Extended Abstracts of the 1993 International Conference on Solid State Devices and Materials, Makuhari, 1993, pp. 588-590

In Situ Chamber Cleaning Using Halogenated-Gas Plasmas Evaluated by Plasma-Parameter Extraction

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Abstract

We have demonstrated that high–efficiency in situ chamber cleaning is available for SiO_2 reactive–ion–etching chambers by use of NF_3 plasma. The plasma of NF_3 gas, which has a low bond energy, can generate high density ions and radicals with low kinetic energy. The cleaning efficiency of NF_3 plasma has been evaluated based on extracted–plasma–parameter analysis. The rf excited plasma potential has been measured directly by a newly developed rf–plasma probing method, which has clarified the relationship between the plasma potential and the rf electrode voltage.

1. Introduction

In order to establish fluctuation–free processing for future ULSI fabrication, it is of paramount importance to make the processing chamber conditions always identical at the start of each processing. To this end, several dummy runs are usually incorporated to coat the chamber inner surfaces with substantially–thick process sub–products, thus guaranteeing near–identical conditions for subsequent processing. However, such a technique is by no means acceptable for high quality processing, because particle generation is quite crucial. Recently the particle generation is the leading cause of decreasing device yield. Therefore in order to keep the chamber inner surface free from sub–products, the establishment of in–situ chamber cleaning technology is desired. The purpose of this paper is to present high–efficiency in situ chamber inner surface cleaning technology, which enables us to ideally initialize the chamber conditions after each process run. And we will also describe a convenient method, which is called extracted–plasma–parameter analysis[1][2], for estimating the cleaning efficiency of several halogenated specialty gases. Based on the results of this analysis, the high–ion–density and low–ion–bombardment–energy plasma has been created. The accuracy of the technique has been confirmed with a newly developed rf–plasma direct probing method[3].

2. Experimental

The apparatus used in these experiments is a parallel–plate capacitively–coupled reactive ion etching equipment (RIE) having 13.56MHz rf excitation. A high–voltage probe (Tektronix P6015) was attached directly to the backside of the plasma excitation electrode in order to minimize the stray impedance effects, which allows for the input voltage waveform Vrf(t) to be read on an oscilloscope. Using this value, we can estimate the ion bombardment energy, the ion flux density, and the time–averaged plasma potential. By use of these plasma–parameters, we have estimated the cleaning efficiency of several halogenated specialty gases. And the rf–excited plasma potential Vp(t) has been measured directly by a newly developed rf–plasma probe[3].

3. Results and Discussion

Figure 1 shows the relationship between plasma parameters and the bond energy for five specialty gases. Plasma parameter has been extracted from the voltage–waveform on the plasma excitation electrode. It can be clearly seen from this graph that the lower the bond energy of a gas is, the lower its ion bombardment energy and the higher its ion flux density. However, the time–averaged plasma potential does not appear to depend on the bond energy. Then the optimal gas for in situ chamber cleaning is halogenated gas with low bond energy, which can generate high density ions and radicals

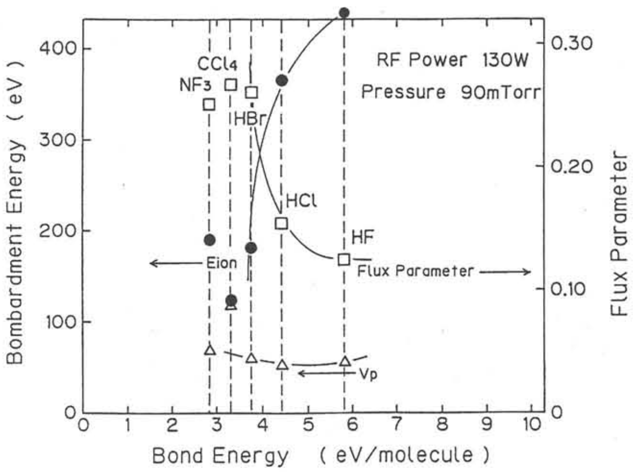
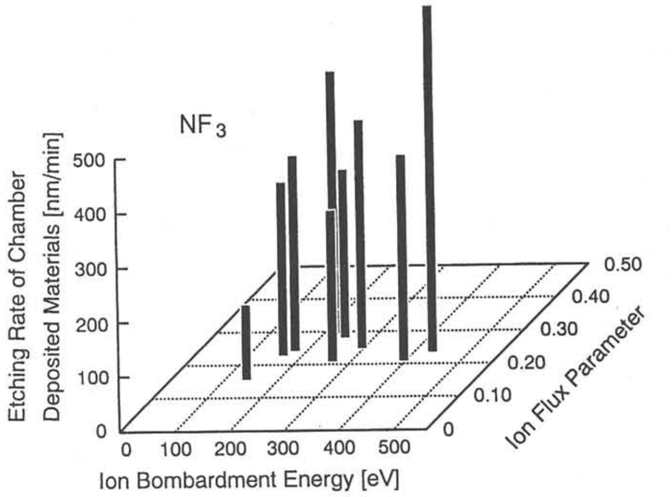


