Journal of Korean Institute of surface Engineering
Vol. 29, No. 6, Dec., 1996

ICP ETCHING OF TUNGSTEN FOR X-RAY MASKS

C. Jeong, K. Song*, C. Park*, Y. Jeon*, D. Lee*, and J. Ahn

Department of Materials Engineering, Hanyang University, Seoul 133-791, Korea
**LG Electronics Research Center, Seoul 137-140, Korea*

ABSTRACT

In this article the effects of process parameters of inductively coupled plasma etching with SF_6/N_2/Ar mixture gas and mask materials on the etched profile of W were investigated. While the etched profile was improved by N_2-addition, low working presure, and reduced SF_6 flow rate, the etching selectity (W against SAL resist) was decreased. Due to the difficulty of W etching with single layer resist, sputter deposited Al_2O_3 film was used as a hardmask. Reduction of required EB resist thickness through Al_2O_3 mask application could reduce proximity effect during e-beam patterning, but the etch anisotropy was degraded by decreased sidewall passiviation effect.

INTRODUCTION

As the device dimension scales down, optical lithography is reaching its resolution liimit, which is mostly determined by the wavelength and depth of focus of the light source used for exposure. X-ray lithography using synch-rotron radiation(SR) is one of the most promising technologies for replication ultralarge-scale integration(ULSI) patterns with less than 0.20㎛ feature size. Precise x-ray mask fabrication is a key techology to apply SR lithography for practical ULSI manufactruing.[1-3]. For producing defect-free x-ray masks, simple process for x-ray absorber pattern fabrication is required. W is one of the most appropriate material due to its strong x-ray attenuation property, thermal stability, and close thermal expansion coefficient with common x-ray membrane materials.

Because x-ray proximity printing requires 1X mask technology, smaller minimum feature size as well as tighter critical dimension (CD) control of high aspect-ratio metal patterns are required compared to that on the equivalent optical mask. To achieve highly anisotropic etching of submicrometer features into tungsten(W), Inductively Copuled Plasma(ICP) etching technology was used,[4-8] where a high density largediameter plasma discharge is generated by applying rf power into an inductive coil capable of transforming power into a low pressure gas. In this papoer, we report the results on anisotropic etching of submicrometer features into W by changing plasma chemistry and etching mask.

EXPERIMENTAL PROCEDURE

W film was deposited on Si using dc sputtering system to a thicknes of 0.45~0.5㎛.

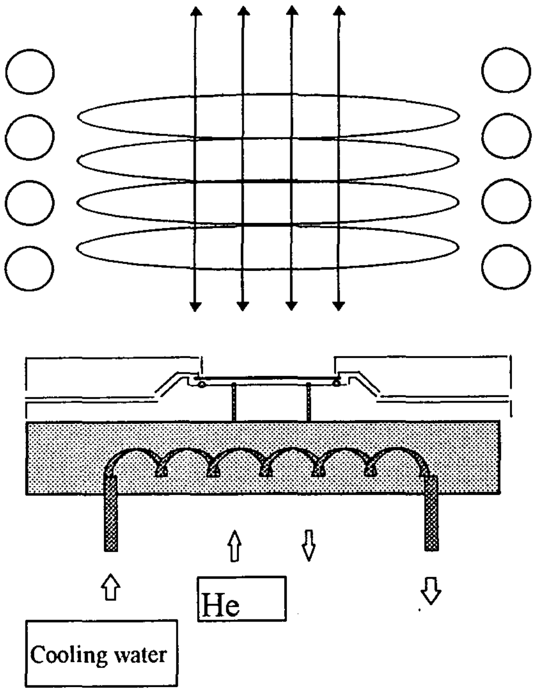


Fig 1. Schematic drawing of ICP etching chamber

The working gas was Ar, and the pressure was selected to be 3.5m Torr at which the resideual stress of the W film was near minimum.[9]

The Al_2O_3 film as a hardmask was deposited using an rf sputtering system if needed. The working gas was Ar at pressure of 5 mTorr where the uniformity and adhesion with W film could be obtained. SAL negative EB resist was spin coated on W layer to a thickness of 0.4㎛. The EB exposure was performed at 30 kV with a dose of 6μC/㎠.

