Characteristics of Ir etching using Ar/Cl_2 inductively coupled plasmas

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Platinum (Pt)-group metals have been used as electrode materials for various memory devices, including dynamic random access memory and ferroelectronic devices [1]. Among them, Pt has been considered a good candidate due to its good electrical conductivity ($\sigma = 0.96 \times 10^5$ ohm^{-1}cm^{-1} at 295 K), low leakage current characteristics, and its stability in the oxygen-containing ambient during BST or PZT deposition [2]. However, in its application to ferroelectric devices, Pt electrodes showed a fatigue phenomenon, characterized by a loss of switchable polarization following repeated cycles [3]. Accordingly, iridium (Ir) electrodes have recently been proposed as an alternative. Since the etching of Ir can be considered to be problematic, due to its chemical inertness; here, the plasma etching of Ir films, using Ar/Cl_2 gas in an inductively coupled plasma (ICP) etcher, is reported. The effects of the gas flow ratio on the Ir etch and photoresist (PR) etch rates, and the Ir-to-PR etch selectivity were investigated. The Ir-to-PR etch selectivity was defined as the ratio of the Ir-to-PR etch rates. In addition, the feasibility of Ir patterning has been demonstrated using a PR mask.

Thermally grown SiO_2 on Si (001) has been used as a starting material, onto which a layer of Ir was deposited by direct current type radio frequency magnetron sputtering. Either patterned or non-patterned (blanket) pieces of wafer have been used. The structure of the patterned sample comprised of a PR mask/Ir 2000 Å/SiO_2/Si substrates. The ICP system used in our experiments has previously been described in the literature [4]. During etching, the main power, substrate bias power, pressure and total gas flow rate were set at 800 W, 80 W, 5 mTorr and 50 standard cubic centimeters per minute (sccm), respectively. A Dektak surface profilometer was used to measure the etch rates and scanning electron microscope (SEM, Hitachi S-4200) to observe the etch profiles.

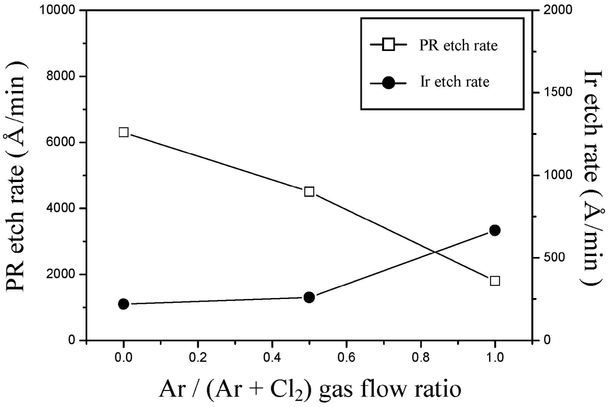

Figure 1 Variations in the Ir and PR etch rates with Ar/(Ar + Cl_2) gas flow ratios ranging from 0 to 1.

In order to investigate the etching characteristics of Ir using Ar/Cl_2 ICP, the Ar/(Ar + Cl_2) gas flow ratio was varied and Fig. 1 shows the variations in the Ir and PR etch rates with Ar/(Ar + Cl_2) gas flow ratios in the range of 0–1. The etch rates of Ir with the Ar/(Ar + Cl_2) gas flow ratios of 0, 0.5 and 1 were about 220, 260 and 670 Å/min, respectively, revealing that the Ir etch rate increases with Ar/(Ar + Cl_2) gas flow ratio. The PR etch rate with Ar/(Ar + Cl_2) gas flow ratios of 0, 0.5 and 1 were about 6300, 4500 and 1800 Å/min, respectively, revealing that the PR etch rate decreases with Ar/(Ar + Cl_2) gas flow ratio. As Ar is an inert gas and iridium chlorides, such as $IrCl_2$ and $IrCl_3$, have melting points higher than 700 °C [5], it was supposed that both the Ar and Cl_2 would contribute more toward the physical sputtering than to the chemical reaction. Therefore, the enhancement of the Ir etch rate by increasing the Ar gas portion may have been due to the more efficient sputtering caused by the Ar gas compared to that with the Cl gas. Accordingly, the Ir-to-PR etch selectivities were revealed to increase with Ar/(Ar + Cl_2) gas flow ratio (Fig. 2); and thus, etching experiments with