Figure 1 Relationship between bond energy and estimated plasma parameters, such as ion bombardment energy(Eion), flux parameter and the time–averaged plasma potential(Vp).

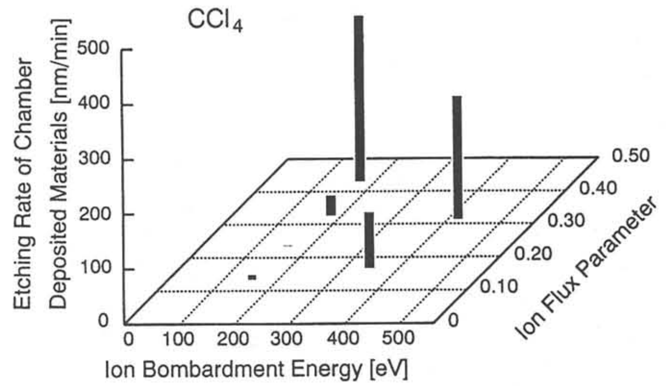
with low kinetic energy.

We have evaluated the etching rate of a mixture of the photoresist TSMR–8900 and an OCD silica solution coated onto a silicon wafer in order to simulate the sub–products adhering on the inner surface of RIE chambers used for SiO_2 etching. The SiO_2 RIE process is believed to be the major cause of yield loss due to process induced particles. Figure 2 shows the etching rate of chamber deposited materials by using NF_3(a), CCl_4(b) and HBr(c) plasmas as a function of bombarding ion energy and ion flux density, where the bombarding ion energy is defined as a difference between the time–averaged plasma potential and the self–bias voltage of the plasma excitation electrode. We have seen that the etching rate of deposited material is in general the greatest when fluorinated gases with low bond energy are used, while chlorinated gases and bromium gases etch it only slowly. It is also seen from Figure 2(a) that a large etching rate is obtained even for smaller ion bombardment energies when the ion flux density is high.

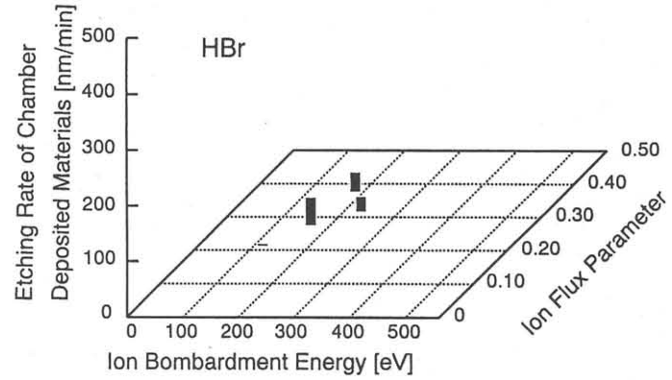
Figure 3 shows the waveforms of the plasma potential Vp(t) and the excitation electrode voltage Vrf(t) at 60mTorr in argon, where the rf input–power is 90W. By use of a newly–developed rf–plasma direct probing method, the relationship between the plasma potential and the rf electrode voltage has been clarified. The important point to note is the distortion of the plasma potential. In general, it has been considered that the waveform of the plasma potential is sinusoidal for the simplified capacitive



(a)



(b)



(c)

Figure 2 The etching rate of a mixture of photoresist and an OCD silica solution modeled sub–products of etching chamber for NF_3(a), CCl_4(b) and HBr(c).

