Argon Plasma Cleaning of Fluorine, Organic and Oxide Contamination Using an Advanced Plasma Treatment System

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INTRODUCTION

Commercially-available plasma treatment systems can be used for effectively cleaning Fluorine, organic, and oxide contamination from the surface of a variety of microelectronic substrates. Typical microelectronic substrates include: Ball grid array (BGA) strips, metal lead frames, semiconductor wafers (usually Silicon or Ga-As wafers), and finished microelectronic packages held in metal “boats” or trays.

An Argon-based plasma cleaning process is suitable [1], because it removes all kinds of contamination via ion bombardment (also known as “sputtering”) without causing a chemical reaction or oxidation on the surface of the substrate. Using Argon plasma, contaminants are literally knocked off of the surface of the substrate at the molecular level, and exhausted out of the process chamber before re-deposition can occur. Moreover, Argon plasma is effective for many types of contamination such as Fluorine, organic contamination and metal oxides, because it is non-selective and removes these contaminants at similar rates.

Figure 1. *Example of a commercially-available RF plasma system for removing Fluorine, organic and metal oxide contamination from semiconductor wafers using Argon-based (dry) plasma.*

In addition to contamination removal, Argon plasma is also used to roughen the substrate or activate chemical bonds on the surface in order to improve bondability and adhesion (for better device reliability), and also to increase the wettability of the substrate surface to improve fluid flow speed and uniformity over the entire substrate.

PERFORMANCE CRITERIA FOR ARGON-BASED (DRY) PLASMA CLEANING OF CONTAMINATION

The following are possible criteria and corresponding target values for Argon-based plasma cleaning of microelectronic substrates.

Criteria	Requirement
Average Etch Rate (Sputtering Rate) of gold (Au) metal layer	≥ 250 Å/min.
Contact Angle, Post-Plasma Treatment, using Contact Angle Meter (CAM) & De-ionized Water Dropper	≤ 10 degrees
Uniformity, Within Substrate, 4 or more points per substrate, 10 mm edge exclusion (Max.-Min./2*Mean)	≤ 10%
Uniformity, Substrate-to-Substrate, at least 25 substrates (Max.-Min./2*Mean)	≤ 5%
Throughput, Steady-state, per Process Module, @125 Å Bulk Removal	≥ 60 WPH

Figure 2. *Possible criteria and corresponding requirements for a successful Argon-based plasma cleaning process (Note: Actual criteria & values will vary depending on customer requirements.)*

Typical Argon-based plasma cleaning processes can remove about 100 angstroms or more from the bulk surface of the substrate in about 30 seconds, which in most cases is sufficient to remove the targeted contamination. The targeted contamination may be Fluorine, organic or metal oxide in nature, or even a combination of contaminants, which is quite common.

Given this process speed, a throughput of greater than 60 wafers per hour (WPH) per plasma process module is reasonably achievable. If the contamination layer is particularly thick or difficult to remove, then the projected throughput value should be adjusted accordingly.

EXPERIMENTAL SET-UP AND METHOD

A commercially-available RF plasma processing system was configured with a 600 watt 13.56 MHz radio frequency (RF) generator. The system had two (2) mass flow controllers (MFC), each rated at max. 500 sccm. Semiconductor-grade Argon gas was used as the process gas. The lower electrode upon which the samples were placed was temperature-controlled during and between process runs using a closed-loop chiller unit with a setpoint of 65°C.

Because each process run was relatively short (approximately 30 seconds RF-On time per substrate), it was not necessary to cool the electrode for the sake of maintaining a low substrate temperature. In fact, a simple “finger-touch” test confirmed that little substrate heating occurred during each process run. Instead, it was desirable to have the electrode itself be held at a constant temperature during and between all runs in order to eliminate electrode temperature as a run-to-run variable.

The strip samples (Qty. 25 in total) were ball grid array (BGA) strips with gold bond pads and lines, which had been previously exposed to both CF_4 plasma and organic die attach epoxy in order to create simultaneous Fluorine and organic contamination over the surface of the substrate.

Due to the presence of simultaneous Fluorine and organic contamination, it was necessary to choose a plasma cleaning process that would remove both kinds of contamination without causing damage or oxidation of the substrate. Therefore, an Argon-only non-Oxygen dry plasma process was chosen as being highly suitable for this contamination cleaning application.

Using a commercially-available Contact Angle Meter (CAM) unit and de-ionized water dropper, 4 points were measured on each substrate (1 measurement near each corner of the substrate), outside of a 10 mm edge exclusion. A total of 25 substrates were processed to demonstrate process repeatability.

