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PLASMA ETCHING OF DEEP Si-TRENCHES WITH $CBrF_3$ AND DILUTIONS

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Experiments with $CBrF_3$ and dilutions of O_2 and SF_6 were made to produce trenches in Si. It is shown that it is possible to realize anisotropic trenches without undercut with $CBrF_3$ and $CBrF_3/O_2$. In contrast to this only isotropic profiles were achieved with $CBrF_3/SF_6$. Some problems and possible reactions in those plasmas are discussed.

I. INTRODUCTION

Today trench structures play an important role in semiconductor technology. In order to get a high packing density of electronic circuits it is necessary to use the third dimension.

One application of those trenches in Si is the dielectric isolation of bipolar and CMOS circuits. The other main application is for storage capacitors of modern DRAM's.

To the 1 Mbit level most storage cell concepts use planar capacitors, but for the 4 Mbit DRAM the main concept is the so-called trench cell, where the vertical direction is used to produce capacitors.

This application requires deep (up. to 4 ... 5 μm), very smooth and slightly tapered trenches easily refilled with the dielectric material and polysilicon. Also a round bottom is needed to obtain high quality dielectrics [1].

These demands can be accomplished by a reactive ion etch process, with chlorine- or bromine-based gases [2—3].

II. EXPERIMENTS

In these experiments we used the diode etch system XPLO1 in the RIE mode. It is a planar single wafer etcher with the possibility of changing the excitation frequency between 5 kHz and 100 kHz.

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The vacuum system consists of a rotary pump, a Roots pump and a cold trap. Before admitting the reactive gases the reactor was pumped to a background pressure of 5×10^{-2} Pa. The chamber includes two Al-electrodes, covered with Al_2O_3, which have a distance of 25 mm and a diameter of 125 mm.

During experiments we kept the temperature of the electrodes (20 °C), the total gas flow rate ($30\ cm^{-3}\ min^{-1}$) and the excitation frequency (45 kHz) constant.

Experiments were made with $CBrF_3$, $CBrF_3/O_2$ (25% and 50%) and $CBrF_3/SF_6$ (25%).

We changed the pressure between 10 Pa and 50 Pa and the power between 50 W and 150 W.

The substrate material and the etch mask which were used in our experiments are (100) Si and a CVD silicondioxide layer of 600 nm. This SiO_2 mask was made by a CHF_3/O_2 plasma etching process.

III. RESULTS

III. 1. Etching with pure $CBrF_3$

Etching of monocrystalline Si in a $CBrF_3$ plasma and the given parameter field results in etch rates between 100 nm/min and 330 nm/min and selectivities (Si to SiO_2) between 3 : 1 and 5 : 1. Because of these relatively small selectivities

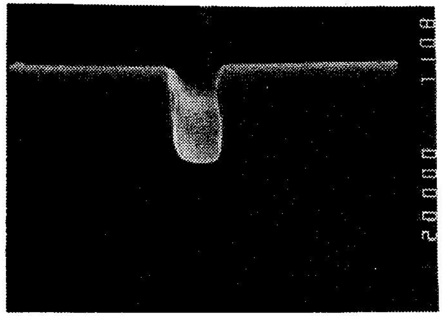

Fig. 1. $CBrF_3$; 30 Pa; 150 W; all SEM pictures were made directly after etching without removing the SiO_2 mask remains.

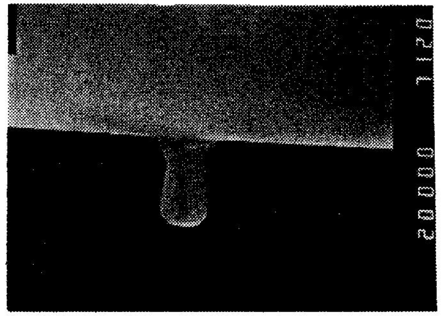

Fig. 2. $CBrF_3$; 10 Pa; 150 W.

and our mask thickness of 600 nm, we only produced trenches in the depth range of 2 ... 3 μm. Anisotropic profiles without undercut were obtained in all cases of the given parameter field (Fig. 1). But in the lower pressure range (10 Pa) we can see for all values of power "V"-shaped corners of the sidewalls (Fig. 2). These corners are more pronounced for a higher power density, but with increasing pressure it disappears. On the other hand the $CBrF_3$ etch process tends to produce "bowings" of the sidewalls at a higher pressure and a lower power. We achieved round bottoms and a smooth surface for all trial points, but particularly for the higher pressure range there is a tendency to deposit visible layers, which suppress the etch attack. On the one hand these layers result in anisotropic profiles but on the other hand there is the problem to remove the layers after etching, because of the negative influence on the following processes. We obtained the best results for a pressure range of 30 Pa to 50 Pa and the highest power level (150 W).

