Electronic Materials Letters, Vol. 5, No. 4 (2009), pp. 205-208
DOI: 10.3365/eml.2009.12.205

High Density Plasma Etching of Platinum Films in BCl_3/Ar and CF_4/Ar Inductively Coupled Plasmas

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The etch characteristics of platinum films and the etch selectivities for platinum over the mask materials in BCl_3/Ar and CF_4/Ar ICP discharges have been investigated to establish a process window for the thick platinum structure formation in MEMS devices. Maximum etch rates of ~1800 Å/minute and ~1200 Å/minute were obtained at a moderate ICP source power (750 W) and a relatively high rf chuck power (400 W) condition for CF_4/Ar and BCl_3/Ar ICP discharges, respectively. Maximum etch selectivities of ~2.6 for platinum over Al and of ~2.1 for platinum over ZnO were obtained. CF_4/Ar ICP etching with aluminum mask layer seems to be a very attractive tool for the fabrication of MEMS devices containing a thick platinum structure layer.

Keywords: high density plasma etching, platinum film, BCl_3/Ar and CF_4/Ar, inductively coupled plasmas, etch rate, etch selectivity

1. INTRODUCTION

The metal or metal alloy layer in microelectromechanical system (MEMS) devices is expected to meet requirements that are necessary for fabrication process compatibility and good device performance. For example, in the MEMS device fabrication process, the metal or metal alloy layer needs to survive the cleaning process and pretreatment of wafers in an oxygen rich environment before wafer bonding.[1,2] Thin metal films in the temperature sensors need to withstand temperatures up to 1000°C for heating and temperature sensing.[3]

Various materials including the noble metals (Au, Pt, Ir, and Pd) and the conductive metal oxides (RuO_2, IrO_2, etc.) have been considered as metallization materials in MEMS fields.[4-6] Platinum (Pt) is one of the most widely used materials in MEMS and microelectronic devices due to its low electrical resistance, and high chemical and temperature stabilities. A Pt layer with thickness in the range of 200-300 nm is generally patterned by conventional lift-off process, consisting of sequential steps of photolithography, metal deposition, and solvent lift-off. However, the platinum particles or wing tips (ears) may remain at the edges after lift-off and cause short circuits when an opposite electrode is placed within 1 μm. Some researchers have reported on modified lift-off techniques to overcome this problem, but these consist of more complicated process steps compared to conventional lift-off.[7-9]

Recently, platinum has often been used as a structural material for the actuating part in MEMS devices, such as cantilevers and bridges, taking advantage of its high resistance to plastic deformation at elevated temperatures while maintaining good conductive properties.[9,10] The typical thickness of the platinum layer as a structure material is expected to be ≥1 μm, which is much thicker than layers in its usual applications. In the fabrication process for MEMS devices containing a platinum structural layer, patterning the ~1 μm thick platinum layer with high accuracy has become one of the most critical technological issues.[8,9] The lift-off process is not suitable to forming a thick platinum structural layer due to the limitations in film thickness and patterning resolution. High density plasma etching combining the practical and controllable etch rate with a reasonable etch selectivity to mask material seems to be an attractive tool for patterning thick platinum structures. In this work, we report on a parametric study of high density plasma etching characteristics of platinum films in BCl_3/Ar and CF_4/Ar inductively coupled plasmas (ICP). The effects of plasma composition, ion flux

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and ion energy on the platinum etch rate and, especially, on the etch selectivities for platinum over the mask materials were examined.

2. EXPERIMENTAL

Platinum films with thicknesses of ~3000 Å were deposited on Φ4" Si substrates by an e-beam evaporation process at the process pressure of 1×10^{-5} Torr; an ~100 Å Ti layer was used as an adhesion promoter. Platinum films were patterned with various mask materials, including photoresist, SnO_2, ZnO and aluminum. High density plasma etching was performed in a planar inductively coupled plasma source operating at 13.56 MHz and power up to 1000 W, and the samples were thermally bonded to an Si carrier wafer that was mechanically clamped to an He backside-cooled, rf-powered (13.56 MHz, up to 450W) chuck. BCl_3/Ar and CF_4/Ar inductively coupled plasmas were employed to etch platinum films; process pressure was varied from 2-20 mTorr, with a gas load of 15-35 standard cubic centimeters per minute (sccm). After removal of the mask material, etch rate, etch selectivity and surface morphology were characterized by stylus profilometry measurements, field-emission scanning electron microscopy (FE-SEM) and atomic force microscopy (AFM).

