Literature Digest
Vol. 14: January 2004

Special Edition: 2003 International Symposium on Dry Process (DPS 2003)

Introduction

For this digest, we selected several papers from the Dry Processing Symposium 2003, which should be of interest to the visitors of www.clarycon.com. They cover topics of plasma generation, plasma etch mechanisms, patterning, critical dimension control, line edge roughness:

Plasma Physics

"Energy Control of Ions Incident to Wafer by Using Active Bias"
N.Yasui, M.Sumiya, H.Tamura, S.Watanabe
Hitachi, Ltd.
This paper describes a method to modulate the ion energy distribution function (IEDF) of an UHF-ECR reactor with a bias frequency of 400 kHz. For these low bias frequencies, the ion energy distribution is typically bi-modal with peaks of equal intensity for the lowest and highest ion energies. It is known that the distribution can be modulated by using a RF signal, which is not sinusoidal. This is typically accomplished by using a signal generator and a power amplifier. This paper presents a method where active elements like diodes and MOSFET's are incorporated into the bias matching network (hence the term "active bias"). The IEDF's were measured in experiments, in which RF voltage waveforms were controlled by a clip circuit and a sag correction circuit. When the RF voltage waveform is clipped flat and is applied to the electrode, the voltage waveform at the wafer surface is sloped (sag). By electric correction, i.e. by clipping the electrode voltage waveform with a reverse slope, the voltage waveform on the wafer becomes flat. As a result, it was shown that the high energy peak ratio of ion energy distribution could be enhanced to more than 80% of the entire distribution.

"Energy Control of Incident Ions to the Chamber-Wall by using Push-Pull Bias (Phase-Controlled Bias) in UHF-ECR Etcher"
Masahiro Sumiya, Naoki Yasui, Kenetsu Yokogawa, Nobuyuki Negishi, Masatoshi Oyama, Tsuyoshi Yoshida, Hironobu Kawahara, Seiichi Watanabe
Hitachi, Ltd.
Generally, if the ratio of the electrode area to the earth area is changed, the energies of the ions impinging the electrode and wall surface will change (asymmetric RF reactors). This paper shows that using a phase-controlled bias, the ion energies are controlled independently of the geometrical ratio of the grounded area to the powered area. In particular, the energies of the ions impinging the reactor walls can be reduced when the phase difference between the top and bottom electrodes is 180 deg (Push-Pull bias). This effect can be used to reduce the sputtering of the chamber-walls. An explanation of this effect is given which involves the orientation of the magnetic field as a function of the phase difference and the corresponding plasma resistances in the direction to the chamber walls.

Beam Studies

"Study of Organic Polymer Thin Film Etching by Plasma Beam Irradiation"
Akihiro Egami[1], Kazuaki Kurihara[1], Teruo Yagishita[1], Yoshikazu Yamaoka[1], Moritaka Nakamura[1], Tetsushi Kawachi[2], Shuhei Seki[2], Seiichi Tagawa[2]
[1]ASET, [2]Osaka University
The etching characteristics of three different methacrylate polymer films (polytbutylmethacrylate (PtBuMA), polycyclohexylmethacrylate (PCHMA) and polybenzylmethacrylate (PBMA) were

studied in a plasma beam apparatus. These polymers have the same main chain but different side chains. In the case of N_2 ion exposure, the organic polymers were found to exhibit different etching yields. This suggests that carbon-nitrogen bonds play an important role of etching by N_2 plasma. On the other hand, in the case of Ar and H_2 plasmas, the dependences of the etching yield on the ion energy were the same for all three polymers.

"Incident Angular Dependence of SiO_2 and SiN Etching with Mass-analyzed CF_x^+ Ion Beam Irradiation"

K. Yanai, K. Karahashi, K. Ishikawa, M. Nakamura
ASET

The surface reactions in the fluorocarbon plasma etching of SiO_2 were investigated by irradiating the surfaces with a mass-analyzed CF_x + (x = 1-3) ion beam at various incident angles. The angular dependence of the etch yields below 60˚ varies greatly for different CF_x^+ ions. When the number of the fluorine atoms in each CF_x^+ ion increases, the etch yield depends less on the incident angle. Higher SiO_2/SiN selectivity is obtained at smaller incident angles and with the CF_x^+ ions having fewer fluorine atoms because a thick a-C:F layer is formed on the etched surface of a SiN film. With increasing incident angle, the thickness of a-C:F layer decreases rapidly, reducing the selectivity. This angular effect makes has consequences for the selectivity at the top corner or shoulder and make it difficult to precisely control the profile of "selfaligned contacts".

"Observation of SiO_2 Surface Irradiated by Fluorocarbon Neutrals and Energetic Ion Beam"

Hirotaka Toyoda, Noriharu Takada, Hideo Sugai
Nagoya University

This paper reports on experiments in which Ar^+ ions and fluorocarbon molecules (CF_4, c-C_4F_8 or C_5F_8) were irradiated on a SiO_2 surface. Compared with pure Ar^+ sputtering of SiO_2, an enhancement of SiO_2 etching was observed in the presence of fluorocarbon molecules on the surface, especially for the C_5F_8/Ar^+ system. In other experiments, the surface was bombarded with Ar^+ before the fluorocarbon gases were introduced. In these experiments, a chemical reaction of C_5F_8 with the SiO_2 surface was observed only when the surface was irradiated by Ar^+ before C_5F_8 exposure.

