
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 Egami1, Kazuaki Kunharaka1, Teruo Yagishita1, Yoshikazu Yamaoka1, Moritaka Nakamura1, Tetsushi Kawachi1, Shuhei Seki2, Seiichi Tagawa2
1ASET, 2Osaka University
The etching characteristics of three different methacrylate polymer films (polybutylmethacrylate (PolyBuMA), polycyclohexymethacrylate (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$_4$F$_8$ or C$_3$F$_6$) 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$_3$F$_6$/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$_3$F$_6$ with the SiO$_2$ surface was observed only when the surface was irradiated by Ar$^+$ before C$_3$F$_6$ 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$^2$, 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 Cl₂/HBr Plasmas”
Nobuhisa Yamagishi¹, Kazuhiro Karahashi¹, Jung-Woo Park¹, Noriyuki Miyata², Hirokazu Hisamatsu¹, Nobuyuki Mise¹, Toshihide Nabatame¹, Tsuyoshi Horikawa², Akira Toriumi²,³
¹ASET, ²AIST, ³University of Tokyo
This paper reports on AFM roughness measurements on thin SiO₂ and HfO₂ surfaces after TiN gate etching in inductively coupled Cl₂/HBr plasmas. It was found that surface roughness of both partially etched TiN and underlying gate dielectrics after gate etching was enhanced in Cl₂ 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 Cl₂ plasma is caused by weakening of N bonds in the grain boundary region of the TiN layer.

“Characteristics of Si Trench Etching using HBr/SF₆/O₂ Plasma”
Setsuko Wakimoto¹, Hiroyuki Tanaka¹, Ayako Yajima¹, Kunio Mochizuki¹, Yukimi Ichikawa¹, Shosaku Matsumura², Yoshihiko Nagayasu¹
¹Fuji Electric, ²Musashi Institute of Technology
This paper reports on silicon deep trench etching in an ICP reactor. The dependence of profile and etch rate on bias power, O₂ and HBr addition are studied and useful process trends are given.

“Optimization of Gate Structure and Etching Flow for Advanced Logic”
Takahiro Maruyama¹, Shinichi Yamanari¹, Nobuo Fujiwara¹, Kazunori Tsujimoto¹, Michinari Yamanaka²
¹Renesas, ²Matsushita
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 HfO₂ Thin Films as a High-k Gate Insulating Material”
Kazu Takahashi, Kouichi Ono, Yuichi Setsuhara
Kyoto University
This paper presents results of the etching of CVD HfO₂ thin films (60 nm) on Si substrates in inductively coupled fluorocarbon plasmas (13.56 source and bias frequencies). Gas mixtures of CF₃/Ar and C₂F₆/Ar, and pure Ar were studied at low pressures (20 mTorr). For the fluorine containing mixtures, the HfO₂ 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 HfO₂ etch rate increased dramatically with increased dc bias. This indicates that etching HfO₂ in these gas mixtures is primarily driven by ion bombardment. The etch rate decreased for very high Ar dilution, i.e. the chemical etching of HfO₂ 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 SiO₂ with fluorocarbon gases. The monitoring device consists of a SiO₂ 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\textsubscript{2} etching processes. These results are of great importance for profile interpretation and profile evolution modeling.