3. RESULTS AND DISCUSSION

Figure 1 shows the plasma composition dependence of the platinum etch rate for BCl_3/Ar and CF_4/Ar inductively coupled plasma discharges at fixed source power (750 W), rf chuck power (250 W) and process pressure (2 mTorr). CF_4/Ar inductively coupled plasma discharges produce much higher platinum etch rates than those with BCl_3/Ar under the same conditions. This result could be readily understood by taking account of the volatility of potential etch products between platinum and the two plasma chemistries. Platinum fluoride etch products (presumably PtF_6: boiling point 69.1°C) are more volatile than platinum chloride etch products (presumably $PtCl_2$: melting point 581°C, $PtCl_4$: melting point 370°C), which leads to the higher platinum etch rates with CF_4/Ar discharges. For CF_4/Ar discharges, platinum etch rate increases as the volume ratio of CF_4 in the gas load increases, indicating the presence of the chemical component of the etching. In sharp contrast, the platinum etch rate stays almost constant regardless of the variation in the plasma composition. It is suggested that the etching of platinum in BCl_3/Ar discharges is inhibited by nonvolatile $PtCl_x$ compounds accumulated on the surface. In other words, the platinum etch rate is limited by the physical desorption of $PtCl_x$ etch products from the surface. Maximum etch rates of ~1500 Å/minute and ~730 Å/minute were obtained with BCl_3/Ar and CF_4/Ar ICP discharges, respectively.

Figure 2 presents the platinum etch rate as a function of the ICP source power with 250 W rf chuck power, 2 mTorr BCl_3/Ar and CF_4/Ar plasmas. For CF_4/Ar chemistries, platinum etch rate initially increases as the source power increases due to the increased ion flux and the atomic fluorine density, but then decreases beyond 750 W. At source powers higher than 750 W, though the ion flux keeps increasing, the average ion energy in the plasma falls below that needed to efficiently remove the platinum fluoride etch products from the surface. A similar behavior is observed for BCl_3/Ar ICP discharges and, again, BCl_3/Ar discharges produce much lower etch rates than CF_4/Ar mixtures.

The effect of rf chuck power on the platinum etch rate in 750 W ICP source power, 2 mTorr BCl_3/Ar and CF_4/Ar plasmas is shown in Figure 3. For both chemistries, the platinum etch rate shows a strong dependence on the rf chuck power, indicating the presence of the physical component of the etching. The platinum etch rate monotonically increases as

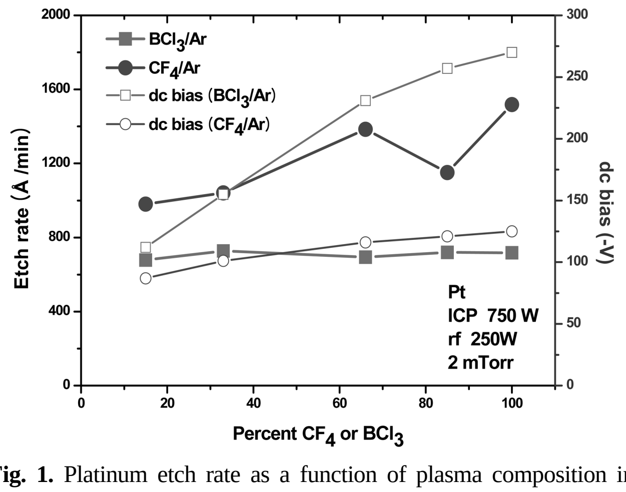

Fig. 1. Platinum etch rate as a function of plasma composition in BCl_3/Ar and CF_4/Ar ICP discharges (750 W source power, 250 W rf chuck power, 2 mTorr).

