

Studying Properties of SF₆ Plasma

Intessar K. Abd
Computer Dep.

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 .

دراسة خواص بلازما SF₆

الخلاصة

استخدم غاز SF₆ كغاز حفر في منظومة محلية الصنع ولدراسة خصائص بلازما SF₆ المتولدة قمنا 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.

Diala, Jour, Volume, 37, 2009

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 fourth state of matter. Solids, fluids and gases being the first three states of matter (1).

When a solid is heated, it liquefies; when a liquid is heated it becomes a gas, when a gas is super-heated, it breaks down into 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 plasmas 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

Diala, Jour, Volume, 37, 2009

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 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

Diala, Jour, Volume, 37, 2009

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 some times 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 by products is an important consideration in choosing the gas chemistry. The volatility or tendency to evaporate, depends on how tightly bound the species is to 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 a 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,

Diala, Jour, Volume, 37, 2009

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 SF₆ 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.

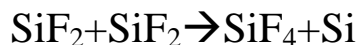
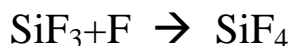
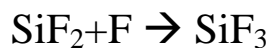
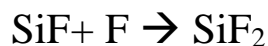
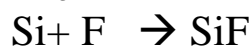
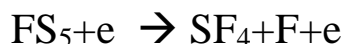
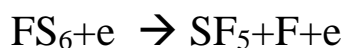
3-As an inert filling for windows.

4-In medical as a contrast agent for ultrasound imaging.

5-SF₆ Plasma is also used in the semiconductor industry as an etchant.

6-The magnesium industry uses large amounts of SF₆ as inter gas to fill casting forms.

Etching with a signification isotropic component can result using source gases such as NF₃, CF₄, SF₆. SF₆ dissociates to form free F in a plasma via the reaction as shown (9):-



Plasma Parameters

1-Pressure effects

Diala, Jour, Volume, 37, 2009

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 kinetics.
- 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 difines 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).

Diala, Jour, Volume, 37, 2009

Result & Discussion

Fig.(1) 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 mobilized limited version of Child-Langmuir equation, the current density is proportional to V² increasing the voltage causes more energetic ion bombardment of the wafer (physical component), with stronger ion bombardment. 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 into 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 of occur 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 (isotropic 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.

Diala, Jour, Volume, 37, 2009

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.

Diala, Jour, Volume, 37, 2009

References

- 1-Jon Gand. Plasma: star Drive, 1star drive /solar/plasma 2008.
- 2-Chuck Laundry "Improving plasma cutting in sheet metal Applications",archive.metalalforming magazine /1997/09/plasma 1997 plasma.htm
- 3- Ruska , W.S.; “ Microelectronics Processing ” w, stephen ,ed. , Mc Graw. Hill , New York ,1986,pp.192,214-218.
- 4-Mucha,J.A: Hess, T.w; "Introduction to Microlithography", (L.F.et,al,ed, American chemical society, Washington.D.C., 1983, pp.316-219.223).
- 5-- Wolf , S.; & Tauber, R.N.; “ Silicon Processing"James D. plummer et .al. " Silicon processing", Lattice press, Sunset Beach, CA,1986,pp.545-546.
- 6-James D plummer et. al." Silicon VLSI Technology" Upper Saddle , River. NJO 7458.2000,pp.643-644.
- 7-"Sulfur hexafluoride",Sciencedaily /articles/s/ Sulfur-hexafluoride 2008.
- 8- Dennis, M. Manose & Daniel , L. Flamm , “ Plasma Etching An Introduction” ,a cademic press, 1985.
- 9-Joosten, et .al, "Dynamics of ion-assisted etching in the Si(100)/XeFe-system on a time scale 100 s.1000s. J.vac. Sci. Techuol. A, vol 12,p,36,1994
- 10-Intessar.k., Munther A.R., "Etching of Silicon wafers using SF₆ plasma", Journal of Diyala, wo22/2006.
- 11- C. J. Mogab , J.Appl. Phys. , Vol.49,(7) P.3796.1985.
- 12- H. D. Blom , et al.; “DC – etching of poly –silicon with fluorine chemistry” Vaccum,Vol.38,no.8-10, 1988, pp.813-816.
- 13-P. Parrens , “Anisotrpic and selective reactive ion etching of polysilicon using SF₆” , J.Vac.Sci.Technol.,Vol.19.No.4, 1981,pp.1403-1306.