The dry etching apparatus used in our expriments was an inductively coupled plasma (ICP) etcher. The ICP etcher consists of a dielectric chamber vessel, an inductive rf coil, a standard rf power supply, and automatic impedance matching network. ICP sources is located in a cylindrical coil configuration. In this configuration, a dielectric vessel is encircled by an inductive coil into which the rf energy is introduced. This induces a strong magnetic field in the center of the chamber. This magnetic field generates a high density plasma in the chamber due to a circular region of H-field that exists concentric to the coil and circulating around the magnetic field lines(Fig 1) The inductive source is mounted on a standard RIE system. The rf frequency powering the coil is adjustable between 1.7 and 2.1 MHz. This frequency is kept low to reduce the RF impedance of the coil allowing a large current flow, but above the average ion transit frequencies to avoid dircet acceleration of the ions by the RF energy.[7-8] The lower electrode is powered with 13.56MHz frequency to allow an independent control of the substrate dc bias voltage which cannot be independelty controlled in coventional RIE system. The substrate is cooled to 10℃ and helium gas at 8~10m Torr is supplied to the gap between the sample and the stage to reduce thermal resistance. Optical emission spectroscopy(OES)

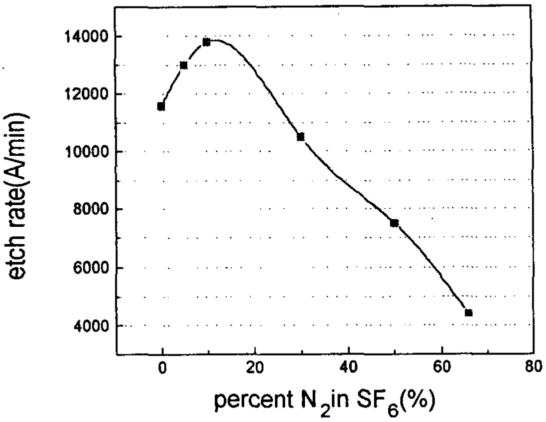


Fig 2. Vertical etch rate of W as a function of the N_2 gas mixture ratio with SF_6(rf bias 100 W, pressure 10 mTorr)

Fig 3. SEM photograph of etched W profile(0.5μm with SAL resist mask at high SF_6, 10m Tprr. rfbisas 100W)

was carried out at the top of the quartz tube through a fiber.[8-10]

The etch rate and profile was observed using the scanning electron microscope(SEM).

RESULT AND DISCUSSION

W etching was performed by fluorine-containing gas mixture ($SF_6/N_2/Ar$) under ICP fixed ICP power(700W), N_2 flow (3 sccm), and Ar flow (2 sccm) due to high vapor pressure of W-fluoride. Increased ionization and excitation rate by addition of inert gas (Ar) is helpful to stabilize and homogenize plasma. Figure 2 shows the etch rate of W as a function of SF_6/N_2 flow ration. It is quite interesting to note that N_2 addition leads to an increase in the etching rate which shows a maximum at 5~10% N_2. Anisotropy of etched W profile was reported to be improved by polymer formation at the side wall[11-17] or by increased vertical etch rate with the formation of active W sites through ion bombardment.[4] In the $SF_6/N_2/Ar$ plasma, the added N_2 is speculated to enhance the cathodic dc bias and atomic fluorine density, and is consumed in the sidewall passivation process by forming WN_x and NS[15]. However, further addition of N_2 is supposed to decrease the available atomic fluorine density, resulting in a lower etching rate. With this plasma chemistry, the effect of masking layer(SAL or Al_2O_3) on the W-etching characteristics has been studied.

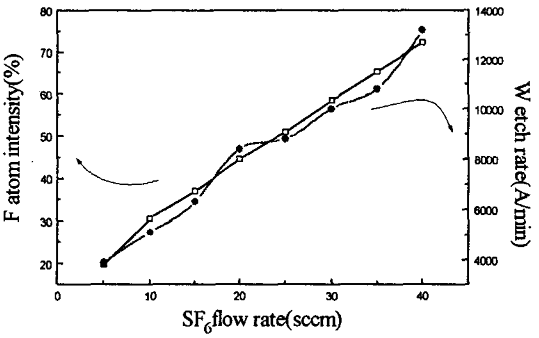


Fig. 4. Vertical etch rate of W and F atom relative intensity measured by OES as a function of SF_6 flow rate

