Research Paper Physics

A Survey on the Chemical Assisted Plasma etching of Semiconductors (ECR Based)

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ABSTRACT

This paper is a brief review of dry etching with emphasis on Chemical Assisted Plasma Etching (CAPE) mode of Semiconductors as applied to pattern transfer. It focuses in concepts and topics for dry etching techniques. The detailed explanation is given for plasma etching and the Electron Cyclotron Resonance (ECR) concept and design and its application in CAPE mode. A micrograph of Si wafer etched using CAPE mode is also included in the study to show the anisotropic etching of CAPE mode.

Keywords : Chemical Assisted Plasma Etching, ECR Plasma

Introduction

Wet etching was the standard method of pattern transfer in early generations of integrated circuits. This stemmed primarily from the fact that etchants with high selectivity to both the substrate and the masking layer were readily available. However, wet etching processes are almost invariably isotropic in nature. Consequently, when the thickness of the film being etched becomes comparable to the minimum pattern dimension, the undesirable lateral undercut due to the etch isotropy of wet etchants is no longer tolerable. In order to overcome the shortcomings of wet etch processes, the technique of ion assisted plasma etching has become widely used in semiconductor manufacturing. Since this method offers the added feature of etch anisotropy, considerable effort has been expanded in recent years to develop dry etch processes. [1-2]

Dry etching is an etching process that does not utilize any liquid chemicals/etchants to remove materials from the wafer, generating only volatile byproducts, in the process. Dry etching may be accomplished by any of the following: 1) through chemical reactions that consume the material, using chemically reactive gases, and/or plasma; 2) physical removal of the material, usually by momentum transfer; or 3) a combination of both physical removal and chemical reactions.

There are many advantages of dry etching compare to wet etching. Since most dry etch process use a low pressure gas in the form of plasma to provide the etching, dry etching has become synonymous with plasma etching. [3]

Plasma Etching

This is largely chemical in action, and relies on the fact that with the right chemistry, surface atoms can be turned into gas phase molecules which can be pumped away (Figure 1). A glow discharge plasma (usually RF) is used to generate reactive species, e.g. atoms, radicals and ions, from parent gases. These diffuse to the surface to be etched, form volatile products which then desorbs from the surface and are pumped away.

Typical reaction examples are:

$CF_4 \rightarrow F, CF, CF_2, CF_3,$ *etc.*

$Si(s) + 4F \rightarrow SiF_4(g)$

Neutral Radical Volatile by-product

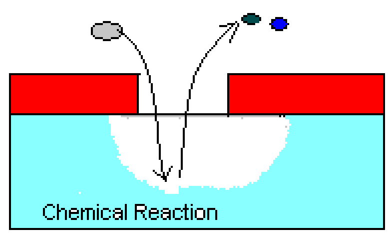

Fig 1. Isotropic, Pure Chemical reaction, Low Vacuum, Less Electrical Damage Plasma Etching

Dimensional control in etching small geometries- necessary for advanced micromachining- is an important topic in fabrication of semiconductors. To achieve this plasma assisted etching is increasingly used due to (1) the achievement of etch directionality without using the crystal orientation as in the case of wet etching of single crystals like Si, Ge or GaAs, (2) the ability to faithfully transfer lithographically defined photo resist patterns into underlying layers and (3) cleanliness and compatibility with vacuum processing technologies. But the chemistry has to be chosen carefully such that the etch products are volatile species. For this reason most process gases in the semiconductor industry utilize halocarbons, such as CF_4 or CF_2Cl_2. For example, to etch Al (the material most IC interconnects are made from), chlorine-containing reactants are used (e.g. BCl_3), since the etch product, $AlCl_3$ is volatile under the low pressure process conditions. Fluorinated gases cannot be used for etching Al since AlF_3 is a hard, crystalline material. It is often desirable to be selective towards the underlying material and masking material that are, to etch the top layer much faster than the lower layer. Again, suitable choice of chemistry allows this.

Electron Cyclotron Resonance Plasma

Theory of Electron Cyclotron Resonance (ECR) centers on the interaction between a time-varying electric field and a static magnetic field. ECR reactors produce higher temperature electrons more efficiently than both ICP setup and MERIE technology.

High temperature electrons increase the ionization probability to produce high density plasma. Electrons moving in a static magnetic field, in the absence of an electrical field, experience a force that causes an electron to spiral in a helical motion where the axis of the spin is parallel to the direction of the magnetic field. The angular speed (ω) of an electron spiraling in a magnetic field is equal to the product of the electron charge (e) and the magnetic field intensity (B) divided by the mass (m) of the electron. Electrons in an electric field, without a magnetic field, accelerate in the opposite direction of the electric field. The combined force on an electron due to both magnetic and electric fields is known as the Lorentz Force as shown in Fig 2.