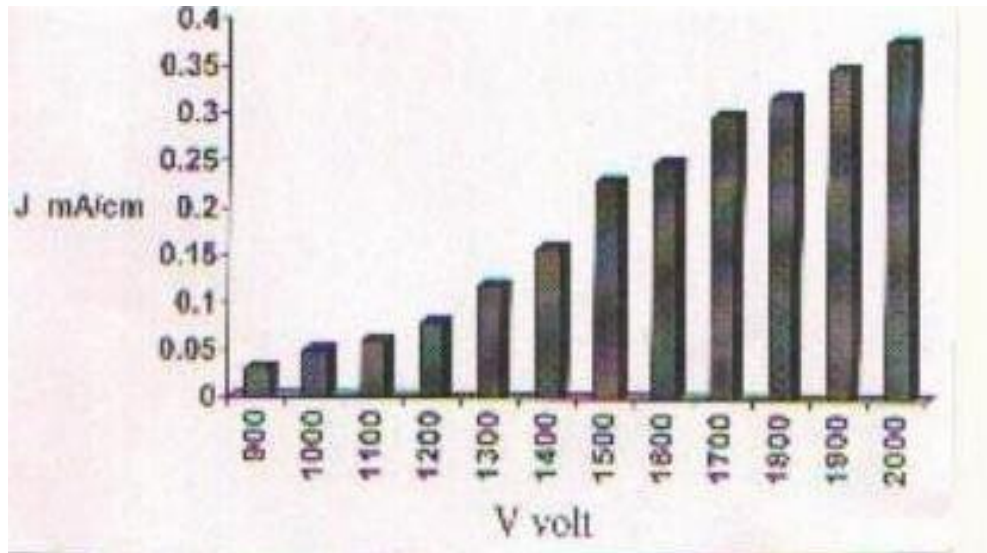


Fig.(1) Current density vs. Voltage at constant pressure 50 mT

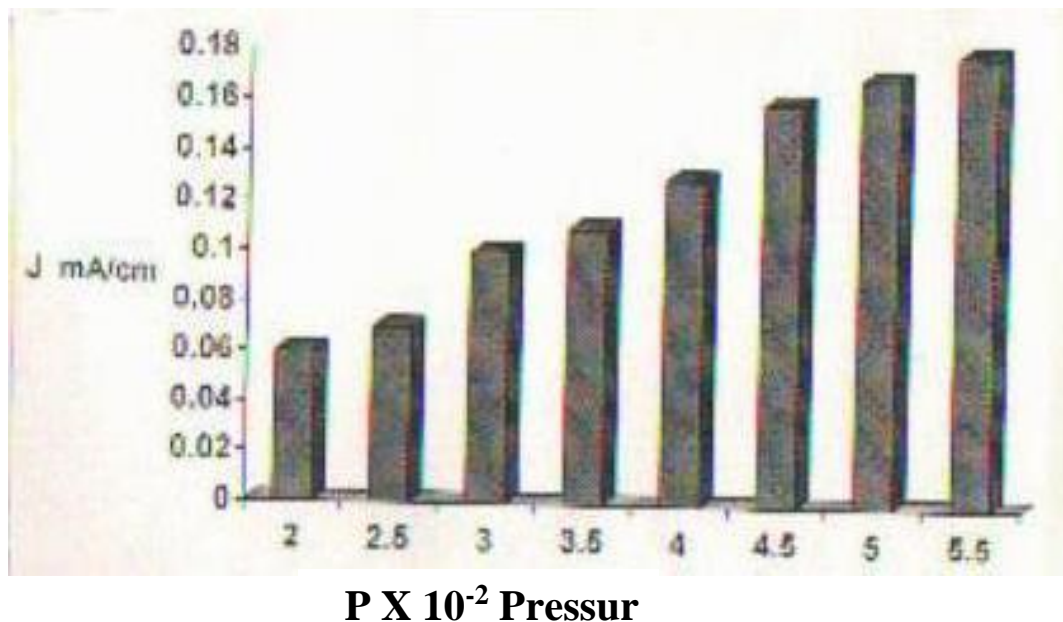


Fig.(2) Current density vs. pressure at constant voltage 1.3 kV



Fig.(3) Shows topographic of Si-surface