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EFFECT OF DEPOSITION CONDITION ON WET AND DRY ETCH RATES OF DEVICE QUALITY INDUCTIVELY COUPLED PLASMA-CHEMICALLY VAPOR DEPOSITED SiN_X

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Abstract—Inductively coupled plasma-chemically vapor deposited (ICP-CVD) SiN_x was grown on Si substrates using a $SiH_4/NH_3/He$ chemistry at 150°C. The influence of source power, chamber pressure, rf chuck power and percentage SiH_4 on the wet (in BOE) and dry (in ICP SF_6/Ar discharges) etch rates of the SiN_x was investigated. The dry etch rates are found to strongly increase with stress in the film above a threshold of ~500 MPa, while the wet etch rates increase rapidly with source power, chamber pressure and hydrogen content. © 1998 Published by Elsevier Science Ltd. All rights reserved

1. INTRODUCTION

Plasma-enhanced chemically vapor deposited (PECVD) SiN_x is widely used for device isolation, long-term passivation layers and annealing caps for implanted compound semiconductors[1–15]. Most of the work in the past has focussed on conventional 13.56 MHz rf PECVD, which typically operates with ion densities of 10^8–10^9 cm^{-3} in the discharge. This low ion density leads to relatively high d.c. self-biases on the sample electrode and can produce lattice disorder in the semiconductor surface. There is intense interest in the development of high density plasma deposition processes for dielectrics, where lower ion energies and potentially higher deposition rates are possible. Moreover, the process pressure is typically much lower in high density plasmas, leading to better gap-fill characteristics[16–22].

In compound semiconductor device technology there has been some work on the use of microwave electron cyclotron resonance (ECR)-CVD for SiN_x and SiO_2, but this technology suffers from uniformity limitations[12,18]. Attention has turned to inductively coupled plasma (ICP) sources, which operate at radio frequencies and feature a relatively inexpensive, scalable design[19]. However, there is little information available on the characteristics of SiN_x deposited by ICP-CVD. In this paper, we describe the results of wet and dry etching experiments on SiN_x deposited by this technique, since these parameters will be good indicators of dielectric quality, and offer a simple way to characterize the material. Both wet and dry etch rates are found to be a strong function of the plasma deposition variables.

2. EXPERIMENTAL

We used 100% pure SiH_4, NH_3 and He for high rate ICP SiN_x deposition on Si substrates. The He and both SiH_4 and NH_3 were introduced through the top and bottom gas rings, respectively. We used a Plasma-Therm VLR series machine for ICP SiN_x deposition. Total gas flow for SiN_x deposition was fixed at 40.6 sccm and chamber pressure was changed from 5–20 mTorr. ICP power was fixed at 800 W and rf chuck power was varied from 10 to 100 W. Deposition temperature of the chuck was held at 150°C. Typical deposition rates were ~300 Å/min. The refractive index of the SiN_x films was measured with ellipsometry and was ~2.0. We compared high plasma density ICP films with both a conventional PECVD film and a thermal SiO_2. The PECVD film was deposited at 300°C with diluted SiH_4 (2% in N_2), NH_3 and N_2 gas.

Wet etching of the ICP SiN_x films was done with a buffered oxide etch (BOE) solution at room temperature. The BOE solution consisted of NFH_4 and HF in the ratio of 7:1. The wet etching rate of thermal SiO_2 in the BOE was 800 Å/min.

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Dry etching of the films was performed in a Plasma-Therm 790 ICP system utilizing a 2 MHz source operating at 300–1500 W. The process pressure was held constant at 5 mTorr, while the total SF_6 + Ar gas load was 15 sccm. The rf chuck power (13.56 MHz) was varied from 50 to 350 W. Etch rates were determined from a stylus profilometer, while the surface morphology was examined by an atomic force microscope (AFM) system operating in tapping mode with Si tip.

3. RESULTS AND DISCUSSION

3.1. *Dry etching*

The effect of ICP power on the etch rates of various SiN_x films in $5SF_6/10Ar$ and 150 W rf discharges is shown in Fig. 1. The d.c. bias decreased from −286 to −130 V as the source power increased from 300 to 1500 W. The lower d.c. biases with higher source powers are mainly due to increased plasma density at higher ICP powers. In general, the etch rate increases as the plasma density increases. However, in this work the etch rate of SiN_x decreased at 500 W due to decreased d.c. bias, and increased again as the source power increased further due to the increased ion flux. As expected, SiO_2 film showed a lower etch rate compared to the SiN_x films.