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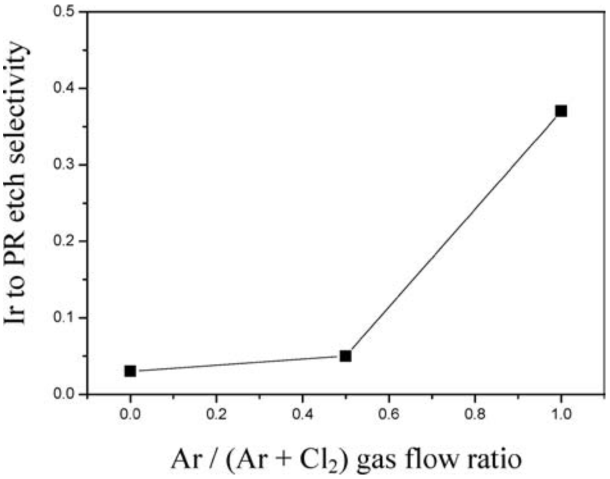

Figure 2 Variations in the Ir-to-PR etch selectivities with Ar/(Ar + Cl_2) gas flow ratios ranging from 0 to 1.

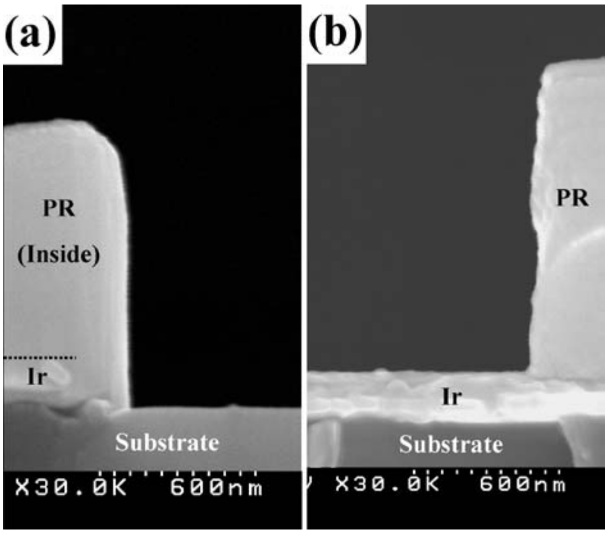

Figure 3 SEM cross-sectional images of the Ir pattern (**a**) after and (**b**) before the etching process with an Ar/(Ar + Cl_2) gas flow ratio of 1.

PR-masked patterns were performed under our process conditions with an Ar/(Ar + Cl_2) gas flow ratio of 1. Fig. 3a and b show the typical SEM cross-sectional images of the Ir electrode storage node pattern after and before the Ir etching process, respectively, indicating that an almost vertical etching slope can be obtained when an appropriate etching process is used. The Ir species were assumed to have been redeposited on the sidewall of both the Ir layer and PR; thus the PR-to-Ir boundaries, redeposition film and PR cannot be clearly observed in Fig. 3a. Since Ir is not supposed to produce the volatile products, especially in the Ar/Cl_2 system under a normal etching environment, the etching process in the present study was surmised to consist mainly of the physical sputtering effect, resulting in redeposition along the PR sidewalls and etched lines [6–8]. Further systematic study will be necessary to reveal the precise mechanism and nature of the redeposition material in Ir etching.

In summary, the etching characteristics of Ir films have been investigated with a PR mask using Ar/Cl_2 gas mixtures in an ICP system. The Ir and PR etch rates were found to increase and decrease, respectively, with Ar/(Ar + Cl_2) gas flow ratio. The Ir-to-PR etch selectivities were revealed to increase with Ar/(Ar + Cl_2) gas flow ratio. With an Ar/(Ar + Cl_2) gas flow ratio of 1, an almost vertical Ir etching profile was obtained with the PR mask.

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