Effects of CH_2F_2 and H_2 flow rates on process window for infinite etch selectivity of silicon nitride to PVD a-C in dual-frequency capacitively coupled plasmas

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Abstract : For the fabrication of a multilevel resist (MLR) based on a very thin amorphous carbon (a-C) layer and Si_3N_4 hard-mask layer, the selective etching of the Si_3N_4 layer using physical-vapor-deposited (PVD) a-C mask was investigated in a dual-frequency superimposed capacitively coupled plasma etcher by varying the following process parameters in $CH_2F_2/H_2/Ar$ plasmas : HF/LF power ratio (P_{HF}/P_{LF}), and CH_2F_2 and H_2 flow rates. It was found that infinitely high etch selectivities of the Si_3N_4 layers to the PVD a-C on both the blanket and patterned wafers could be obtained for certain gas flow conditions. The H_2 and CH_2F_2 flow ratio was found to play a critical role in determining the process window for infinite Si_3N_4/PVDa-C etch selectivity, due to the change in the degree of polymerization. Etching of ArF PR/BARC/SiO_x/PVDa-C/Si_3N_4 MLR structure supported the possibility of using a very thin PVD a-C layer as an etch-mask layer for the Si_3N_4 layer.

1. Introduction

With the continuously increasing degree of device integration or the fabrication of Si semiconductor devices, horter wavelengths such as 193 nm ArF excimer laser or 3.4 nm extreme ultraviolet (EUV) light have become necessary to increase the resolution of the photolithographic process. However, the photoresist (PR) needs to become thinner due to the lower depth of focus at shorter wavelengths, which, in turn, limits the process capability of a dry etcher[3]. Therefore, nanoscale plasma etching requires new schemes, such as multilevel resist (MLR), in the etching mask structure, due to the difficulty in patterning the layer directly with ArF or EUV PR below 50-nm technology node [1]. A patterned PVD a-C mask layer is used as an etch mask to etch the underlayer or another hard-mask layer. The PVD a-C has extremely high hardness, high melting temperature, good wear resistance, outstanding chemical inertness, and good corrosion resistance [1-3]. These properties enable the use of PVD a-C films as an etch mask for nanoscale plasma etch applications. In this study, we therefore investigated the fabrication of a MLR structure of ArF PR/bottom antireflective coating (BARC)/SiO_x/PVD a-C/Si_3N_4. We studied the etching process of Si_3N_4 by varying the following process parameters in $CH_2F_2/H_2/Ar$ dual-frequency superimposed capacitively coupled plasma (DFS-CCP) [4] : HF/LF power ratio (P_{HF}/P_{LF}), and CH_2F_2 and H_2 flow rates.

2. Experimental

An 8-inch, DFS-CCP dielectric etcher was used for the etching experiments. A high-frequency (HF) power source controls plasma generation, i.e., the fluxes and species of the ions and radicals, while a low-frequency (LF) power source controls the dynamics of ions in the sheath where the degree of ion acceleration, i.e., ion energy, is controlled [9,10]. The DFS-CCP etch system used in the present experiment has been schematically described elsewhere. The system is equipped with three different PHF sources (13.56, 27.12, and 60 MHz) and an LF power (P_{LF}) source (2 MHz). The chamber is evacuated by a turbomolecular pump with a pumping speed of 1500 ℓ/s and is backed by a combined booster and rotary pumping system. The pressure during the etching process was controlled automatically by adjusting a throttle valve. To apply PVD a-C as an etch mask for Si_3N_4 etching, wafers with line and space patterns of ArF PR(150 nm) were prepared on the stack of BARC(30 nm)/SiOx(50 nm)/PVD a-C(80 nm)/Si3N4(300 nm)/Si(001) by photolithographic patterning using an ArF scanner.