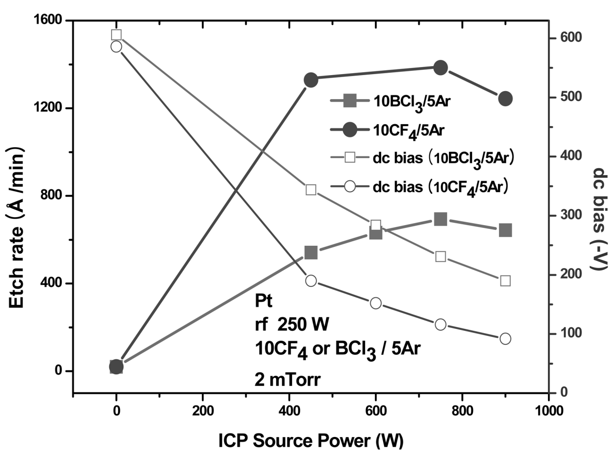

Fig. 2. Platinum etch rate as a function of source power in $10BCl_3/5Ar$ and $10CF_4/5Ar$ ICP discharges (250 W rf chuck, 2 mTorr).

the rf chuck power increases due to the enhanced ion-assisted desorption of the platinum chloride and fluoride etch products. Maximum etch rates of ~1800 Å/minute and ~1200 Å/minute were obtained at a moderate ICP source power (750 W) and a relatively high rf chuck power (400 W) condition for CF_4/Ar and BCl_3/Ar ICP discharges, respectively.

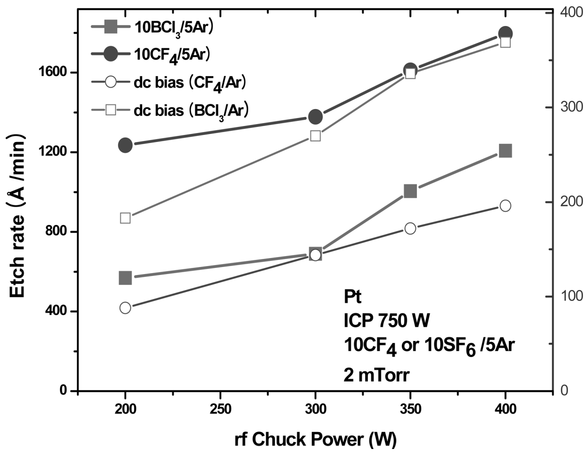

Fig. 3. Platinum etch rate as a function of rf chuck power in $10BCl_3$/5Ar and $10CF_4$/5Ar ICP discharges (750 W source power, 2 mTorr).

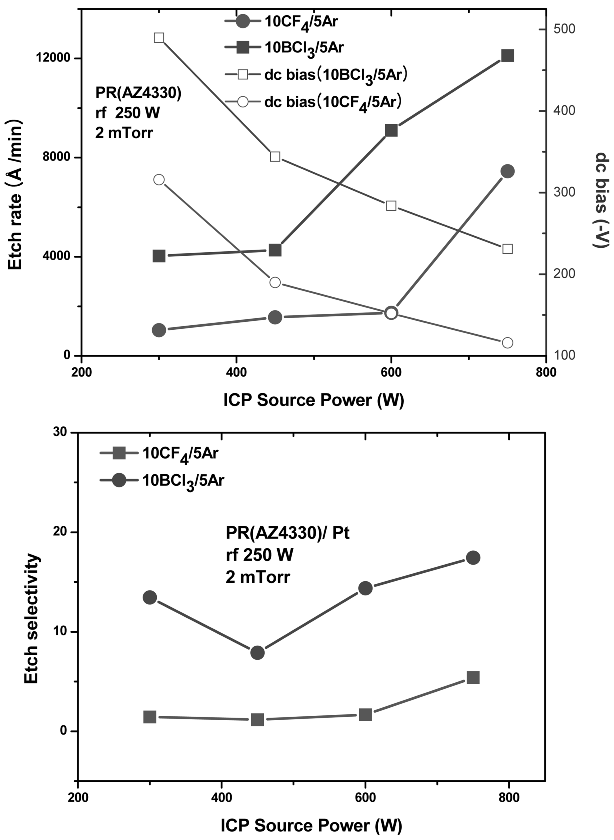

Fig. 4. PR (AZ4330) etch rate as a function of ICP source power (top) and etch selectivity for PR over platinum (bottom) in $10BCl_3$/5Ar and $10CF_4$/5Ar ICP discharges (250 W rf chuck power, 2 mTorr).

