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Multi-layer resist (MLR) structure with a very thin DLC layer

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Abstract

In this study, we investigated the fabrication of MLR (multi-layer resist) with a very thin diamond-like carbon (DLC) layer. ArF PR/SiO_2/DLC MLR structure was investigated and etching characteristics of the DLC layer was patterned using SiO_2 hard-mask by varying the process parameters such as different high-frequency/low-frequency combination (f_{LF}/f_{HF}), HF/LF power ratio (P_{HF}/P_{LF}), O_2 flow and N_2 flow rate in $O_2/N_2/Ar$ plasmas. The results indicated an increased etch rate of DLC for the higher f_{LF}/f_{HF} combination and for the increased low-frequency power (P_{LF}). And the etch rate of DLC was decreased with increasing the N_2 flow rate in $O_2/N_2/Ar$ plasmas. In order to confirm the application of DLC MLR for the etching process of silicon oxide, the stack of ArF PR/BARC/SiO_2/DLC/TEOS/Si was investigated.

1. Introduction

As the CD (critical dimension) of advanced CMOS devices is scaled down below 90 nm, multi-layer resist (MLR) including the hard-mask layer needs to be used for various dielectric etch processes due to very thin photoresist (PR) resulting in a loss of PR mask during etch process [1]. MLR structure often employs the amorphous carbon layers. Recently, MLR structure including amorphous carbon mask has attracted a lot of attention. A major benefit of these carbon films is that they can be deposited and patterned over a wide range of film thickness and can be removed by O_2 or N_2 based plasma [1, 2]. Diamond-like carbon (DLC) may be also considered for a mask material because of its hardness and etch resistance to fluorine etch chemistry. In this study, we investigated etching characteristics of DLC in the MLR structure by varying process parameters including different frequency combination (f_{HF}/f_{LF}), HF/LF power ratio (P_{HF}/P_{LF}), O_2 flow, and N_2 flow rate in $O_2/N_2/Ar$ plasmas. And in order to confirm the application of DLC layer as a mask for the following etch process of silicon oxide layer, the stack of ArF PR/BARC/SiO_2/DLC/TEOS/Si was etched.

2. Experiment

The DFS-CCP (dual frequency superimposed capacitively coupled plasma) etcher with multiple power sources is depicted in Fig. 1(a). The system is equipped with the three different HF (high-frequency) power sources (13.56, 27, and 60 MHz) and a LF (low-frequency) power source (2 MHz). DLC thin films with the hardness of 20 GPa were prepared on 6-inch Si wafer substrates by close field unbalanced magnetron (CFUBM) sputtering method [3] and photolithographic patterning of a positive photoresist (PR) mask (AZ 7220) on DLC/Si substrates was followed for the measurement of DLC etch characteristics in a dual frequency superimposed capacitively coupled plasma. Wafers with line and space patterns of ArF PR on the stack of bottom anti-reflective coatings (BARC, ≅30 nm)/SiO_2(≅120 nm)/DLC(≅30 nm)/TEOS(≅420 nm)/Si(001) were also prepared by photolithographic patterning using a ArF scanner for the application of DLC as a hard mask. The critical dimension (CD) of the pattern used in this work was ≅94 nm. The silicon oxide [tetraethyl orthosilicate (TEOS) oxide] layers were deposited by low-pressure chemical-vapor deposition (LPCVD).

3. Result and discussions

A. Effect of HF/LF frequency combination (f_{HF}/f_{LF}) and HF/LF power ratio (P_{HF}/P_{LF})

Fig. 1(b) shows the DLC etch rates in the $O_2/N_2/Ar$ plasmas as a function of f_{HF}/f_{LF} and low-frequency power (P_{LF}) for blanket and patterned samples. The etch rate of DLC sample gradually increased with increasing the P_{LF} due to increased ion energy. And Fig. 1(b) indicate that the etch rate of DLC at the same P_{LF} was faster in the $f_{HF}(60)/f_{LF}(2)$ plasma than in the $f_{HF}(13.56)/f_{LF}(2)$ and $f_{HF}(27)/f_{LF}(2)$ plasmas. Because a higher ion flux together with an enhanced O density under the higher f_{HF}/f_{LF} condition is expected to play an important role in increasing the DLC etch rate. And etch rate of the patterned DLC sample was similar to etch tendency of the samples unpatterned for f_{HF}(13.56 MHz)/f_{LF}(2 MHz).