W etching with SAL resist mask

PMMA(polymethylmethacrylatea) and SAL are widely used as positive and negative EB resist, respectively. The selectivities of W against PMMA and SAL resist are 0.75 and 1.2, respectively, at SF_6 flow rate 35 sccm and working pressure of 10m Torr. Since SAL shows relatively high thermal and dry etch resistance, SAL/W/Si layer was used in patterning W. Relatively good etch rate, selectivity, and etch profile was achieved for 1 μm or larger patterns with SAL mask patterns at SF_6 35 sccm, working pressure 10m Torr. Since SAL shows relatively high thermal and dry etch resistance, SAL/W/Si layer was used in patterning W. Relatively good etch rate, selectivity, and etch profile was

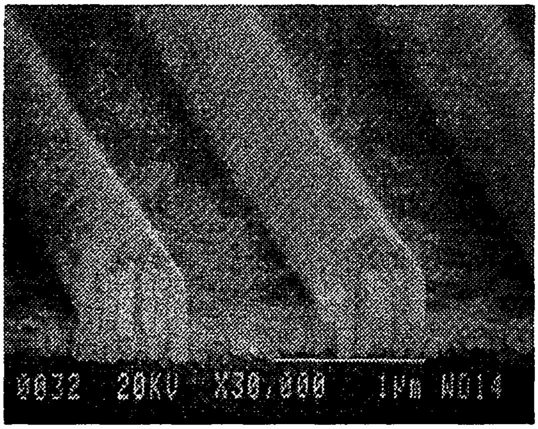


Fig 5. SEM photograph of etched W profile((0.5μm pattern with SAL resist mask at low SF_6 flow rate(20 sccm SF_6, 5m Torr rfbias 100W))

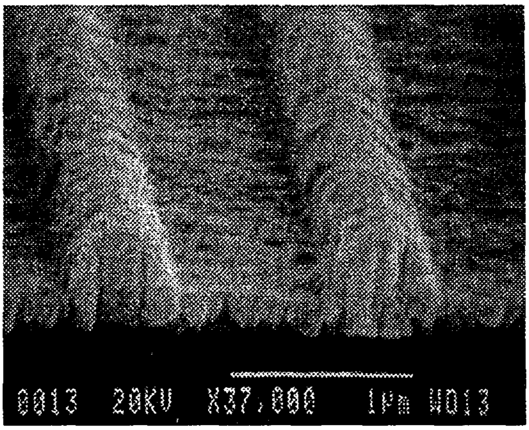


Fig 6. SEM photograph of etched profile((0.5μm pattern with SAL resist mask at high rfbias (20 sccm SF_6, 5mTorr, rf bias 200W))

achieved for 1μm or larger patterns with SAL mask patterns at SF_6 35 sccm, working pressure 10m Torr etching condition. However, as the pattern size was reduced to 0.5μm, undercut was discovered, as can be seen in Fig 3. The relative F atom intensity measured by Optical Emission Spectroscopy(OES) and the W etch rate increased with increasing SF_6 flow rate, as shown in Fig 4. This result confirms that F atom readly etch W. Fig 5 shows the SEM photograph of 0.5μm W patterns etched under the conditions where SF_6 flow rate and working pressure are 20 sccm and 5m Torr, respectively. Compared to etched profile at higher SF_6 flow rate and pressure, undercut was reduced and anisotropic profile could be achieved. Reducing F atom concentration seems to be effective for improving etched profile. However, selectivity of W aganist SAL resist decreased by reducing pressure and SF_6 flow rate. The selectivity of W against SAL was reduced from 1.2 (35 sccm SF_6, 10m Torr) to 1.05(20 sccm SF_6, 5m Torr). To obtain W patterns at anisotropic etching condition with SAL single layer masking layer, a thick resist layer is needed.

Since thick resist required for thick W patterning limits resoulution and exposure latitude at electron beam lithography, a hard-mask, having a sufficient selectivity against tungsten, was needed.[18,19]

Another approach for anisotripic etching is to increase the ratio of the ion assisted reaction to the readical assisted reaction.[8] It was anticipated that undercut could be reduced by increasing rf bias power which increases cathodic DC bias. Anisotropic profile could be achieved by increasing rf bias to w00W, but whole SAL mask layer was etched away before W etching was compledted(Fig 6). While no significant increase of W etch rate was observed as shown in Fig 7, the resist etch rate was increased significantly with increasing applied rf bias. It is due to the fact that the etching of resist is strongly ion enhanced compared to the W etching.[20] So selectivity over SAL EB resist was decreased

