the etch rate of NiFe in $CH_4/O_2/NH_3$ discharges was higher than that in $CHF_3/O_2/NH_3$ discharges. The etch rate of NiFe at the ICP source power of 500 W and O_2 gas flow of 10 SCCM was the highest in the whole range of CH_4 gas rate.

Fig. 2 shows the etch rate of organic resist mask as a function of ratio of CH_4 gas. The ICP source power and O_2 gas flow carried out in the same condition of NiFe-etching. The etch rate of resist at the ICP source power of 500 W was high that at ICP source power of 300 W. The etch rate of the resist at the ICP source power of 300 W was decreased by exchanging O_2 gas flow of 10 SCCM to that of 5 SCCM. The relative etch rate of the resist against NiFe showed 29 under the condition of $CH_4/O_2/NH_3$ discharges, the ICP source power of 300 W and O_2 gas flow of 5 SCCM. This experimental result shows that the organic photo-resist mask can be used for the NiFe etching in this plasma conditions with the exception of requiring high aspect-ratio structures.

Fig. 3 shows the etch rate of NiFe and that of Ti mask as a function of ratio of CH_4 gas. The etching was carried out under the ICP source power of 500 W and O_2 gas flow of 10 SCCM. The etch rate of NiFe was increased from 1.7 nm/min to 5.6 nm/min and that of Ti mask was

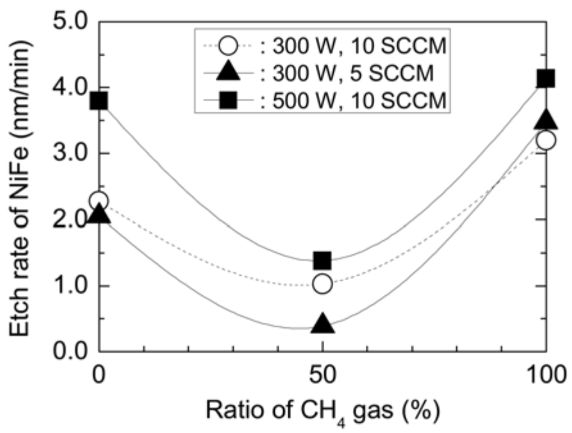

Fig. 1. Etch rate of NiFe as a function of the ratio of CH_4 gas. The ICP source power and the O_2 gas flow carried out in the etching was 300 W and 10 SCCM, 300 W and 5 SCCM, 500 W and 10 SCCM, respectively. Organic resist was used as the etch mask on the NiFe film.

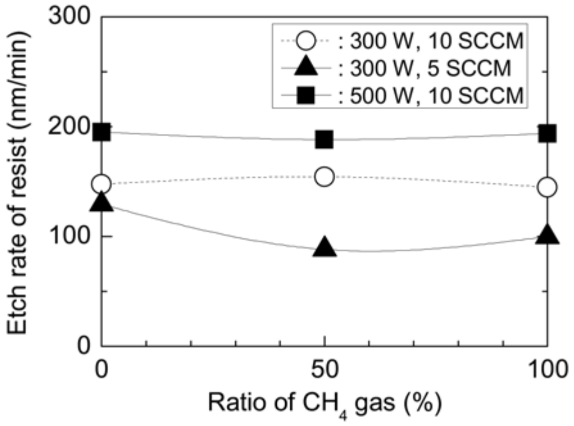

Fig. 2. Etch rate of organic resist mask as a function of the ratio of CH_4 gas. The ICP source power and the O_2 gas flow carried out in the etching was 300 W and 10 SCCM, 300 W and 5 SCCM, 500 W and 10 SCCM, respectively.

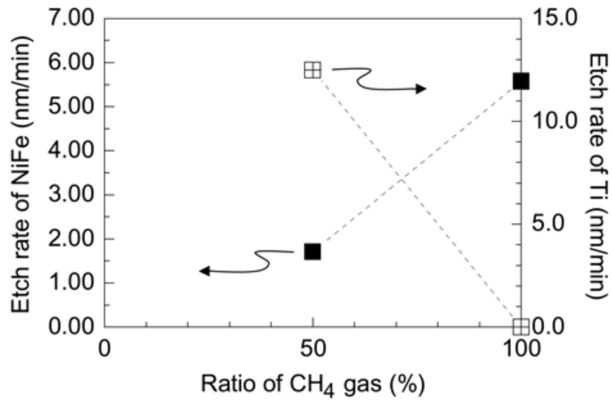

Fig. 3. Etch rate of NiFe and that of the Ti mask as a function of the ratio of CH_4 gas. The etching was carried out under the ICP source power of 500 W and the O_2 gas flow of 10 SCCM.

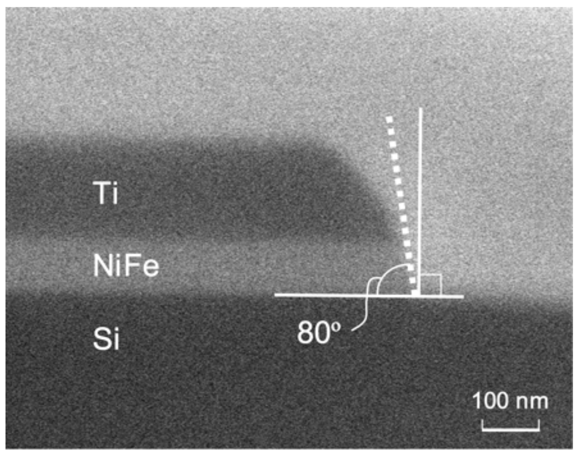

Fig. 4. Cross-sectional SEM image of NiFe etched in the plasma condition as $CH_4/O_2/NH_3$ discharges, the ICP source power of 500 W and the O_2 gas flow of 10 SCCM.

decreased from 12.5 nm/min to ~0 nm/min by changing 50% to 100% of CH_4 gas. The etching-selectivity Ti as the mask against NiFe was significantly varied from 7.3 to ~0 by changing $CHF_3/CH_4/O_2/NH_3$ to $CH_4/O_2/NH_3$ discharges. We concluded that the etching of Ti was governed by a F-related chemical reaction. The etching of Ti was probably prevented by piling up carbon on its surface from C-rich plasma conditions as $CH_4/O_2/NH_3$ discharges. Fig. 4 shows the Cross-sectional SEM image of NiFe etched in the plasma condition as $CH_4/O_2/NH_3$ discharges, ICP source power of 500 W and O_2 gas flow of 10 SCCM. This SEM image shows that the angle between sidewall and surface of Si was about 80^o though the RF source power was relatively low, that is 150 W. Note that the angle will be close to 90^o by increasing the RF source power.

4. Conclusion

We have succeeded in developing that the ICP-RIE of NiFe with the etch mask of the organic photo-resist and Ti by using $CHF_3/O_2/NH_3$ discharges exchanging CHF_3 for CH_4 gas gradually. We shows that the organic photo-resist mask can be applied the NiFe etching in that plasma conditions with the exception of requiring high aspect structures. It was found that the etching-selectivity Ti as mask against NiFe was significantly varied from 7.3 to ~0 by changing $CHF_3/CH_4/O_2/NH_3$ to $CH_4/O_2/NH_3$ discharges used in the ICP-RIE system. The present results show that the RIE of NiFe proceeded chemically.

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