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CONTROLLED CHEMICAL PLASMA ETCHING FOR ADVANCED TECHNOLOGY APPLICATIONS

Application Note

INTRODUCTION

Over the past thirty years, plasma, the fourth state of matter, has become a very useful means of removing small quantities of material from a variety of substrates quickly and efficiently. Plasma processes have been used in many highly sensitive integrated circuit packaging and optoelectronic applications to precisely remove specific materials from sample surfaces. The theory of chemical etch plasmas, some typical advanced technology applications, and how to control the plasma etch process for these applications will be discussed.

THE CHEMICAL PLASMA

The room-temperature gas plasmas employed are typically generated in a vacuum chamber. To generate plasma, the chamber is pumped to a pre-set base pressure, process gas is introduced, and a radio frequency (RF) electromagnetic field is applied to the electrodes in the chamber producing a glow-discharge plasma. In the plasma, many different gaseous species are produced. These species include ions, free radicals, electrons, photons, neutrals, and reaction by-products such as ozone. These species make a highly active, low-temperature plasma that can etch material selectively and quickly.

Controlling this type of plasma for effective etching is a balancing exercise. The proper amount of ions and free radicals (the species that do most of the work) in and around the area to be etched must balance with the RF power input into the system. Generally, the amount of ions and free radicals is governed by the process pressure, thus making process pressure a very important process parameter. RF power input, on the other hand, must be selected so that the highest etch rate is produced without over etching or inadvertently damaging other materials or substrates. The process time parameter must also be selected with care because it, like power and pressure, can greatly affect the outcome of the process cycle.

One significant advantage that chemical plasmas have over other types of plasma is their natural selectivity. Selectivity, in this sense, is defined as a chemical's propensity to react with one substance rather than another. In plasma, this is extremely useful characteristic. It provides the opportunity to tailor the plasma etching process to the substance of interest and not cause unwanted etching to other substances which can be in close proximity.

Reactive Ion Etching (RIE) is a type of chemical plasma. It is characterized not only by the parameters and characteristics mentioned above, but also RIE is extremely directional and anisotropic. It has many applications, this Application Note discusses applications specific to semiconductor and optoelectronic processing and packaging.

APPLICATIONS

Photoresist Removal

Photoresist removal has two plasma process applications. The first application is uniform removal of small quantities of resist over the entire surface of a wafer. This is known as "descum". In this case, etch rate should be moderate, and a low-reactivity process gas, such as O_2, is used. RF power should be kept low as well. To increase the uniformity of the descum operation, operating pressure must remain relatively high and usually from 600 mTorr to 1000 mTorr. At low power and high pressure, a very isotropic and uniform distribution of ions exists thus achieving a highly uniform, moderately rapid etching operation.

The other plasma application for photoresist removal is etching features from patterned photoresist. In this case, the etching operation must be fast and especially anisotropic. The isotropic etch must produce very vertical wall features with no undercutting. As a rule, highly reactive process gases or gas combinations such as CF_4 or a mixture of CF_4 and O_2 are used. To make the plasma as anisotropic as possible, pressure is lower than the descum process discussed above, while RF power is increased. The decreased pressure (usually in the 100 to 200 mTorr range) provides the anisotropic nature of the plasma, and the increased power compensates for the lack of ions to increase the etch rate. The side effects of this operation are over etching and non-uniformity. Process time will manage any over etching issues, but increased uniformity will require a rather close balance of power and pressure. This power and pressure balance will be material and substrate-geometry specific and may take a small amount of process development to achieve satisfactory results.

Glass and Glass-like Compound Etching

In many ways, etching glass or glass-like substances like SiO_2, Si_3N_4, and single-crystal silicon is similar to photoresist etching. The biggest difference is process gas selection. Glass is a very non-reactive or stable substance. Consequently, highly reactive process gases like CF_4 and SF_6 are employed. Analogous to photoresist removal, the degree of anisotropy and uniformity can be controlled largely by pressure and power using the gases mentioned. However, unlike photoresist removal, etch rate will vary widely due to the fact that glass is an amorphous substance that can vary widely in composition. Care must be taken when developing etching recipes not to damage valuable parts by inadvertent over etching. Applications for this type of etch include fused-silica optical fiber etching and etching BPSG, SiO_2 and Si_3N_4 in IC failure analysis operations.