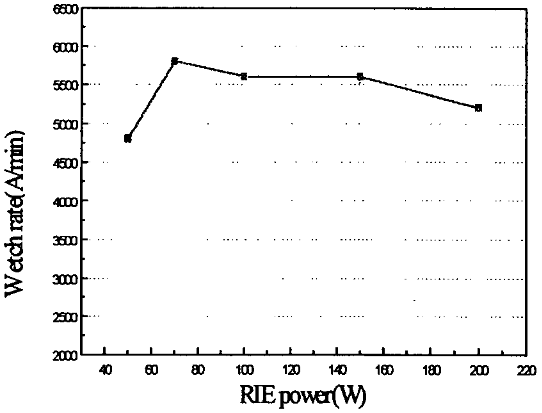


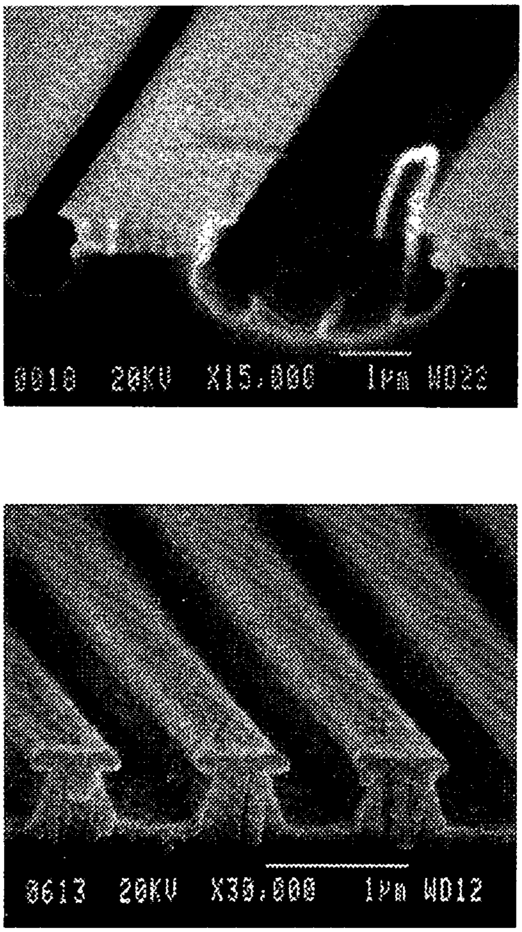
Fig 7. Vertical etch rate of W as a function of rf bias(5m Torr, SF_6 20sccm)

significantly at 200W rf bias, and increasing rf bias is not a practical way to improve etch profile.

W etching with Al_2O_3 hardmask

In this experiment, sputter deposited Al_2O_3 was selected as a hardmask.[13,21] As shown in Table 1, Al_2O_3 has good selectivity agsinst W since the selectivity was 65.7 at 5m Torr and SF_6 flow rate of 20 sccm, the required thickness of the Al_2O_3 layer was only 0.01㎛.

Cl_2, BCl_3, Cl_2/BCl_3 chemistry was used to etch Al_2O_3 hardmask. While etched pattern was covered with etch product when using Cl_2 gas, relatively clean etch profile was obtained with BCl_3. There was no significant advantage for etch rate and selectivity by using Cl_2/BCl_3 over BCl_3 gas as shown at Table 1. BCl_3 is known to scavenge water vapor and successfully assist the removal of native oxide, thus promoting Al etching. To promote removal of etch products, BCl_3/Ar chemistry was used with a SAL resist mask. Because the required Al_2O_3 thickness as a W etching mask was thin, the SAL resist thickness as Al_2O_3 etching mask needs not to be thick as using SAL resist as W etching mask. Thin SAL resist could improve e-beam writing process by reducing proximity effect.[20,21]



(b)

Fig 8. SEM photograph of etched W profile with Al_2O_3 hard mask at
(a) high SF_6 flow(35 sccm, 10m Torr)
(b) low SF_6 flow(20 sccm, 5m Torr)

As shown in Fig 8(a), undercut problem is very serious with Al_2O_3 hardmask at the etching condition SF_6 flow rate of 34 sccm and working pressure of 10m Torr. This is due to the fact that SAL resist fragments which is sputtered by ion bombardment can form a sidewall passivation film, but Al_2O_3 hardmask which is little etched can not form a passivation film.[22, 23] By reducing SF_6 flow ratio to 20 sccm and working pressure to 5m Torr etching condition, undercut problem was significantly reduced(Fig 8(b)). Microloading effect which results in the decrease of etch rate almost linearly with the increase of aspect ratio is also expected to be improved by reducing pressure. This suppression of the microloading effect is due to the fact that the number of incident ions impacting the surface to be etched increases with decreasing pressue. But considerable slope on vertical profile is still observed. It is speculated that further reduction of SF_6 flow rate(F atom intensity) or addition of other gas forming a passivation film may improve anisotropic profile using Al_2O_3 hardmask.

