Abstract

SF₆ plasma properties has studied SF₆ gas was used as an etching gas. A home built lab. Scale plasma etching system was employed to generate DC plasma. A current density as a function of etch rate vs. voltage at constant pressure and current density as a function of etch rate vs. pressure at constant voltage without wafer were obtained the topography of etchant Silicon - wafer i.e., anisotropy under cutting and dimension were tested. The results were: increasing the voltage and pressure led to increase the current density.

SF₆ دراسة خواص بلازما 

الخلاصة

استخدم غاز SF₆ كغاز حفر في منظومة محلية الصنع ولدراسة خصائص بلازما SF₆ المتولدة فمنا بقياس الكثافة التيارية كدالة للحفر مع الفولتية بثبوت الضغط والضغط بثبوت الفولتية على التوالي، لاحظ الباحث حصول زيادة في الكثافة التيارية عند زيادة الضغط والفولتية. كذلك اخذ صورة للعينة المحفورة لمعرفة نوع الحفر الحاصل وخصائصه.
**Introduction**

With the advancement of microelectronic fabrication, new technologies and techniques have been developed to meet the demands of changing design for integrated circuits. As the dimensions for these solid state device shrink, processing techniques must constantly be re-evaluated to ensure reproducible and precise results. One such process that has changed considerably since the introduction of the micro chip is the etch process.

The logic behind the etching process is fairly simple. During etching; a film or layer on the wafer which is not protected is chemically removed. For example, after photolithography forms patterns on the wafer, etching is used to remove the areas where resist is not present. Etching may also be used to clean away resist in future steps. This process has evolved over the past 30 years from a liquid etch technique to a dry etch step, or plasma etching (3). Finally the two main types of species involved in plasma etching are:-

the chemical component and the physical component.

Plasma is the forth state of matter. Solids, fluids and gasses being the first three state of matter (1).

When a solid is heated, it liquefies; when a liquid is heated it become a gas , when a gas is super-heated, it breaks down in to free electrons and positively charged ions. (An ion is part of an atom or molecule with an electrical charge). This "ionized" gas is called a plasma. It conducts electricity. A common example of plasma(on the earth) is a lightning bolt (2).

Mucha and Hess define a plasma or glow discharge as "a partially ionized gas composed of electrons, ions, and a variety of neutral species (4). These plasma contain approximately equal concentrations of positive and negative charge carriers. The reactive species that bombard the wafer in chemical/physical etching and the reactive species that undergo
reactions at the surface (pure chemical etching) are produced in the plasma (5).

These species are formed by applying an electric or magnetic field to a volume of gas; however, high temperatures may also be used. Many types of plasma may be formed based on electron concentration, n (densities between $10^9$ and $10^{12}$ cm$^{-3}$), and average electron energy (kTe), where is K= Boltzmann's constant. The electron energy (typically 1-10 eV) is described by the ratio of electric field strength to the pressure, E/p.(4)

Case Studies

- Mogab et al. (1985) (11) they used a planar reactor with a 13.5 MHz rf supply and a mass spectrometer analysing the gas in the effluent line. They concluded that the F atoms were the principal etching species.
- Blom et al. (1988) (12) have studied the plasma etching of poly-Silicon in a dc discharge. By using a dc plasma, it is possible to measure voltage and current separately. Hence it is possible to study the effect of both the ion flux and the gas flux on to the etched surface. The etching behaviour of CF$_4$, NF$_3$, and SF$_6$ has been investigated. They found the etching yield was larger for the SF$_6$ gas than for the other gases.
- Parrens (1981) (13) experiments performed in a reactive ion etching system are discussed with the purpose of displaying the influence of reactive gas nature on etching anisotropy and selectivity. Using SF$_6$ etching he found that the higher selectivity but under cutting appears with an overetch.

Advantages of Plasma etching

Dry, or Plasma, etching has presented solution to virtually all of the difficulties associated with wet etching. Adhesion is not critical with this process and under cutting may be
controlled by altering chemistries, gas pressures, and electrode potentials. In addition, large amounts of dangerous solvents and acids may be avoided with dry etching. Dry etching is also carried out more easily with fully automated processes. These advantages have fueled the motivation to move from wet to plasma etching (4).

**Plasma etch methods for various films**

Most reactant gases for plasma etching contain halogens, generally C1 and F, and sometimes Br. Free radicals of these species can easily be produced in a plasma which can efficiently etch many films, and volatile etch products commonly result with these species. The exact choice of reactant gases to etch a specific film depends on a variety of factors. The most important being:

1. Etching selectivity to underlying films.
2. Anisotropic etching.
3. Volatility of main etch byproducts.

Since in an etch process it is necessary to remove the species byproducts from the surface keep them off the wafer and pump them out of the system, the volatility of the main byproducts is an important consideration in choosing the gas chemistry. The volatility or tendency to evaporate, depends on how tightly bound the species is to the surface (6).

**SF₆ gas**

Fluorine-based chemistries are usually used to etch Si, the volatility of the main etch product SiF₄ is very high as indicated by its low boiling point (-86°C) and thus the SiF₄ can easily leave the surface via thermal desorption (6).