Polymer Etching

Etching polymers can be exceedingly challenging or exceedingly simple. The challenge springs from the fact that polymeric substances are widely varied in their makeup. For instance, polypropylene encompasses several hundred different compounds of polymer, all of which conform to the characteristics innate to polypropylene. The slightest change in plasticizer or UV stabilizer makes developing a single, all-encompassing etching recipe nearly impossible because there is usually no common starting point. The technique for etching polymers is the use of a mixture of process gases. Oxygen and tetrafluoromethane (CF_4), when mixed together for use in plasma etching, create the oxyfluoride ion (OF^-). The oxyfluoride ion is a powerful etching agent for polymeric substances. This ion is particularly adept at cutting the carbon-carbon molecular bonds in the polymer backbone and removing the molecule quickly.

One application of polymer etching is hole boring in polyamide when the polyamide is sandwiched between two, conductive sheets of metal. The holes are easily made using a ratio 80% oxygen and 20% CF_4 at low pressure and high power. Time will depend on the polyamide make up and the depth, but low pressure will insure clean, straight sidewalls in the hole. Selectivity will insure that only the polymer inside the whole is etched. Due to the selectivity of the etching process, the metal around should be unharmed by the etching operation.

Another application is the etching of polyamide in bulk form such as off a wafer. This, again, is similar to etching photoresist in that the process pressure is set relatively high for good uniformity, and the power is increased to speed etching rate. In addition, this operation is like etching glass because the composition of the polyamide can be varied, thus causing unpredictable etch rates. Generally, a good starting point for process recipe development is high pressure and moderate power.

A final application in the discussion of polymer etch is optical fiber cladding etching. Optical fibers consist of a fused silica core, which is approximately 100 μm thick surrounded by polyurethane cladding usually another 125 μm thick. The application here is to etch the cladding completely off a specific section of the fiber expose the fused silica core without damaging it. To uniformly treat all the fiber optic strand, an especially isotropic plasma is needed. Thus, pressure should be near 500 mTorr with high power. Time is the most important parameter in this application, because, even at 90% O_2 and 10 % CF_4, the CF_4 can damage the silica core and diminish strand pull strength. The fiber optic stand must be etched only long enough to remove the cladding.

Bleedout Removal

During epoxy dispensing operations, the amount of dispensed epoxy is excessive or the substrate material causes a small quantity of the epoxy to wet out over its surface. This problem is particularly critical when subsequent wire bonding is required. The epoxy residue can contaminate wire bond pads causing poor bond strength or wire bond “pull-up” which is the complete failure of the wire bond. To remove the epoxy contamination, an argon, argon and oxygen, or argon and hydrogen plasma is used around the 200mTorr to 250 mTorr pressure range. Argon is an inert gas, but it can be highly effective in removal of the epoxy bleedout through pure bombardment using Ar+ ions. The bombardment cleans the surfaces of the wire bond sites by ablating the epoxy and leaving a pristine metal surface behind. The addition of a chemically reactive agent such as oxygen or hydrogen simply increases the reaction rate. The amount of reactive gas can vary, but usually, no more than 30% by volume is added. There is one caveat however: addition of oxygen can cause oxidation of silver-filled epoxies thus turning them black. This oxidation is nothing more than the surface tarnishing of the silver in the epoxy, and it does not affect the epoxy’s ability to conduct heat or electricity.

APPLICATIONS LABORATORY

The technical staff at March Plasma Systems is pleased to offer its experience in plasma technology for your applications. We would be happy to publish any data you would like to share with others in the field. Direct your calls and faxes to March Plasma Systems, Attention: Applications Laboratory.

RECIPE SELECTION

Below is a chart for selecting the proper process gasses for etching process recipe development.

Substance	Process Gases	Mixtures
Photoresist	O_2 $O_2 + CF_4$	100% 80% + 20%
Polyimide	O_2 $O_2 + CF_4$	100% 80% + 20%
Polyuethane	O_2 $O_2 + CF_4$	100% 80% + 20%
Single Crystal Silicon	CF_4 $CF_4 + O_2$ SF_6 $SF_6 + O_2$	100% (80% - 92%) + (20% - 8%) 100% (80% - 90%) + (20% - 10%)
Silicon Oxide (SiO_2)	CF_4 $CF_4 + O_2$ C_2F_6 CF_3H C_3F_8	100% (80% - 92%) + (20% - 8%) 100% 100% 100%
Silicon Nitride (Si_3N_4)	CF_4 $CF_4 + O_2$ SF_6 CF_3H NF_3	100% (80% - 92%) + (20% - 8%) 100% 100% 100%
Epoxy Bleedout	Ar Ar + O_2 Ar + H_2	100% (90% - 70%) + (10% - 30%) (90% - 70%) + (10% - 30%)
Tungsten	$CF_4 + O_2$	(70% - 92%) + (30% - 8%)
GaAs	CH_4	100%