3. Results and discussion

Fig. 1 shows the etch rate and selectivity of the Si_3N_4 layers to PVD a-C as a function of the Si_3N_4 etched by varying the $CH_2F_2/(CH_2F_2+H_2)$ flow ratio from 10 to 40% at a fixed Ar flow rate of 500 sccm and a total flow rate of 100 sccm for 60 s and PHF/PLF of 400 W/300 W and fHF/ fLF of 27.12 MHz/2MHz. The etch rate of Si_3N_4 was increased with increasing the flow rates of CH_2F_2 in $CH_2F_2/H_2/Ar$ chemistry. And infinitely high etch selectivities were obtained in this experiment when the $CH_2F_2/(CH_2F_2+H_2)$ flow ratio from 20 to 40% because the hydrofluorocarbon layer was deposited on the top of the PVD a-C surface, while the silicon nitride layers were continuously being etched.

Fig. 2 show the Si_3N_4/PVD a-C etch selectivity and etch rates of the layers etched by varying the P_{HF}/P_{LF}. the silicon nitride etch rate increases significantly with increasing P_{LF}, but Si_3N_4/PVD a-C etch selectivity was decreased. Increasing P_{LF} leads to an increase in the etch rate of the silicon nitride, due to the resultant increase in the mean ion bombardment energy.

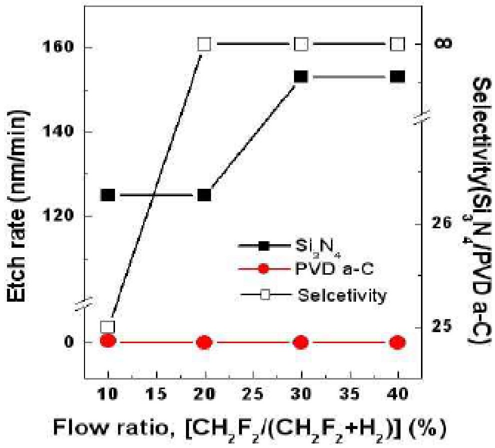

Fig. 1. Etch rates of the blanket Si_3N_4 and PVD a-C etched for 1 min under the condition of the $CH_2F_2/(CH_2F_2+H_2)$ gas mixture ratio at a fixed total gas of 100 sccm flow, P_{HF} of 400 W, P_{LF} of 300W, and operating pressure of 260 mTorr. Ar flow rate was fixed at 500 sccm.

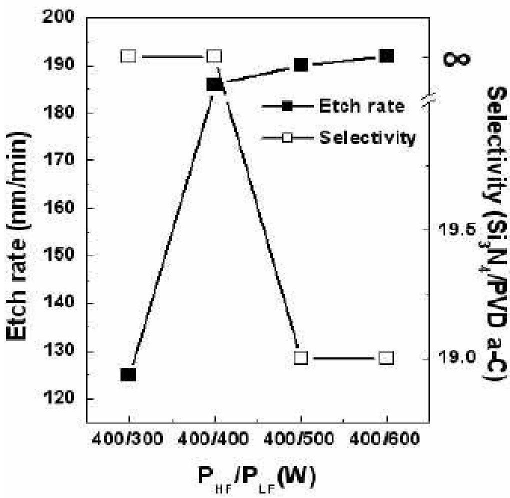

Fig. 2. Etch rates of the blanket Si_3N_4 etched for 1 min under the condition of the varied P_{HF}(W) / P_{LF}(W). CH_2F_2(20)/H_2(80)/Ar(500) sccm and operating pressure of 260 mTorr.

4. Conclusion

In this work, we investigated the effects of the process conditions, such as the CH_2F_2 and H_2 flow rates, and low-frequency power (P_{LF}), on the etch selectivity of silicon nitride to PVD a-C in $CH_2F_2/H_2/Ar$ plasmas using a DFS-CCP etcher. In conclusion, the process regime for infinitely high Si_3N_4/PVD a-C etch selectivity could be obtained by controlling the CH_2F_2 and H_2 flow rates as well as the low-frequency power.

References

[1] H. T. Kim, B. S. Kwon, and N.-E. Lee American Vacuum Society (2008)
[2] W. I. Urruchi, M. Massi, H. S. Maciel, C. Otani, and L. N. Nishioka, Diamond Relat. Mater. 9, (2000) 685
[3] Y. S. Park, H. S. Myung, J. G. Han, and B. Hong, Surf. Coat. Technol. 180, (2004) 218.
[4] C. K. Park, C. H. Lee, and N.-E. Lee, Electrochem. Solid-State Lett. 10, (2007) H11 .