

Dry Etching Technology for Fine Pattern Fabrication Using Precise Ion Energy Control イオンエネルギー制御による微細加工技術

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1 MHz pulsed-DC superimposed 100 MHz rf CCP (capacitive coupled plasma) RIE was studied to control the ion bombardment energy precisely. Maximum ion energy in the ion energy distribution function (IEDF) was able to be controlled by the pulsed-DC voltage, and about 70% of the total ion flux was concentrated at the maximum ion energy region. Minimum CD shift with high etch rate was realized when the pulsed-DC superimposed (p-DCS) 100 MHz rf CCP was applied to the SOC (spun-on carbon) RIE with SOG as mask.

1. Introduction

As LSI device size shrinks, precise control of the fine pattern etching is required. We have reported that the precise control of ion energy represented as self-bias voltage was an essential factor for fine pattern etching as well as etch chemistry and plasma density [1,2]. Maximum ion energy in bimodal ion energy distribution due to the bias rf affected the etched pattern inaccuracy, and high rf reduced the maximum ion energy resulting in etched pattern accuracy [3]. Furthermore we have studied fine ion energy control using pulsed-DC superimposed (p-DCS) 100 MHz rf CCP. In this paper, we report the ion energy distribution function (IEDF) of the p-DCS CCP compared with 13.56 MHz superimposed 100 MHz (DFS: dual frequency superimposed) CCP, and its effect on fine pattern etching.

2. Experimental

The experimental setup of the p-DCS CCP is shown in Fig. 1. The 100 MHz rf power to generate plasma and 1 MHz negatively biased rectangular pulsed-DC voltage at 70% duty to accelerate positive ions were applied to the cathode which has a ϕ 300 mm Si wafer. The DFS CCP was used as a reference [3].

The SOC etch rates, the etched profiles of the SOC hole patterns with SOG as mask and the CD shift (as RIE – initial, which was measured by the cross-sectional SEM images of SOC profiles), were measured as a function of the pulsed-DC voltage and the 13.56 MHz rf power. The etch conditions of the 100 MHz rf power of 1200 W, H₂ based gas chemistry, and the gas pressure of 20 mTorr were kept constant.

3. Results and discussion

Figure 2 shows the measured superimposed waveform on the wafer which had a copper electrode window connected to the feed thru in series with high voltage capacitor, 1/10 probe, and oscilloscope. The pulsed-DC superimposed 100 MHz waveform was observed on the wafer. The input 1 MHz pulsed-DC voltage appeared on the wafer as expected.

The IEDFs of the incident H₂⁺ ions to the wafer were calculated based on the measured waveforms for both p-DCS and DFS by using a 1 dimensional transient plasma simulator [4]. The pulsed-DC voltages were varied from 0 to 750 V, and 13.56 MHz rf power were varied from 0 to 800 W. In the p-DCS case (Fig. 3(a)), all the IEDFs except 0 V case showed the two sharp peaks profiles, and about 70% of the total ion flux was concentrated at the higher energy peak region. The ratio of the ion flux in the higher peak region to the total ion flux corresponded to the duty ratio of the pulsed-DC. Then, the ion energies and the energy width (FWHM: full width at half maximum) in the higher peak region were plotted as a function of pulsed-DC voltage as shown in Fig. 4. The peak ion energy increased linearly with increasing pulsed-DC voltage, however the FWHM did not increase much. In the case of 13.56 MHz (Fig. 3(b)), the IEDFs showed the bimodal shapes, and ion flux was widely distributed between two peaks. Maximum ion energy increased and IEDFs became broader with increasing rf power.

These simulation results indicate that fine ion energy control could be realized by using the p-DCS CCP having high voltage DC generator with high repetition frequency of 1 MHz and high duty ratio of 70%.

Next, the p-DCS CCP was applied to the SOC hole pattern etching. The SOC etch rates, the CD shift and the SOC etched profiles were shown in Fig. 5. The SOC etch rates in both of the 13.56 MHz and the pulsed-DC cases, increased with increasing superimposed power and voltage, respectively.

Under the 100 MHz single frequency CCP condition, large SOC undercuts below the SOG mask were observed, and the CD shift was 19 nm. In the p-DCS case, the CD shifts decreased with pulsed-DC voltage increase, and it decreased to 3 nm at the voltage of 750 V. In the case of 13.56 MHz, with increasing rf power, the CD shifts decreased to 9 nm at 400 W and then increased to 20 nm at 800 W, because the SOG mask severely eroded as shown in Fig. 5. The SOC etch rate at the 13.56 MHz power of 800 W was the same as that of the pulsed-DC of 750 V, but SOG mask erosion was

different. It was supposed that erosion was enhanced by the higher ion energy of 740 V at the higher peak of 13.56 MHz case (Fig. 3(b)) compared to that of 510 V in the p-DCS case (Fig. 3(a)). SOG mask erosion was influenced severely by high energy ion bombardment. It was confirmed that fine ion energy control was the key factor for fine pattern etching. Highly concentrated ion energy distribution by p-DCS CCP was effective for SOC etch.