Samples were sent to a 3rd party testing house for pull-strength testing, before and after plasma treatment, in order to confirm the effectiveness of the Argon plasma processing.

Finally, some samples were analyzed by X-Ray Photoelectron Spectroscopy (XPS) before and after plasma treatment, in order to confirm the presence of Fluorine and Carbon (i.e. organic contamination) before plasma processing, and subsequent reduction of these contaminants after Argon plasma processing.

EXPERIMENTAL RESULTS

Results for BGA sample strip #1 for an optimized Argon-based plasma cleaning process are shown below.

Criteria	Result
Average Contact Angle, **Pre-Etch** (4 points,10mm E.E.)	91 degrees
Average Contact Angle, **Post-Etch** (4 points,10mm E.E.)	< **10 degrees** (Drops completely “wet out”)
Average Wire Pull Strength, **Pre-Etch** (32 wires)	3.4 grams
Average Wire Pull Strength, **Post-Etch** (32 wires)	**10.1 grams**

Figure 3. *Within Substrate results for sample BGA strip #1 using an optimized Argon-based dry plasma cleaning process.*

Substrate-to-Substrate repeatability was confirmed by running the same process conditions for a total of 25 BGA substrates. CAM measurement results are shown in the table below.

X-Ray Photoelectron Spectroscopy (XPS) was used to confirm that the Argon-based plasma was\ in fact removing contaminants from the substrate surface. XPS measurements were done on the bond pads of several samples before and after Argon plasma processing.

As a result, Fluorine was removed to the point of non-detection after Argon plasma treatment. Carbon levels were greatly reduced after Argon plasma treatment. A summary of these XPS results is shown in the table below.

Criteria	Result
Fluorine %, Pre-Etch	1.3%
Fluorine %, Post-Etch	Not detected
Carbon %, Pre-Etch	70.9%
Carbon %, Post-Etch	50.3%

Figure 5. *Summary of X-Ray Photoelectron Spectroscopy (XPS) results, before and after Argon plasma treatment to confirm Fluorine and organic contamination removal.*

CONCLUSION

Using an advanced RF plasma cleaning system and an optimized Argon-based plasma process for contamination removal, it is possible to achieve successful substrate cleaning results, even when several types of contamination (in this case, Fluorine and organic contamination) are present simultaneously.

ARGON PLASMA TREATMENT TO ROUGHEN SUBSTRATE SURFACE, IMPROVE ADHESION AND INCREASE WETTABILITY

When doing microelectronic packaging, the material deposited after plasma cleaning should make complete contact with the underlying surface. Also, the material placed down should have maximized adhesion to the underlying layer.

Argon plasma treatments are an attractive solution to remove contamination without causing damage to the substrate or device package. As long as the plasma cycle time is short enough, the substrate does not experience excessive heating or become damaged during plasma processing.

In reality, most substrates and device packages are very robust and can easily deal with the small temperature increases normally encountered during short Argon plasma processing. Short plasma processes typically have an RF-On time of between 30 and 300 seconds, and are highly effective.

Furthermore, Argon plasma treatments are well known for their ability to increase the adhesion ability of a surface by a process called “surface activation”[2]. Making a hydrophobic (non-wettable) surface into a hydrophilic (highly-wettable) surface using Argon plasma is also documented[3, 4].

An increase in the hydrophilic characteristic of a surface correlates directly to an increase in both pull and shear strengths[5]. Having materials bond as strongly as possible to the underlying layers is highly desirable in order to maximize the reliability and quality of the finished product.

The effectiveness of the plasma treatment can be easily measured using a commercially-available Contact Angle Meter (CAM) and de-ionized water dropper. Prior to Argon plasma treatment, contact angle measurements >90 degrees are common. After a suitable Argon plasma treatment, the contact angle of many surfaces drops to <10 degrees (That is, the drop completely “wets out” on the surface of the substrate). A surface with a contact angle of <10 degrees is referred to as “highly-wettable.”

Figure 6. *Example of a commercially-available RF plasma system for removing Fluorine, organic and oxide contamination from BGA strips and metal lead frames using Argon-based (dry) plasma.*

Figure 7. *Example of a commercially-available RF plasma system for removing Fluorine, organic and oxide contamination from microelectronic devices held in metal boats and trays using Argon-based (dry) plasma.*

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Additional background information on Cleaning Systems for WLP & Advanced/3-D Packaging: Terrence E. Thompson, “Out Damned Spot! Today’s Requirements Are Upping the Stakes for Cleaning Systems,” *Chip Scale Review*, November/December issue, 2006, pp. 36-40.