CONCLUSION

W film was anisotropically dry-etched using a SF_6, Ar and N_2 gas mixture. We have clearly demonstrated that the etch rate of W is linearly correlated to the fluorine atom concentation, suggesting that its etching is predominantly due to chemical process. At low operating pressure and low SF_6 flow rate, anisotropic profile could be achieved. In order to compensate low dry etching selectivity of W against the EB resist, Al_2O_3 was introduced as a hardmask. While significantly high etching selectivity of Al_2O_3 against W (65.7) was achieved, tapered profile was obtained due to the lack of sidewall passivation film.

REFERENCES

1. S. Tsuboi, Y. Yamashita, T. Matsuo, T. Ohta, T. Shoki, T. Yoshihara, T. Taguchi, S. Mitsui, S. Noda, K. Suzuki, H. Hoga, Y. Yamaguchi and K. Suzuki, Jpn. J. Appl. Phys. 35, 2845 (1996)
2. S. Ohki and H. Yoshihara, Jpn. J. Appl. Phys. 29, 2600 (1990)
3. K. Suzuki, SPIE 773, 23 (1987)
4. Y. Hikosaka, M. Nakamura and H. Sugai, Jpn. J. Appl. Phys. 33, 215 (1994)
5. M. Tuszewski, J. T. Scheuer and J. A. Tobin, J. Vac. Sci. Technol. A 13, 839 (1995)
6. T. Shirakawa, H. Toyoda and H. Sugai, Jpn. J. Appl. Phys. 29, L1015(1990)
7. S. M. Rossnagel, J. J. Cuomo and W. D. Westwood, Handbook of Plasma Processing Technology, Noyes Publications, (1990) pp. 14~66.
8. D. M. Manos and D. L. Flam, Plasma Etching an introduction, Academic Press, INC. (1989) pp. 186~258
9. M. S. Aouadi, R. R. Parsons, P. C. Wong and K. A. R. Mitchell, J. Vac. Sci. Technol. A 10, 273 (1992)
10. H. E. Litvak, J. Vac. Sci. Technol. B 14, 516 (1996)
11. D. W. Hess, Solid State Technology, April, 97 (1988)
12. T. Fujino, K. Sasaki, K. Marumoto, H. Yabe, N. Yoshioka and Y. Watakabe, Jpn. J. Appl. Phys. 31, 4086 (1992)
13. S. Sugihara, M. Itoh and Y. Gomei, Jpn. J. Appl. Phys. 31, 4200 (1992)
14. S. K. Kwon, K. N. Kim, C. W. Nam and S. I. Woo, J. Vac. Sci. Technol. B 13, 914 (1995)

15. N. Mutsukura and G. Turban, J. Electrochem. Soc. 137, 225 (1990)
16. R. Rossen, Michroelectronics Manufacturing Technology 18, 17 (1991)
17. D. S. Fischl and D. W. Hess, J. Electrochem. Soc. 134, 2265 (1987)
18. K. D. Cummings, D. J. Resnick, J. Frackoviak, R. R. Kola, L. E. Trimble, B. Grant, S. Silverman, L. Hass and B. Jennings, J. Vac. Sci. Technol B. 11, 2872 (1993)
19. M. A. McCord, A. Wagner and T. Donohue, J. Vac. Sci. Technol. B 11, 2958 (1993)
20. F. Bounasri, M. Moisan, L. St-Onge, J. Margot, M. Chaker, J. Pelletier, M. A. El Khanani and E. Gat, Jpn. J. Appl. Phys. 77, 4030 (1995)
21. T. Ohta, T. Kanayama, H. Tanoue and M. Komuro, J. Vac. Sci. Technol. B 7, 89 (1989)
22. S. Adachi and N. Suda, J. Electrochem. Soc. 132, 2980 (1985)
23. T. Sato, N. Fujiwa and M. Yoneda, Jpn. J. Appl. Phys. 34, 2142 (1995)