To pattern a thick platinum structure layer, it is critical to find a suitable mask material that can provide a reasonable etch selectivity to the platinum film. First, AZ4330, one of the most commonly used photoresists (PRs), was chosen to evaluate the etch selectivity for platinum. Figure 4 shows the PR etch rate as a function of ICP source power (top) and the resultant etch selectivity for PR over platinum (bottom) at fixed plasma composition ($10BCl_3$/5Ar or $10CF_4$/5Ar), rf chuck power (250 W) and pressure (2 mTorr). Both BCl_3/Ar and CF_4/Ar ICP plasmas produce much higher etch rates for PR compared to platinum, as shown in Fig. 2. Etch selectivities for PR over platinum in the range of 7.9-17 for BCl_3/Ar and 1.2-5.4 for CF_4/Ar ICP plasmas were obtained, and this shows that AZ4330 is not a suitable mask material for the thick platinum structure formation.

Second, aluminum (Al), tin oxide (SnO_2) and zinc oxide (ZnO), which are expected to form relatively nonvolatile etch products with fluorine-based mixtures, have been evaluated as to their potential as mask materials for thick platinum structure formation. The material etch rates in $10CF_4$/5Ar ICP discharges (top) at 450 W source power and 2 mTorr pressure condition and the resultant etch selectivities for platinum over the mask materials (bottom) are shown in Fig. 5. Aluminum and ZnO showed much lower etch rates

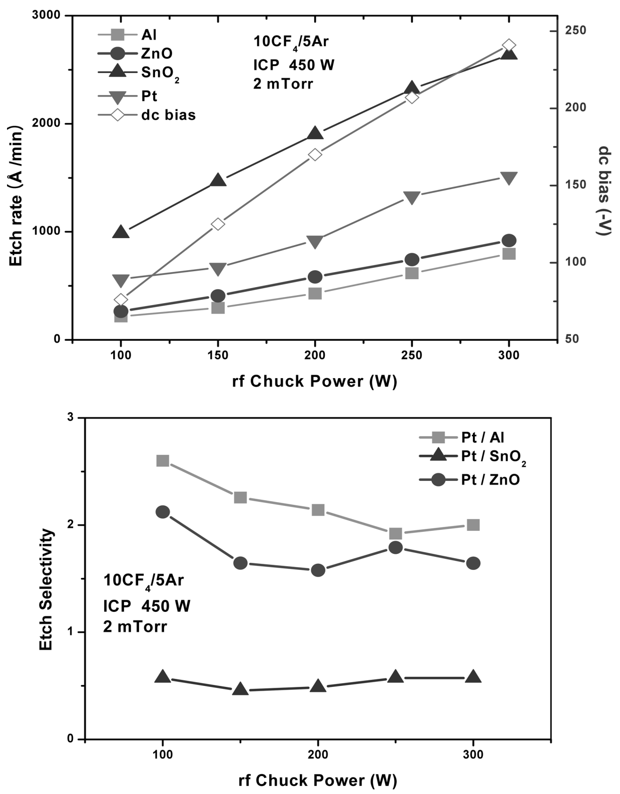

Fig. 5. Etch rates of platinum, Al, ZnO and SnO_2 (top) and etch selectivities for platinum over aluminum, ZnO and SnO_2 (bottom) as a function of rf chuck power in $10CF_4$/5Ar ICP discharges (450 W source power, 2 mTorr).