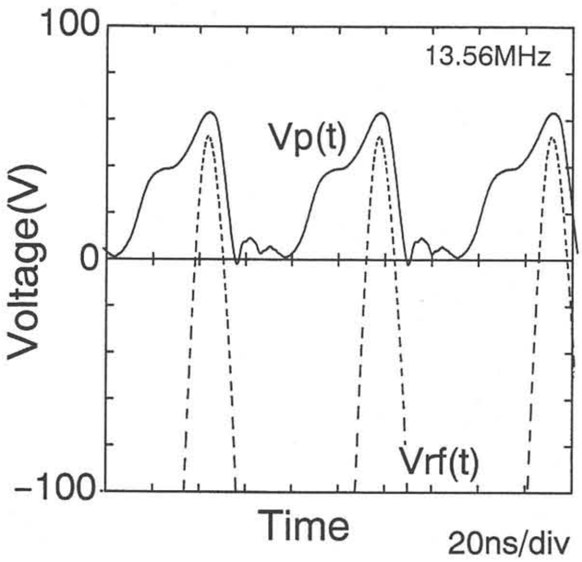


Figure 3 The waveforms of plasma potential Vp(t) and excitation electrode voltage Vrf(t) at 60mTorr in argon. The rf input-power is 90W.

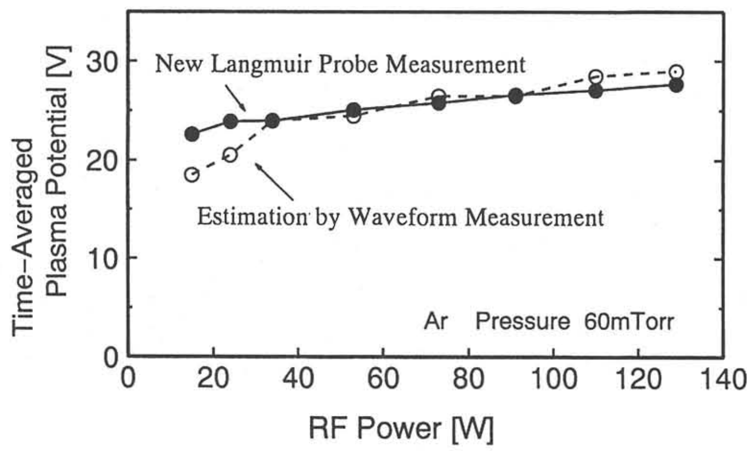


Figure 4 The rf input-power dependence of the time-averaged plasma potential which is measured by newly developed rf Langmuir probe and estimated from voltage waveform of plasma excitation electrode.

model of the sheath[4]. Therefore the distortion of the measured waveform seems to be caused by the increased direct current (i.e. the positive ion current and the electron current) for the resistive model of the sheath.

Figure 4 shows the rf input-power dependence of the time-averaged plasma potentials which are measured by two different methods. One is measured by a newly developed rf Langmuir probe and the other is estimated from the voltage waveform of the plasma excitation electrode. As can be seen in the figure, estimated values from voltage waveforms are in good agreement with those which are accurately measured by the new rf Langmuir probe. Then the accuracy of extracted-plasma-parameter analysis has been confirmed.

4. Conclusion

We have demonstrated that high-efficiency in situ chamber cleaning is available for SiO_2 RIE chambers by using the plasma of NF_3 gas which has a low bond energy. And the accuracy of extracted-plasma-parameter analysis has been verified by the accurate characterization of rf-generated plasma by a new probe measurement technique. Moreover the rf-excited plasma potential has been measured directly by the probing method, which has clarified the relationship between the plasma potential and the rf electrode voltage.

Acknowledgment

This study was carried out at the Super Clean Room of Laboratory for Microelectronics, Research Institute of Electrical Communication, Tohoku University.

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