The reason for the decrease in etch rate at 500 and 750 W could potentially be attributed to one or combined effects of three possible reasons: (1) the reduction of reactive radicals due to recombination of SiF_x ions with F neutrals and of adsorbed F atoms on the surface, (2) the redeposition of etch products and (3) the formation of polymer $(SiF_x)_n$ as a protective coating on the surface. The recombination reactions of $SiF_x^+ + F + e \rightarrow SF_4$ in the gas phase and $F \cdot S + F \cdot S \rightarrow F_2(g) + 2S$ at the substrate surface may occur and reduce the amount of reactive F radicals. However, as the ICP power increases further, the increased ion density makes the surface more active with respect to the reactive neutral species and the rate of mass transfer of F neutrals in the gas phase is faster due to increased concentration than the recombination rate. Hence, recombination and polymerization decrease at ICP powers greater than 750 W, and instead the etch rate increases due to the increased concentration of reactive neutrals and ion flux.

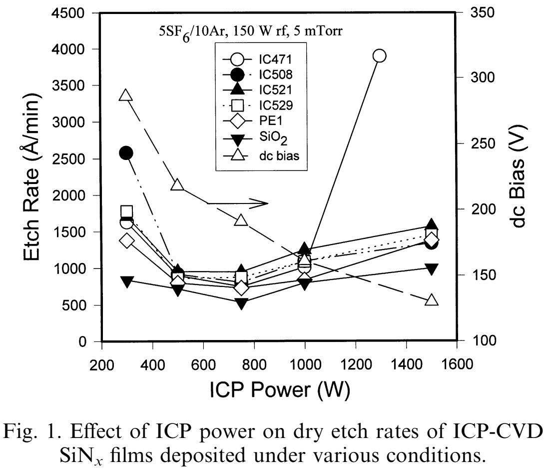

Fig. 1. Effect of ICP power on dry etch rates of ICP-CVD SiN_x films deposited under various conditions.

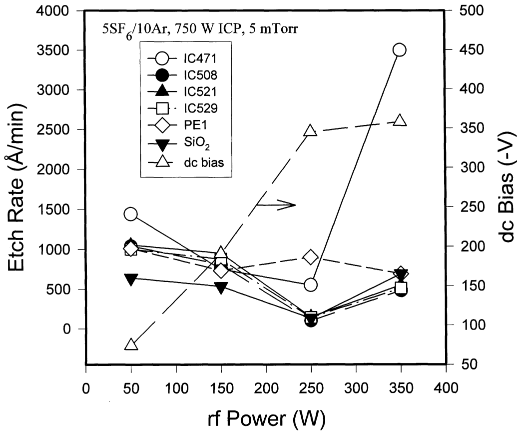

Fig. 2. Effect of rf chuck power on dry etch rates of ICP-CVD SiN_x films deposited under various conditions.

The effect of rf power on the etch rates and d.c. bias are shown in Fig. 2. The SiN_x films except the sample numbered IC471 and PE1 showed a slight decrease in etch rate up to 250 W and increase at > 250 W rf power. However, the etch rates decreased overall as the rf power increased. This result may be due to the sputter desorption of reactive adspecies from the substrate surface before etch reaction occurs. Such a result also implies that in order to obtain a high etch rate of SiN_x films chemical etch is more important than physical etch induced by increased ion energies. The sample PE1 showed less dependency on rf power compared to others, but the sample IC471 showed the largest etch rate at 350 W. Again, SiO_2 showed the lowest etch rates compared to SiN_x films, indicating a most stable film. In general, compared to the films prepared by thermal CVD, the plasma enhanced CVD SiN_x grown at temperatures less than 400°C does not necessarily have 3:4 Si/N stoichiometry and has a significant fraction of hydrogen atoms in the lattice. Furthermore, since the SiO_2 surface is chemically less active than the SiN_x surface, reactive radicals incident on SiO_2 surface desorb, without leading to etching. This explains why the SiN_x films show greater etch rates than SiO_2.

Figure 3 shows the effect of SF_6 concentration on dielectric etch rate in a SF_6/Ar ICP-generated plasma. The total flow rate was held constant at 15 sccm. It is seen that the etch rates and d.c. biases increase substantially with increasing SF_6 concentration. Increase in d.c. bias with SF_6 flow rates implies that the electronegative SF_6 is decreasing the positive ion density in the discharge. All