III. 2. Etching with $CBrF_3$ and dilutions of O_2 (25% and 50%)

We diluted oxygen in $CBrF_3$ to see the influence on the etch rate of Si and the selectivity (Si to SiO_2). But there is no significant influence on either. In the lower pressure range (10 Pa) the profiles of the Si trenches are in both cases (25% and 50% O_2) unsatisfactory. At 25% O_2 in $CBrF_3$ there are layers on the sidewalls and the ground of the structures which suppress the etch attack. In the case of 50% of O_2 the trenching problems are visible at all power levels, but stronger at a higher power (Fig. 3). Against this it is possible to realize anisotropic trenches with a smooth surface and round bottoms at a higher pressure (30 Pa—50 Pa). But in the same way as for pure $CBrF_3$ it is necessary to use high power (150 W) to obtain good profiles. We achieved here the best results also between 30 Pa and 50 Pa for 150 W (Fig. 4 and Fig. 5).

Fig. 3. $CBrF_3/O_2$ (50%); 10 Pa; 150 W.

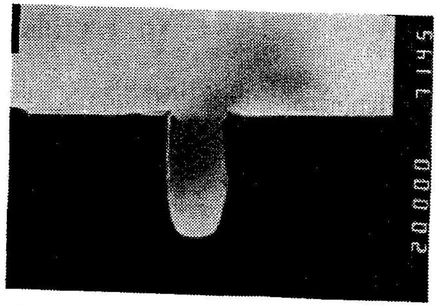

Fig. 4. $CBrF_3/O_2$ (25%); 30 Pa; 150 W.

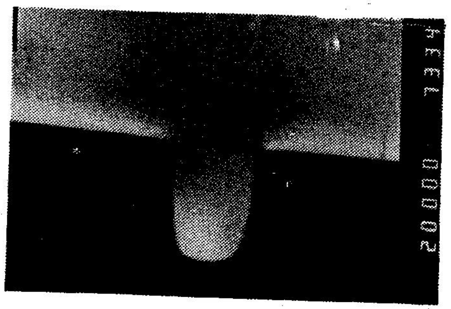

Fig. 5. $CBrF_3/O_2$ (50%); 50 Pa; 150 W.

III. 3. Etching with $CBrF_3$ and 25% SF_6

Mixtures of a fluorine containing gas and a chlorine and/or bromine containing gas are often used for Si-plasma etch processes. The reason is to combine the anisotropic character of chlorine and/or bromine containing gases with the possibility to obtain high Si etch rates, which is typically for fluorine containing gases. That is why we used a mixture of $CBrF_3$ and SF_6, which can provide a big amount of fluorine and/or fluorine containing species. In these experiments we obtained higher Si etch rates up to 500 nm/min. But the selectivities are only slightly higher, because the etch rates of SiO_2 also increase. Etching Si with a $CBrF_3$ and 25% SF_6 in the given parameter field generally has the disadvantage of producing only isotropic profiles (Fig. 6).

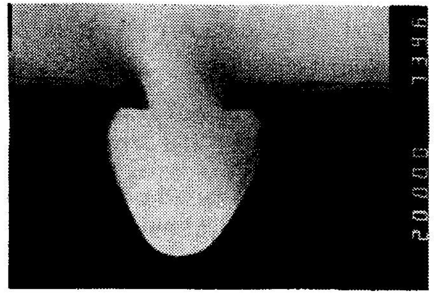

Fig. 6. $CBrF_3/SF_6$ (25%); 50 Pa; 100 W.

