Refinements in the Plasma Processing of Polyimide and B.C.B.

Plasma is a state of matter represented by a collection of positively charged ions and negative electrons, capable of conducting electricity and absorbing energy from an electrical supply. Lightning and the Aurora Borealis are examples of plasma that occur naturally, and taking a cue from the Aurora Borealis, plasma is generally created in a low-pressure environment with vacuum.

When a gas absorbs electrical energy, its temperature increases causing the ions to vibrate faster. In an inert gas such as Argon, this absorbed energy can "scrub" a surface clean by bombarding it with ions, but in the case of an active gas, ion bombardment and chemical reactions both occur.

There are a number of ways of initiating plasma and the most common are:

1) Inductive units (Barrel type) running at 13 to 14 MHz and pressures of 200 mTorr to 2 Torr.
2) Capacitive units from D.C. to lower frequencies up to 50 KHz and the same pressure region.
3) Microwave systems at 2.54 GHz and pressures of 200 mTorr to 2 Torr.

These three common methods of plasma generation each have their respective problems and benefits. The inductive systems usually have low-watt density and use a circular inductive coil, making the energy distribution radial and causing diminished plasma activity towards the center of the chamber. The capacitive systems produce more uniformity for flat surfaces arranged parallel to the plates, but the amount of plasma energy is limited. The microwave systems offer higher energy but some non-uniformity.

The microcircuit industry's photoresist community has tested and refined these types of systems and the winner for single wafer, high-power resist strip is the microwave unit. Yield Engineering Systems developed a charge-grounded, microwave system that ensured no free electrons passing through, and thus no C.V. shift for delicate M.O.S. devices. This feature has attracted a number of Gallium Arsenide circuit manufacturers to the CV100PZ.

In addition to our other successes, Y.E.S. has established itself as a leader in polyimide bake ovens. Standard production models have controlled low level oxygen, laminar flow, controlled vacuum level, and are rampable to 450 degrees. When our customers realized we had plasma resist strippers, a number of them gave us itemized lists of modifications they required for better plasma etch of a polyimide surface. We narrowed the list to the following essentials:

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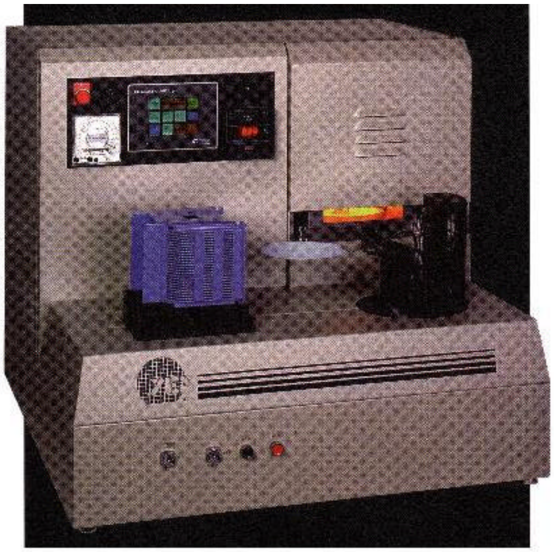


YES CV100PZ

YES PB 450

1) More uniform etching than standard off the shelf strippers.
2) Higher power for etching thick areas of polyimide.
3) Adjustable to provide low power for descum conditions.
4) More direct control of wafer temperature to avoid over-temp conditions.
5) Endpoint indication without the associated problems.

Items two and three were easy, simply investing in higher power microwave supplies with better control. At that time, the typical power supply was a 1 Kw source, but a little research produced a vendor with a power supply adjustable up to 2 Kw. During the development of the unit with this adjustable power supply, a basic problem was observed. The shape of the process chamber and the load placed in it gave variations in reflected power back to the power supply. This reflected power could be modified to a great extent by an automatic tunable wave-guide in the delivery system that drives to the state of lowest reflected power. This is an advantage because it gives more power to the process chamber and less reflected power, which is destructive and contributes to a high rate of over-heating and failure in the magnetron. A simple but neat addition was a microwave isolator that absorbed any reflected power into a dummy load, extending the life of the magnetron.