In this paper we study SF₆ properties to contain on larger number from F-atoms.

Sulfur hexafluoride is an inorganic compound with the formula SF₆. It is a colorless, odorless, non-toxic and non-flammable gas (under standard conditions) SF₆ has an octahedral geometry,
consisting of six fluorine atoms attached to a central sulfur atom. It is a hypervalent molecule.

Typical for a nonpolar gas, it is poorly soluble in water but soluble in nonpolar organic solvents it is generally transported as a liquified compressed gas. It has a density of 6.13 g/L at sea level conditions.(7)

**Applications**

Of the 8000 tones produced per year, most of the SF$_6$ goes in to many applications (7):

1. As a gaseous dielectric medium or other use in the electrical industry which accounts for 6000 tones.
2. As an inert gas for the casting of magnesium.
3. An inert filling for windows.
4. In medical as a contrast agent for ultrasound imaging.
5. SF$_6$ Plasma is also used in the semiconductor industry as an etchant.
6. The magnesium industry uses large amounts of SF$_6$ as inert gas to fill casting forms.

Etching with a signification isotropic component can result using source gases such as NF$_3$, CF$_4$, SF$_6$. SF$_6$ dissociates to form free F in a plasma via the reaction as shown (9):

\[
\begin{align*}
    \text{FS}_6 + e & \rightarrow \text{SF}_5 + F + e \\
    \text{FS}_5 + e & \rightarrow \text{SF}_4 + F + e \\
    \text{Si} + F & \rightarrow \text{SiF} \\
    \text{SiF} + F & \rightarrow \text{SiF}_2 \\
    \text{SiF}_2 + F & \rightarrow \text{SiF}_3 \\
    \text{SiF}_3 + F & \rightarrow \text{SiF}_4 \\
    \text{SiF}_2 + \text{SiF}_2 & \rightarrow \text{SiF}_4 + \text{Si}
\end{align*}
\]

**Plasma Parameters**

1. Pressure effects
Pressure directly influence major phenomena that control plasma etching. Among these are:
1-The sheath potentials and energy of ions bombarding surface.
2-The electron energy.
3-The ion-to neutral abundance ratio and fluxes of these species to surfaces.
4-The relative rate of higher to lower order chemical kineties.
5- A surface coverage by physisorption.
6-The relative rates of mass transport processes (8).

2-potentials effects

The characteristic potentials across the sheaths and the voltage applied to a discharge increase sharply, from some tens of volts up to 1000 V or more. As bias is proportional to the peak applied voltage, $V_p$, it rises too. Since the mean-free-paths of species are inversely proportional to pressure, the rise in potential translates into a higher energy ion flux to substrate surfaces (8).

Experimental setup

A home-built DC lab-scale plasma etching system. The system consist of tow parallel with equal area electrodes. The cathode surrounded by cathode shield. The shield has a central circular shape aperture arrange to consiste with the center of cathode. The electrodes were cooled by water cooling system and separated by an average distance of 3 cm. The wafers were placed under the ground shield covering partially the shield hole opening. This arrangement defines the etching area and make it possible to calculate current density. A regulated home made DC power supply (2kV,0.5 A) was connected to the electrode via current limiter of 13k (10).
Result & Discussion

Fig.(1) is shows the current density as a function of etching rate vs. voltage in a Dc SF₆ plasma at 50 mT pressure. We can conclude that increasing the voltage led to increase the current density because the mobilited limited version of chid. Langmuir equation, the current density is proportional to \( V^2 \) increasing the voltage causes more energetic ion bombardment of the wafer (physical component), with stronger ion achieved. In addition, the higher physical bombardment more directional etching can be a component can lead to less selectivity with more damage on the surface of the wafer which etched.

Increasing the pressure causes increase in the plasma density (since there are more atoms, molecules to begin with generation of reactive neutral radicals and a gas atoms available to be ionized or converted in to radicals), That is shown in Fig.(2). Here the current density as a function of etch rate vs. pressure at 1.3kV in SF₆ plasma, increases pressure will increase the current density. In addition, also increasing the pressure causes more gas phase collisions to happen decreasing the directionality of the etching with better selectivity.

In Fig.(3) displays, p-type Si wafer etched by using SF₆ plasma under condition operating at 1.3kV, 50 mT, we get on etch rate was good (2178.6 A/min), with selectivity etch (isotropical etch), because the etching was chemical component (generally the chemical flux increases with pressure). The etching is purely chemical. It can be very selective. It also causes very little damage to the Surface because of the lack of ion bombardment.
Conclusions

1- Increasing the voltage led to increase the current density as a function of etch rate.
2- The current density increases with increase in pressure.
3- Obtain on isotropic etch.
4- Obtain on selectivity etch with little damage to the surface of wafer.
References
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Fig. (1) Current density vs. Voltage at constant pressure 50 mT

Fig. (2) Current density vs. pressur at constant voltage 1.3 kV
Fig.(3) Shows topographic of Si-surface