B. Effect of the O_2 and N_2 flow rate

The effect of O_2 flow rate in f_{HF} (13.56 MHz)/f_{LF} (2 MHz) plasmas on the etch characteristics of the DLC layer was investigated. Fig. 2(a) shows the etch rates of an unpatterned and patterned DLC sample etched under different O_2 flow rate. The flow rate of N_2 and Ar are fixed at 50 and 200 sccm, respectively. The etch rate of unpatterned DLC sample was highest at 400 sccm of O_2 flow rate. And, as shown in Fig. 2(a), etch tendency of patterned DLC sample was also the same as that of unpatterned DLC layer. The role of N_2 flow rate for f_{HF} (13.56 MHz)/f_{LF} (2 MHz) combination on the etch characteristics of DLC layer was also investigated. Fig. 2(b) shows the etch rates of unpatterned and patterned DLC sample etched under different N_2 flow rate. The flow rate of O_2 and Ar are fixed at 400 and 200 sccm, respectively. The etch rate of unpatterned and DLC sample was decreased with increasing the N_2 flow rate. And etch tendency of patterned DLC sample was also similar to that of etch characteristics of unpatterned DLC.

C. TEOS etching with patterned DLC mask

The application of DLC layer as a hard mask for the etching of silicon oxide layer, the stack of ArF PR/BARC/SiO_2/DLC/TEOS/Si was etched. The schematic of this process is shown in Fig. 3(a) and FE-SEM image of etched TEOS layer is shown in Fig. 3(b). As a result, we could obtain the high etch selectivity of TEOS to DLC layer (≅ 14:1)

4. Conclusion

The etching characteristics of diamond-like carbon (DLC) layers with the SiO_2 hard-mask investigated by varying the process parameters in $O_2/N_2/Ar$ plasma showed that the DLC etch rate was increased with increasing the f_{HF}/f_{LF}, and P_{LF} but decreased with increasing the N_2 flow rate. The $N_2/O_2/Ar$ chemistry was effective for DLC etching. And in order to confirm the application of DLC layer as a mask for the following etching of silicon oxide layer, the stack of ArF PR/BARC/SiO_2/DLC/TEOS/Si was etched. The results showed that the DLC mask deposited by closed field unbalanced magnetron (CFUBM) sputtering method can be successfully applied to the silicon oxide etching with a high etch selectivity of TEOS to DLC (≅ 14:1)

Acknowledgments

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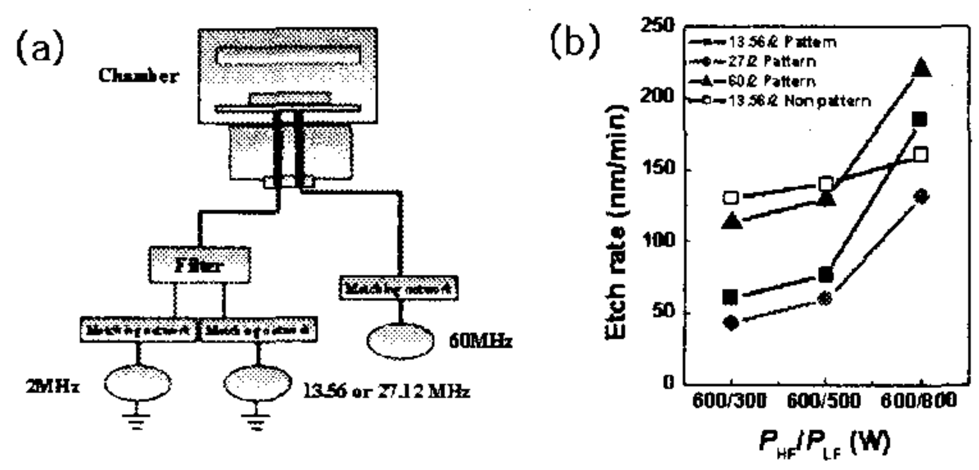

Fig.1. (a) A schematic diagram of DFS-CCP etching system used in this study and (b) etch rate of unpatterned and patterned DLC samples as a function of the low-frequency power.

