Effect of substrate temperature on the magnetic tunnel junction material etching using inductively coupled CH_3OH plasma

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It is very challenging to develop reactive ion etching of the magnetic tunnel junction (MTJ) in STT-MRAM due to the non-volatility of etching byproduct. Furthermore, the conventional reactive ion etching using chlorine based chemistry shows corrosion after MTJ etching. To avoid this corrosion, non-corrosive gases such as CO/ NH_3 and CH_3OH were introduced in MTJ etch recently.[1,2,3] However, the etching mechanism of magnetic films using these gases has not been clearly understood. In this study, we investigate the etching characteristics with non-corrosive CH_3OH gas, as a function of substrate temperature and bias power in ICP etching system. We also try to find the relationship between polymer removal rate and MTJ etch rate during MTJ etching. The characteristics of etching profile and surface were analyzed by transmission electron microscope (TEM), Fourier transform infrared spectroscopy (FT-IR) and X-ray photoelectron spectroscopy (XPS).

Fig.1 shows that etch rate of MTJ increases linearly as the bias power increases, which implies that the etch rate is a function of ion energy and it is also dependent on the substrate temperature. The etch rate would be independent on substrate temperature, if the etch mechanism is simple physical sputtering. However, etch rate increases as a function of temperature, as shown in Fig.1. Then we also checked etch rate using Ar gas with the same etching condition except CH_3OH gas. The etch rate using Ar sputtering (5.1Å/sec) is quite faster than that of CH_3OH plasma (1.5Å/sec) at 60℃, so it is hard to interpret that volatile metal carbonyl compound is formed on the etching surface during the MTJ etching using CH_3OH plasma. To analyze the etch rate quantitatively, we assume that part of measured MTJ etching time is spent on removal of simultaneously deposited polymer during MTJ etch. Carbon-hydrogen polymer was deposited on the bare Si wafer with the bias-power-off condition using CH_3OH plasma. Polymer deposition rate decreases as the substrate temperature increases. The surface analysis with XPS and FT-IR reveals that the bonding structure between carbon, hydrogen and oxygen in polymer is changed as the substrate temperature increases. (Fig.2) The deposition and etch rates increase as the substrate temperature decreases, which indicates that the polymer deposited in lower temperature is more dense than deposited in higher temperature (table.1). We calculated the actual MTJ etching time by subtracting the time taken to remove depositing polymer from the measured MTJ etching time. Due to the decrease of etching time by considering the polymer deposition and removal rate, calculated MTJ etch rate is faster than measured etch rate over the temperature range. (Fig.3) Calculated MTJ etch rate is not constant and still quite lower than that of Ar sputtering. It also increases with the same manner of measured etch rate as a function of temperature. According to these results, we conclude that the etch mechanism of MTJ is neither simple physical sputtering nor formation of volatile metal carbonyl compound. Rate limiting step that determines the etch rate would be chemical reactions on etching surface being affected by substrate temperature. For instance, atomic hydrogen in CH_3OH plasma could reduce metal oxide to pure metal which could be easily removed by sputtering. It is needed more detail investigation about each single magnetic materials composing MTJ stack.

References

1. I. Nakatani, *IEEE Trans. Magn.* **32** (1996) 4448
2. N. Matsui *et al.*, *Vacuum* **66** (2002) 479
3. T. Osada *et al.*, in *Proceedings of International Symposium on Dry Process 2004* (2004) 127

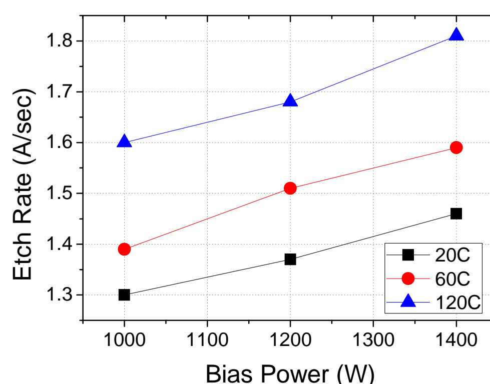

Fig.1 Etch rate of MTJ as functions of bias power and substrate temperature

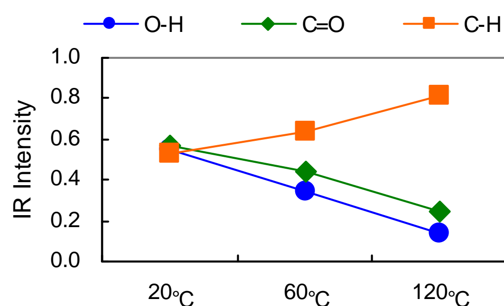

Fig.2 Dependence of FT-IR intensity on substrate temperature

Temp.	Dep. Rate (Å /sec)	Polymer E/R (Å /sec)
20℃	3.7	10.2
60℃	3.2	8.3
120℃	2.7	6.6

Table.1 polymer deposition rate and etch rate by substrate temperature

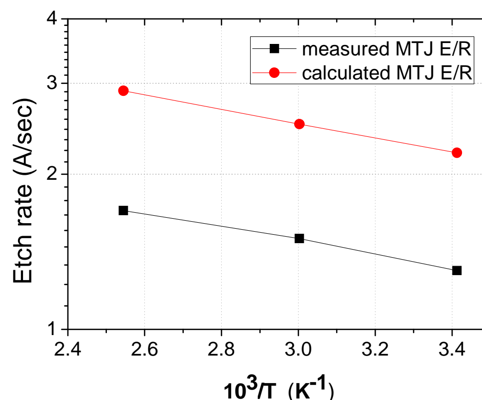

Fig.3 calculated etch rate as a function of substrate temperature

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