IV. DISCUSSION

It is well known that there is the following order of the bonding energies of etch halogens to carbon:

$$C—F(\text{about 5eV}) > C—Cl > C—Br(\text{about 3eV}) > C—J.$$

That is why in an $CBrF_3$ plasma a reactive particle could be produced by electron collision corresponding to

$$CBrF_3 + e \rightarrow CF_3 + Br + e \quad (1)$$

$$CBrF_3 + e \rightarrow CF_3 + Br + 2e. \quad (2)$$

However, there exist two different hypotheses about the etch reaction of silicon in such a $CBrF_3$ plasma. Matsuo [4] and also Abachev et al. [3] interpreted the etch process as an reaction of Si with fluorine and/or fluorine containing species, where bromine plays the role of a chemisorbed protective monolayer, which suppresses the etch attack. Only in places where ions bombard the surface, the Si etch process takes place, which means in a vertical but not in a horizontal direction. Thus anisotropy is achieved. This reaction can be described as follows

$$Si + Br + CF_a \rightarrow \underset{\text{(f.e. } SiF_4)}{SiF_a} + CBr. \quad (3)$$

The model assumes that chemisorbed bromine is not able to produce volatile products with Si [3].

El-Masry et al. [5] described Si etch experiments with pure Br_2. These results show that bromine does not etch silicon spontaneously. But above a 50V self-bias voltage it is possible to etch Si with bromine anisotropically with very good selectivities to silicon dioxide. The second hypothesis, proposed for instance by Morgan [6], suggests that silicon reacts with bromine. The anisotropy is due to a recombining mechanism involving CF_3 radicals. This mechanism is known from the etching of poly-Si with C_2F_6/Cl_2 and CF_3Cl (Mogab/Levinstein) [7]. It is possible to describe this reaction by the following equation

$$Si + X_b(\text{f.e. Br}) + CF_a \rightarrow \underset{\text{(f.e. } SiBr_4)}{SiX_b} + \underset{\text{(f.e. } CF_3)}{CFa} \quad (4)$$

This hypothesis is based on typical emission data from Flamm et al. [8]. He only found concentrations of Br_2, Br, CF_2 and CF_3 radicals but no measurable concentrations of F_2 or F.

Also polymer films produced in an $CBrF_3$ plasma were analysed by Flamm et al. [8] with XPS and RBS. From these techniques, Br was not observed in the film itself, only at the silicon/polymer interface. Our results in the given parameter field show no mask undercut. From this it can be concluded that there is no atomic fluorine in the plasma, because it is well known that atomic fluorine results in isotropic profiles. It is also possible to see the so-called sidewall passivation layers in the SEM pictures (see Fig. 1). These layers seems to be absent with a big amount of O_2 (50%) in $CBrF_3$. That is why we think that these are carbon containing polymer layers, which suppress the etch attack in the vertical direction (compare Fig. 1 and Fig. 5).

Sazukawa et al. [9] analysed (AES) those sidewall deposition layers (which were) produced in a triode etch system (13.56 MHz + 100 kHz) using a $CBrF_3$ and a SiO_2 mask.

They detected a 20 ... 30 nm thick carboniferous polymer layer and in the upper part and near the trench bottom thin SiO_2 layers. These layers probably,

together with the ion bombardment result in the "V"-shape corners in the lower pressure range of the pure $CBrF_3$ etch process (Fig. 2), which would mean that these corners consist of polymers and not of silicon. Against this, no passivation layer is visible in the $CBrF_3$ and SF_6 process. The reason seems to be a high concentration of fluorine atoms and radicals, as it is known in pure SF_6 plasmas. That is why the achieved profiles were only isotropic.

V. CONCLUSIONS

Experiments were made to produce deep trenches in Si with $CBrF_3$ and dilutions of O_2 and SF_6. The results show that it is possible to obtain anisotropic trenches without a mask undercut, with slightly tapered sidewalls and a round bottom for $CBrF_3$ as well as for $CBrF_3$ and O_2 (25% and 50%). We achieved the best profiles at 30 Pa to 50 Pa and 150 W for $CBrF_3$ and 50% O_2 (Fig. 5). In contrast only isotropic profiles were produced with a mixture of $CBrF_3/SF_6$ (25%). To fully understand the etch mechanisms further experiments including optical emission spectroscopy will be carried out.

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ПЛАЗМЕННОЕ ТРАВЛЕНИЕ ГЛУБОКИХ КАНАВОК В Si С ПРИМЕНЕНИЕМ $CBrF_3$ И РАСТВОРОВ

В работе приводятся результаты экспериментов с использованием $CBrF_3$ и растворами O_2 и SF_6 при травлении канавок в Si. Показано, что анизотропические канавы с неподтравленными краями обеспечивают с $CBrF_3$ и $CBrF_3/O_2$. Изотропический профиль канавы получен с раствором $CBrF_3/SF_6$. Некоторые проблемы и возможные реакции в плазме приведены в дискуссии.