With a rock solid power supply and good control of this system as a starting point, we examined material removal rate. At high power and the best pressure, we are able to remove one micron of hard-baked polyimide per minute on an eight-inch wafer. With low power and pressure, we removed 100 angstroms per minute with good control.

We were now ready to study uniformity of material removal. A number of factors could influence this and in no particular order, we investigated the following:

a) Wafer temperature uniformity.
b) Chamber temperature variations.
c) Microwave mode formation.
d) Gas distribution.
e) Process pressure.
f) Microwave power.

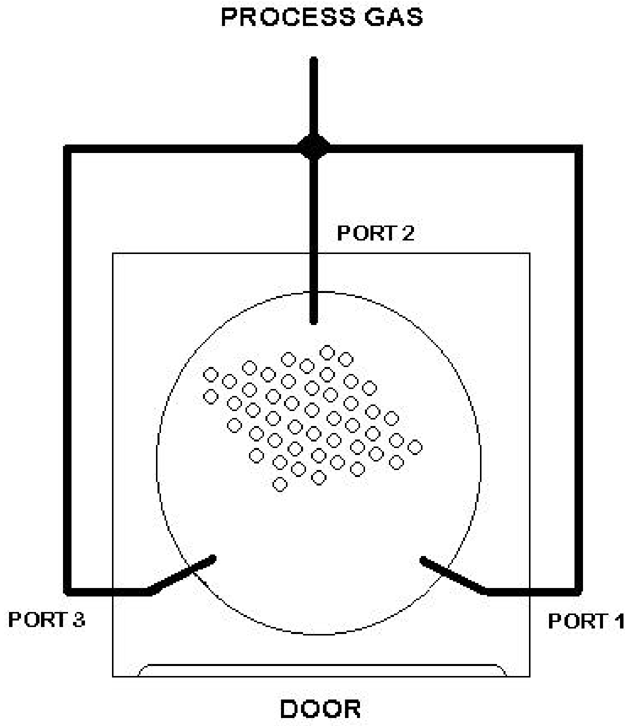
The temperature uniformity can almost be discounted if a hot plate is used for heating the wafer, but for flexible processing a light source is a better solution. A hot plate also gave us problems with chamber temperature uniformity, and although there is non-uniformity inherent in a light source for heating, the conduction of heat in the wafer helps equalize this. The most important parameter to consider was better control of the wafer temperature, so a system was developed for intimate contact of the wafer with the controlling thermocouple. The wafer sits on three quartz pegs, but one has a “Sensoray” ™ thermocouple chip embedded in it to directly control the wafer temperature.

The chamber uniformity was then addressed and the major problem was the difficulty with increases in temperature. As the process progresses, the chamber is heating up with each wafer. Eventually, the chamber radiates heat to the wafer making control difficult, but this is overcome by maintaining the chamber at a constant temperature with a water-cooling jacket.

Microwave mode formation was a more evasive problem. Depending upon chamber size and frequency of the microwave supply, sources of high and low power, modes, are set up. In general, if the process chamber is below a half-wavelength in size there will be no mode formation, but this is too small for most applic ations (with the standard frequency of 2.54GHz the chamber size would be below 2.4 inches.)

The simplistic approach used in most microwave ovens of a rotating fan in the wave-guide delivery system gave problems with control of the reflected energy. A better solution was to minimize the mode formation with chamber design. This worked well with our charge grounding plate because it did not allow microwaves near the wafer. A further bonus was auto tuning varied the impedance dramatically as a microwave oven fan does, reducing the number of modes and varying their positions to give better uniformity.