4. Conclusions

1 MHz pulsed-DC superimposed 100 MHz rf CCP RIE was studied to control the ion bombardment energy precisely. Maximum ion energy in the IEDF was able to be controlled by the pulsed-DC voltage, and about 70% of the total ion flux was concentrated at the maximum ion energy region. Minimum CD shift with high etch rate was realized when the p-DCS 100 MHz rf CCP was applied to the SOC RIE with SOG as mask.

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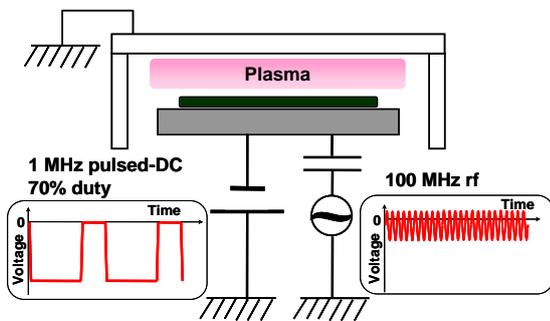


Fig. 1 Experimental setup of the pulsed-DC superimposed 100 MHz rf CCP.

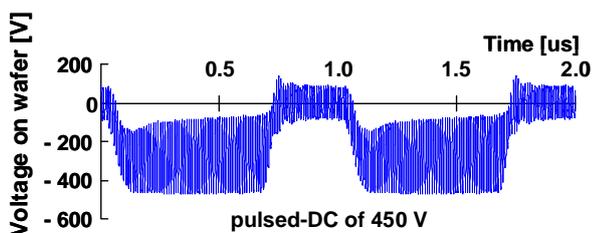


Fig. 2 Measured waveform on wafer for the pulsed-DC / 100 MHz CCP.

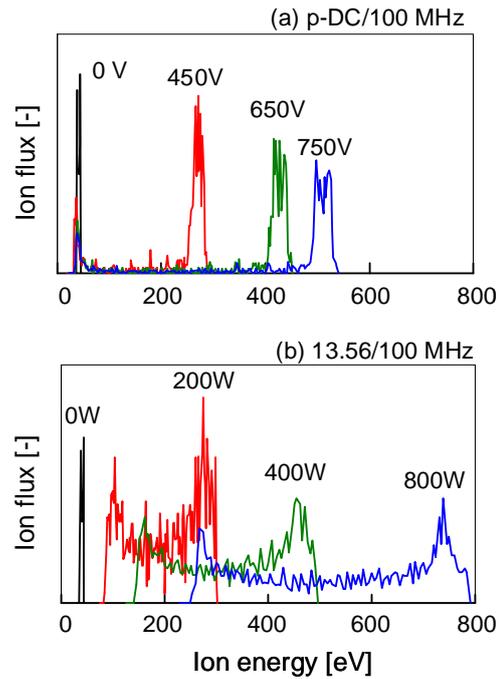


Fig. 3 IEDFs of H_2^+ ions for (a) the pulsed-DC / 100 MHz CCP and (b) 13.56 / 100 MHz CCP.

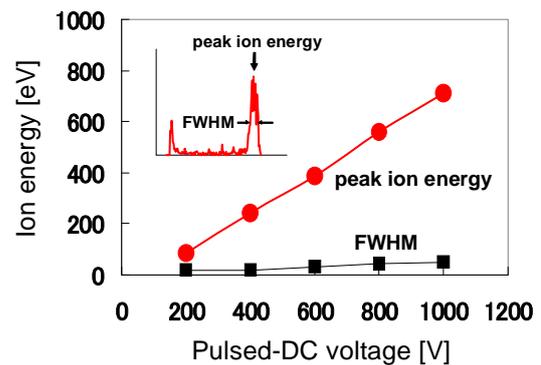


Fig. 4 Ion energy at higher peak and the energy width as a function of pulsed-DC voltage.

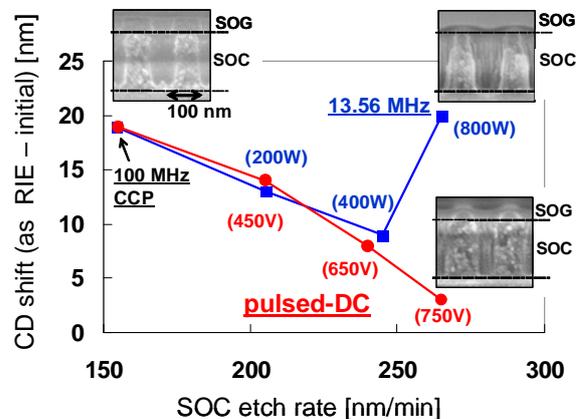


Fig. 5 CD shift as a function of SOC etch rate, and SEM images of SOC hole patterns.