Characterization of magnetic thin films etch process in N₂ plasmas
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Abstract: The etching of magnetic metal, NiFe, is investigated and compared with that of Ti using dual-frequency capacitively coupled plasma (2f-CCP) reactor in a N₂/Ar system. As the N₂ concentrations increased, the etch rate is gradually decreased. Maximum etch rate of 27.6 nm/min and 7.3 nm/min in pure Ar plasmas and minimum etch rate of 12.0 nm/min and 0.61 nm/min in pure N₂ plasmas were obtained for NiFe and Ti, respectively. Because of the formation of TiN layer on the Ti substrate and its low etch rate, the etch selectivity is increased from 3.7 in pure Ar plasmas and 19.7 in pure N₂ plasmas with the increase of N₂ concentration.

Keywords: Magnetic metal; NiFe; N₂ plasma; etching, two-frequency capacitively coupled plasma, hard mask; Ti

1. Introduction
At present magnetic metals involving multi-layer stacks such as MRAM are being made increasingly a larger capacity and high storage density. Conventional reactive ion etching (RIE) using halogen-based gas, however, can not be applied for the etching of magnetic metals because the vapor pressure of halogenated compound of magnetic metals, such as Ni and Fe, is usually too low to etch them. An ion milling such as Ar plasma has been used when the RIE technique is not applicable. However, there have several problems that machining precision and the etch selectivity are not run fully. This is the reason why a reactive ion etching (RIE) using non-halogen-based gas, such as CO/NH₃, has been studied for the micro-fabrication technique of magnetic metals [3-5]. Nakatani et al, reported that CO is expected to react with Ni or Fe, forming volatile metal carbonyls such as Ni(CO)₄ or Fe(CO)₅. But there are some problems such as the deterioration in magnetic characteristics and the disposal of corrosive gases of NH₃ [6].

Recently, several groups have reported the use of magnetic metal etch technique using noncorrosive etching gases such as CH₃OH and CH₄[6-7].

In this study, the etching of magnetic metal, NiFe, is studied and compared with that of hard mask, Ti, using dual-frequency capacitively coupled plasma (2f-CCP) reactor. The etch rate of NiFe and selectivity for NiFe over Ti were investigated as a function of N₂ gas concentration in N₂/Ar plasmas.

2. Experiment
The sample of Ti and NiFe sheets are prepared for 2 cm square. For measurement of etch rate and selectivity with respect to NiFe over Ti, samples are etched as a different N₂ gas concentration in N₂/Ar (0, 25, 50, 75, 100 %) at 2f-CCP reactor. A schematic representation of the experimental apparatus is shown in Fig. 1.

The plasma power is controlled by the 13.56 MHz RF generator which is connected to the top electrode with the input power of 100 W and the bias voltage is controlled by the 900 kHz power source which is connected to the bottom electrode with the input power of 100 W. The substrate is placed on the bottom electrode which is cooled by the cooling water of 20 °C.

So that an independent control of plasma density and ion energy could be achieved in the etching process. The etching is carried out for 20 min. The pressure is 16.7 Pa.
Total flow rate is 10 sccm. Etch rate and selectivity are calculated by the weight change of sample before and after etching.

Fig.1 Schematic diagram of 2f-CCP system for NiFe and Ti etching.

3. Result & Discussion

Figure 2 shows the etch rate of Ti and NiFe as a function of N₂ gas concentration in N₂/Ar discharges at 2f-CCP reactor. The etch rate is calculated using equation (1).

\[
V = \frac{(M_{\text{after}} - M_{\text{before}})}{S \rho t}
\]

Here, \( V \) is the etch rate of sample, \( M_{\text{after}} \) is the weight of sample after etching, \( M_{\text{before}} \) is the weight of sample before etching, \( S \) is the area of sample (2 cm x 2 cm), \( \rho \) is density of sample, and \( t \) is experimental time (20 min). As shown in Fig.2(a), (b), the etch rate of Ti and NiFe in pure N₂ plasmas is less than that of in pure Ar plasmas. The etch rate of NiFe and Ti gradually decreased as the N₂ concentration increased. Maximum etch rate of 27.6 nm/min and 7.3 nm/min in pure Ar plasmas and minimum etch rate of 12.0 nm/min and 0.61 nm/min in pure N₂ plasmas were obtained for NiFe and Ti, respectively.

We compare the etch rate of NiFe and Ti for different N₂ gas concentrations using etch selectivity. The etch selectivity is calculated by equation (2) with etch rate of
be reasonable to consider that the TiN is formed on the surface of Ti substrates although the peak of TiN overlaps with that of TiO.

The etch of TiN is more difficult than that of Ti because the binding energy of TiN is larger than that of Ti. However, the etch rate of NiFe is not significantly affected by the increase of N₂ gas fraction. Therefore, we could obtain high etch selectivity using N₂ plasmas.

\[ \delta = \frac{V_{NiFe}}{V_{Ti}} \]  

Here, \( \delta \) is etch selectivity, \( V_{NiFe} \) is the etch rate of NiFe, and \( V_{Ti} \) is the etch rate of Ti. Figure 3 shows the etch selectivity (NiFe/Ti) with a different N₂ gas concentration in N₂/Ar 2f-CCP reactor. As shown in Fig. 3, the etch selectivity is increasing as the N₂ concentration increased. The etch selectivity increased from 3.7 in pure Ar to 19.7 in pure N₂. So it is found that NiFe and Ti can be etched selectively using N₂ plasmas.

<table>
<thead>
<tr>
<th>Plasma Gas</th>
<th>Etch Rate of NiFe (nm/min)</th>
<th>Etch Selectivity (NiFe/Ti)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ar</td>
<td>5</td>
<td>3.7</td>
</tr>
<tr>
<td>0.25N₂</td>
<td>9</td>
<td>4.5</td>
</tr>
<tr>
<td>0.5N₂</td>
<td>15</td>
<td>9.5</td>
</tr>
<tr>
<td>0.75N₂</td>
<td>19</td>
<td>19.7</td>
</tr>
<tr>
<td>N₂</td>
<td>25</td>
<td>25.0</td>
</tr>
</tbody>
</table>

Fig. 3 The etching selectivity of NiFe and Ti as a function of N₂ gas concentration in N₂/Ar plasmas. Plasma power: 100W, bias power: 100W, pressure: 16.7 Pa, flow rate: 10 sccm, etching time: 20 min.

As shown in Fig. 4(b), we confirmed that the TiN was formed after the etching by N₂ plasma. Because of the reduction of peak ratio between Ti and TiO/TiN, it would

![Graph showing etch rate and selectivity](image)

![Graph showing XRD patterns](image)

Fig. 4 XRD pattern of Ti; (a) before etching using N₂ plasmas, (b) after etching using N₂ plasmas.
4. Conclusion

The etching of NiFe and Ti as a function of N$_2$ gas concentration in N$_2$/Ar plasmas at 2f-CCP reactor was studied. The etch rate in the range of 12.0 nm/min and 27.6 nm/min and 0.61 nm/min and 7.3 nm/min were obtained for NiFe and Ti respectively. The etch rate strongly depends on the type of gas. The etch rate using N2 plasmas is lower than that of using Ar plasmas. The etch selectivity is 3.7 and 19.7 using Ar and N2 plasmas respectively.

5. Acknowledgements

We thank Mr. Y. Suzuki and M. Tada of the Center for Advanced Material Analysis in Tokyo Tech. for assistance with the XRD analysis.

6. References