The frequency of cyclotron due to Lorentz force is

$\omega_{ce} = (eB)/m_e$

Whereas: $\omega = 2\pi f$, e= 1.6×10^{-19} C, m=9.1×10^{-31} Kg, B = 875 G = 0.0875 T

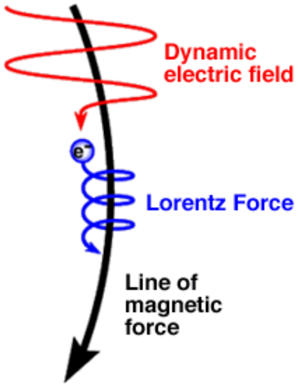

Fig 2. Lorentz Force

Chemical Assisted Plasma Etching

The development of Reactive Ion Etching (RIE) & Chemically Assisted Ion Beam Etching (CAIBE) has contributed a great deal to the fabrication of much smaller semiconductor devices [4] MEMS [5], Nanocavities and nanostructure [6]. The processing in these modes has achieved very good maturity for etching of silicon and silicon related materials but however some improvement in etching is always been carried out mainly by trial and error on the work front.

The ECR plasma has very low plasma potential. In ECR plasma there is no self-biasing of the wafer and therefore etching experiments are carried out in Chemically Assisted Plasma Etching (CAPE) mode [3], the micrograph of Si etching profile of chemical assisted plasma etching is shown in Fig 3.

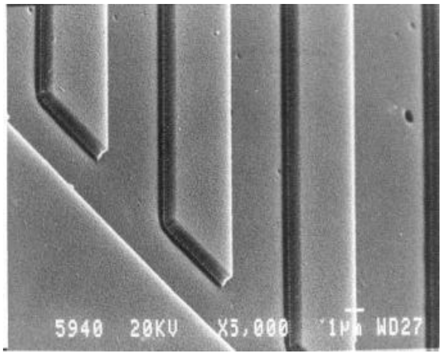

Figure 3. Micrograph of Si etching profile in CAPE mode

In order to active significant sputtering rates at the wafer, precise control of ion energy, it is necessary to apply RF or dc bias [7], which involves separate power supply and matching network (but has the nice feature that plasma density and ion energy are then independently controllable). The beneficial features of the ECR plasma are the generation of high-density plasma at low pressure $10^{-4}/10^{-5}$ Torr and low energy

Industrial plasma etching is complex. While the clearest insight into basic mechanisms comes from studies in simple chemical systems such as F, Cl_2 etc or with plasma like radicals or reactive species studied outside of a plasma complex feeds have been empirically formulated to meet practical process needs. One of the earliest plasma feeds to fine widespread use was CF_4/O_2. Plasmas sustained in this feed selectively etch silicon over SiO_2 and resist. The feed mixture itself is non-toxic and easy to handle. This process was in use for many years before the active etchant was clearly identified as atomic fluorine. ECR plasma has been used widely and industrially for Chemical Vapor Deposition (CVD) and etching in semiconductor processes. ECR plasma source has some excellent features such as low pressure (approximately 1 mTorr) plasma generation, the capability of low ion energy (< or =15 eV) control and high ion density (< or approximately =1012 cm^{-3}) [9-10]. The uniformity and the throughput of ECR plasma equipment are remarkably improved by using a dual magnetic coil, a high power microwave generator and a large capacity exhaust. The improved equipment is suitable for various kinds of application. The ECR plasma will play an important role in VLSI processes [8].

The Electron Cyclotron Resonance (ECR) discharge is used as plasma sources for substrate etching and deposition. Typically; they are configured with a source chamber that produces plasma that flows downstream to a substrate. They provide what is desired in the fabrication of microelectronic circuits: good anisotropy, high etch rate, and little substrate damage.

The ECR sputtering method has been reported as a low-damage deposition method. That can form a high-quality HfO_2 films at different materials.

ECR used in etching of Si [11-12], SiO_2[13], Si_3N_4[14] and also used for Kinetic study of low energy argon ion-enhanced plasma etching of poly-silicon with atomic/molecular chlorine[15].

ECR system is also ideally suited for dry etching of III-V semiconductor devices, for etching of InP based devices in CH_4/H_2 plasmas [16] and GaAs [17], GaN[18]/InGaN/AlGaN[19] based devices and GaInAs [20] with different gases e.g. Cl_2, CCl_2F_2,Ar, PCl_3, O_2,CH_4 plasma.

Conclusion

Dry etching, which continues to be the technology of the choice for the industry and expected to dominate for the subquarter micron line width fabrication of the semiconductor devices. The inclusion of anisotropic parameter in dry etching process leads to the horizon for fabrication of the Micro-electromechanical system and micro-sensors where high anisotropy is the prime condition. In process of precise replication of the patterns for the different materials, the different environment of plasma generation is required. The electron-molecules reactions are responsible for ionization and dissociation in the plasma and the etching process is mainly characterized by the chemically species, momentum and energy of these species and residence time. The direct exposure of the high energy plasma to wafer, leads to given isotropic etching and radiation damage to the substrate/wafer during the etching. Therefore, the prime condition for damage less and high anisotropic pattern replication needs a remote exposure of the low energy plasma at low pressure. The Electron Cyclotron Resonance based chemical assisted plasma etching is the best choice for generation of the low energy ion and high flux at low pressure for etching of semiconductor and compound semiconductor etching

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