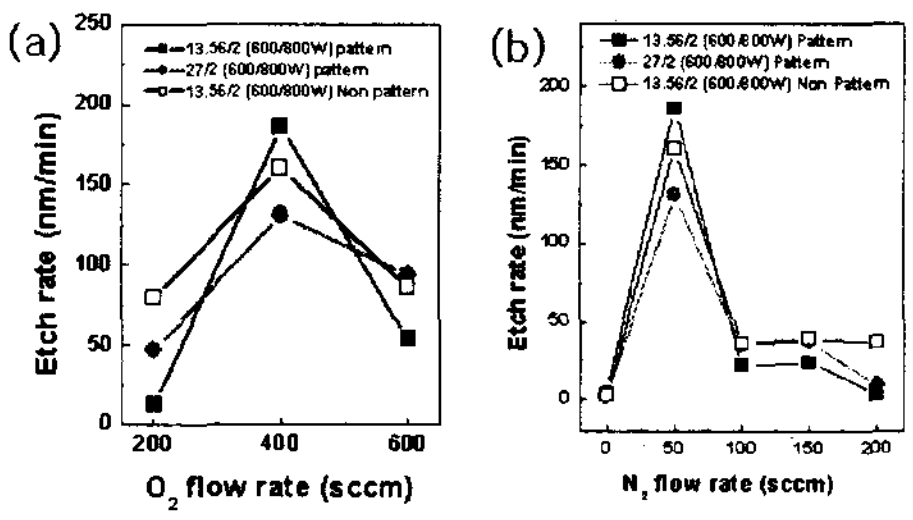

Fig.2. Etch rate of unpatterned and patterned DLC samples as a function of the (a) O_2 and (b) N_2 flow rate.

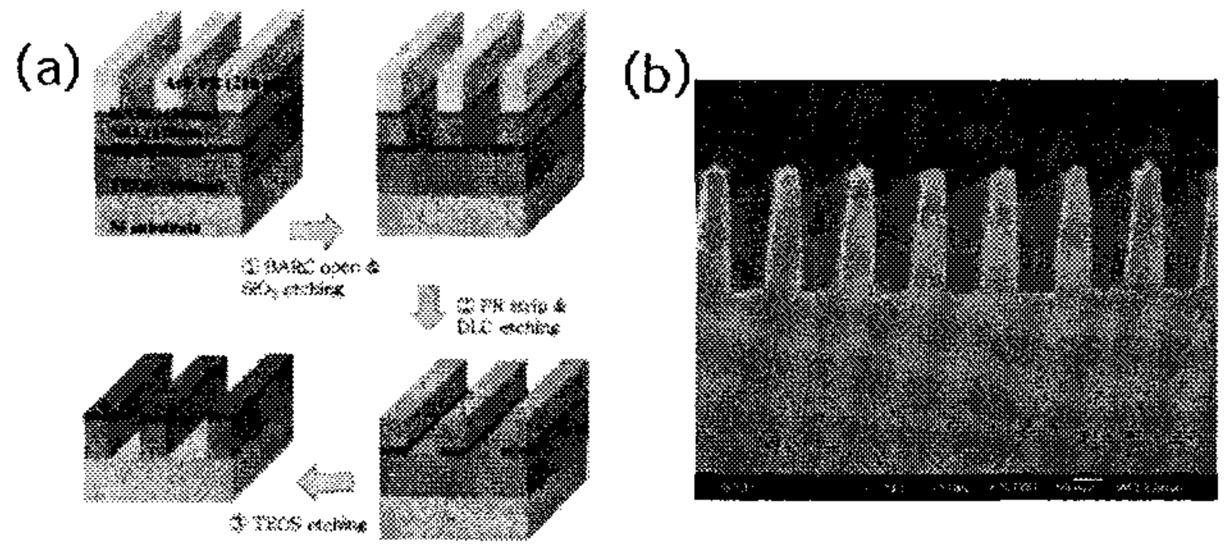

Fig.3. (a) The schematic of process flow and (b) FE-SEM image of etched TEOS oxide with the patterned DLC mask.