Etch Mechanisms

"Patterning Challenges with Thin Resists"

A. P. Mahorowala[1], D. L. Goldfarb[1], K. Temple[1], K. E. Petrillo[1], D. Pfeiffer[1], K. Babich[1], M. Angelopoulos[1], G. Gallatin[1], S. Rasgon[2], H. H. Sawin[2], S. D. Allen[1], R. N. Lang[1], M. C. Lawson[1], R. W. Kwong[1], K. -J. Chen[1], W. Li[1], M. Khojasteh[1], P. R. Varanasi[1], M. I. Sanchez[1], H. Ito[1], G. M. Wallraff[1], R. D. Allen[1]
[1]IBM, [2]MIT

This paper reports on a systematic study of line edge roughness (LER) and feature sidewall roughness for different patterning schemes. An AFM technique was used to measure the feature sidewall roughness as a function of etch depth. This technique allows to calculate the roughness of the sidewalls of all the layers as well as substrate surfaces roughness simultaneously. This enables the identification of correlations between these values. The post-develop resist sidewall roughness was found to be isotropic and varied in the 3-5 nm rms range for 248 and 193 nm resists. The etch steps were shown to either decrease or increase the sidewall roughness (strong dependence on chemistry) and can introduce an anisotropic character to the roughness in the form of sidewall striations.

"Roughness Variations on Gate Dielectric Surfaces through Metal Gate Etching in Inductively Coupled Cl_2/HBr Plasmas"

Nobuhisa Yamagishi[1], Kazuhiro Karahashi[1], Jung-Woo Park[1], Noriyuki Miyata[2], Hirokazu Hisamatsu[1], Nobuyuki Mise[1], Toshihide Nabatame[1], Tsuyoshi Horikawa[2], Akira Toriumi[2,3]
[1]ASET, [2]AIST, [3]Unversity of Tokyo

This paper reports on AFM roughness measurements on thin SiO_2 and HfO_2 surfaces after TiN gate etching in inductively coupled Cl_2/HBr plasmas. It was found that surface roughness of both partially etched TiN and underlying gate dielectrics after gate etching was enhanced in Cl_2 plasma, while it was significantly suppressed by adding HBr. The roughness developed on the TiN surface during etching and was transferred to the surface of dielectric films. The authors propose that the roughness enhancement of partially etched TiN surface in Cl_2 plasma is caused by weakening of N bonds in the grain boundary region of the TiN layer.

"Characteristics of Si Trench Etching using HBr/SF_6/O_2 Plasma"

Setsuko Wakimoto[1], Hiroyuki Tanaka[1], Ayako Yajima[1], Kunio Mochizuki[1], Yukimi Ichikawa[1], Shosaku Matsumura[2], Yoshihiko Nagayasu[1]
[1]Fuji Electric, [2]Musashi Institute of Technology

This papers reports on silicon deep trench etching in a ICP reactor. The dependence of profile and etch rate on bias power, O_2 and HBr addition are studied and useful process trends are given.

"Optimization of Gate Structure and Etching Flow for Advanced Logic"

Takahiro Maruyama[1], Shinichi Yamanari[1], Nobuo Fujiwara[1], Kazunori Tsujimoto[1], Michinari Yamanaka[2]
[1]Renesas, [2]Matsushita

This paper reports on in-situ BARC/hardmask/poly-Si etching in an ECR reactor. The CD perturbations (wiggling) were reduced with the in-situ processing scheme. It also reduced CD variations from wafer to wafer. This is explained by the time dependent formation of native oxide in an ex-situ scheme.

"Performance of Inductively Coupled Fluorocarbon Plasmas in Etching of HfO_2 Thin Films as a High-k Gate Insulating Material"

Kazuo Takahashi, Kouichi Ono, Yuichi Setsuhara
Kyoto University

This paper presents results of the etching of CVD HfO_2 thin films (60 nm) on Si substrates in inductively coupled fluorocarbon plasmas (13.56 source and bias frequencies). Gas mixtures of CF_4/Ar and C_4F_8/Ar, and pure Ar were studied at low pressures (20 mTorr). For the fluorine containing mixtures, the HfO_2 etch rate was almost independent on the flow of the fluorocarbon gases and the selectivity to silicon was therefore higher for Ar rich gas mixtures. For the pure Ar process, the HfO_2 etch rate increased dramatically with increased dc bias. This indicates that etching HfO_2 in these gas mixtures is primarily driven by ion bombardment. The etch rate decreased fir very high Ar dilution, i.e. the chemical etching of HfO_2 in fluorine radical plays a role, too.

"Mitigation of accumulated electric charge by deposited fluorocarbon film during SiO2 etching"

Y.Suzuki, T.Shinmura, M.Koyanagi, K.Hane, S.Samukawa
Touhoku University

This paper reports on in-situ on-wafer monitoring for the build up of charging potential during plasma etching of SiO_2 with fluorocarbon gases. The monitoring device consists of a SiO_2 layer with contact holes and bottom and top poly-Si electrodes. The results show that the sidewall deposited fluorocarbon film has high electric conductivity and mitigates the electric charge

accumulation at the contact hole bottom during the SiO_2 etching processes. These results are of great importance for profile interpretation and profile evolution modeling.