For better gas distribution, we arranged to swirl the plasma above the grounding plate before delivering it to the process area. This gas swirl technique was utilized previously by



TOP VIEW OF REACTOR

Y.E.S. to solve a process problem encountered by one of our customers. We named this technique the Texas tornado. Instead of delivering the gas through one port, we arranged three ports at 120-degree angles around the chamber and toggled them giving a gentle swirl in either a clockwise or anti-clockwise direction. This was originally developed to get plasma gas below protrusions and effectively clean in difficult to reach areas. Ultimately we discovered that lower power and pressure gave better uniformity, and we now operate in a descum mode that automatically adjusts the power and the pressure to give optimum uniformity, better than 1% variation in removed material!

The need for a more consistent and reliable endpoint detector was then addressed. The standard endpoint detector for the photo resist strippers had problems. They were usually spectrophotometers that looked for the spectra of Carbon Monoxide and Dioxide, both of which are given off while resist is being consumed. The usual method of heating the wafer is to use a light source, so the spectrophotometer head had to look into a bright process chamber and isolate one or more low intensity wavelengths of light. To further confuse the device, any use of CF4 in the plasma tended to destroy the detector and make it more difficult to function. With this type of detector it was common to run till the detector indicated endpoint, then add a number of seconds to the process because there was always a faint trace of resist left.

We purchased two different types of endpoint detectors and found that these problems were evident. However while conducting experiments we discovered there was a significant change in process pressure when endpoint was reached. As the organic was being consumed it was liberating a gas, and increasing the pressure of the system. This gave us a better method of endpoint detection, because the pressure sensor is not confused by light or destroyed by CF4 plasma. Since the pressure sensor was an integral part of the base unit, simple software modifications allowed us to detect endpoint with most of the problems addressed and for free. Nevertheless, we still had a problem. The purchased detectors would indicate endpoint with a small amount of material left on the wafer. This small amount of material was out of the direct gas flow on the one port system. As soon as we switched to the toggled, swirling gas flow, the endpoint detector signaled completion without any traces of organic residue. Although we were unsure of what gases would be liberated for various materials, it was comforting to know we were not relying on them, but just any increase in pressure caused by the etching of an organic.

Experimental observations :- Taking 25 Silicon wafers 8 inches in diameter we coated them with 16,000 Angstroms of organic material. We then measured the thickness of the material in up to 41 across the wafers using a S.C. Technologies Inspector 3000 automatic ellipsometer. This unit locates the notch on the edge of the wafer automatically then runs a preprogrammed pattern of thickness readings. The findings can be printed out as a series of thickness measurements with automatic uniformity readings and a colored topological map can be produced giving a clear indication of low and high points across the wafers.

The 25 wafers were then treated for a variety of times, pressures and plasma power settings. Then the thickness of the organic material was read again. See typical reading and picture for wafer 4 at the end of this paper.

Conclusion:-

The starting uniformity was 1% with a high of 15,967 Angstroms and a low of 15,664 Angstroms located in the center of the wafer, indicative of a normal spun resist thickness. After 20 seconds of plasma we removed approximately 3,400 angstroms of material with a uniformity of 2.8%. the difference of 1.8% is the non-uniformity we can attribute to the plasma reaction. Studies of the pattern gave some encouraging details. There are distinct patterns that point to two correctable errors in the original reactor. 1) Material was being removed in a pattern that suggested non-planarity and subsequent measurement showed the wafers were not flat and planar. The high point of the wafer corresponded to an area of faster removal. When the wafers are planarized with more care we expect better uniformity. Even more significantly the sketch of the gas toggling is a good representation of the gas lines and one of the gas lines was significantly shorter than the other 2. This again corresponds to an area of higher removal rate. The reactor is being rebuilt with better planarity and equal length of gas lines for each toggled port.

The net result of all this work with and for our Polymide customers has led to an off the shelf plasma unit that is becoming a world leader in the specialized area of Polymide and B.C.B. treatment. The Y.E.S. CV108 downstream plasma resist stripper is the result of years of experience in the industry and the request of our customers for their process needs.

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YES CV108

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