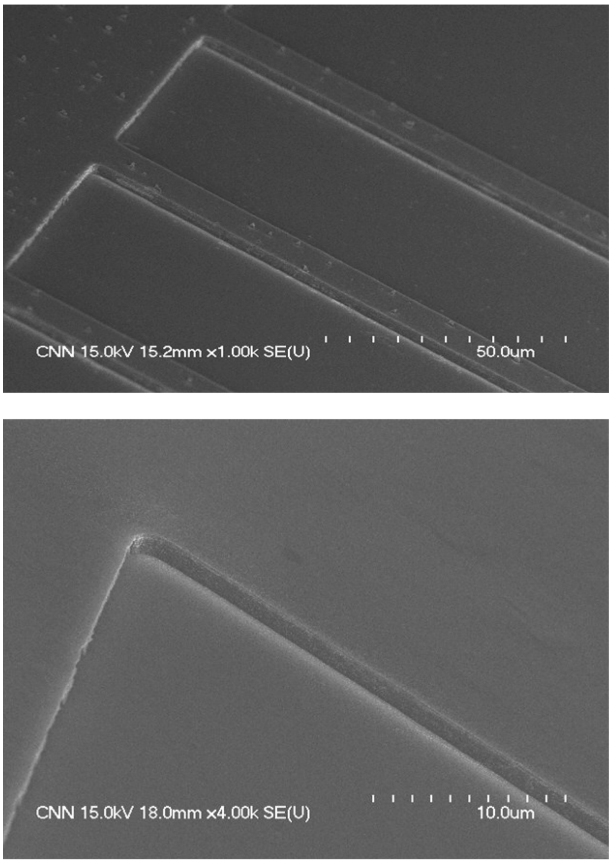

Fig. 6. SEM micrographs of features etched into Pt/Ti using $10CF_4$/5Ar ICP discharges (450 W source power, 250 W rf chuck power, 2 mTorr).

than platinum under most of the conditions examined, which result is ascribed to the formation of nonvolatile metal fluoride etch products (compare boiling points of potential etch products; AlF_3: melting point 1291°C, ZnF_2: 1500°C, SnF_4: sublimes 705°C, SnF_2: 853°C). Maximum etch selectivities of ~2.6 and ~2.1 were obtained for platinum over Al and platinum over ZnO, respectively. From this result, Al and ZnO are thought to be promising mask materials for the platinum structure formation.

Figure 6 shows SEM micrographs of features etched into Pt/Ti films deposited on Si using $10CF_4$/5Ar ICP discharges with 450 W source power, 250 W rf chuck power, and 2 mTorr pressure. An ~2500 Å thick Al film was used as the mask layer and the etched depth is ~9500 Å. Please note that the Al mask layer is still in place. The etched surface shows a smooth morphology and a vertical sidewall profile is obtained.

4. SUMMARY AND CONCLUSIONS

In order to find a process window that allows thick platinum structure formation in microelectromechanical system devices, the etch characteristics of platinum films and the etch selectivities for platinum over the mask materials in BCl_3/Ar and CF_4/Ar inductively coupled plasmas have been studied. Both chemistries were found to be capable of producing practical and controllable etch rates for platinum. CF_4/Ar ICP discharges produced higher platinum etch rates than BCl_3/Ar due to the high volatility of the platinum fluoride etch products compared to those of the platinum chloride compounds. Maximum etch rates of ~1800 Å/minute and ~1200 Å/minute were obtained at a moderate ICP source power (750 W) and a relatively high rf chuck power (400 W) condition for CF_4/Ar and BCl_3/Ar ICP discharges, respectively. The potential of aluminum, ZnO and SnO_2 as mask materials for thick platinum structure formation has been evaluated. Aluminum and ZnO were found to show reasonable etch selectivities of ~2.1-2.6 to platinum. High density plasma etching combining CF_4/Ar ICP discharges and aluminum mask layer seems to be a very attractive tool for the fabrication of microelectromechanical system devices containing a thick platinum structure layer.

ACKNOWLEDGMENTS

This research was supported by a grant (code #: 2009K000476) from ‘Center for Nanostructured Materials Technology’ under ‘21st Century Frontier R&D Programs’ of the Ministry of Education, Science and Technology, Korea.

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