Hybrid Cleaning with Plasma for Increased Yield

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Abstract

This seminar is intended to provide a general understanding of:

1. What is a plasma?
2. The interaction mechanisms between organics and plasma.
3. A brief overview of process and system configurations.

Plasma is the most environmentally safe method of both organic removal and surface modification to date. Plasma processes can be tailored to both in-line and batch production product lines. Hybrid circuits have begun to approach the critical dimensions of semiconductors in the late 1960's. These new "smaller" circuits are presenting a whole new criteria for cleaning and removal of organics before bonding. This seminar will review the current industry and how it addresses the cleaning issue in terms of effectiveness and application.

What is Plasma?

Plasma can loosely be defined as a partially or wholly ionized gas with a roughly equal number of positively and negatively charged particles. It has been dubbed as the "fourth state of matter" because of its general properties which are similar to both a gas and a liquid.

There are both high and low temperature plasmas. High temperature plasma is found at atmosphere in its manmade form as a plasma torch or naturally in the form of lightning,. Low temperature plasmas, as used in etching, surface modification and organic cleaning, are ionized gases generated at low pressures. These low pressures allow for a relatively long free path of accelerated electrons and ions which are essentially at ambient temperatures. With relatively few collisions there is a low energy transfer thus keeping the temperature of the reaction in the ambient range.

The ionization of the gas is accomplished by applying an energy field using one of three government regulated source frequencies:

1. Low frequency or < 100 KHZ.
2. RF frequency or 13.56 MHZ.
3. Microwave frequency or 2.45 GHZ.

The frequencies selected for these sources are controlled by international agreements to prevent use of sources which would interfere with communication bands worldwide.

Unfortunately for manufacturers, the least desirable method of generation is also the least expensive - low frequency. Low frequency plasmas are the least efficient for several reasons which go beyond the scope of this presentation. The efficiency is related to the energy necessary to sustain the ionization and both the intensity and frequency of vacuum ultraviolet (VUV) radiation.

Most plasma system manufacturers use either RF frequency or MW frequency sources. Anatech Ltd. uses almost exclusively RF sources because of the overall advantages associated with this method. RF plasmas have been shown to exhibit significantly higher levels of VUV which in part explains the higher concentrations of electronically charged particles than found in the other plasma sources. RF plasmas have also been noted to be more homogeneous which is critical in treating irregularly shaped and overly large objects.

MW source plasmas are generated “downstream” or in a secondary environment. This means that the plasma is generated in one chamber and the active species are drawn by vacuum differential into the work area. Though this does produce a less homogeneous process and as a result provides reduced uniformity across the work area.

Organic Removal

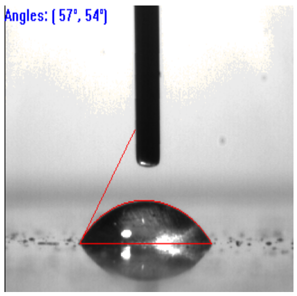
One of the prime problems with bond strength is the presence of organic contamination on the surface. This contamination may be in the form of residues, flux resins, carbon residues or some other organic. Oxygen plasmas are excellent in removing organics but they will also cause oxidation of metals as silver. An oxygen plasma is a chemical reaction and thus is viable in both the down-stream configurations and in the secondary plasma.
O_2 when exposed to the RF energy field is broken down into monatomic oxygen (O), O^+ and O^-. The O at pressures above .1 torr is the most reactive element in the plasma and will readily combine with any organic hydrocarbon. The resultant combination is water vapor, CO and CO_2 which is carried away in the vacuum steam. The reaction is by its nature complete with no residual surface products; however non-organics such as salts are not so readily removed. Sufficient RF energy must be applied to produce a high plasma density. Lower power densities do not just remove contamination at a slower rate but can actually impede the removal process. While the top layers of organics are being removed with low power density, underlying layers may actually cross-link in three dimensions creating a stable but unremoved new structure.

$$-CH_2-CH-CH_2\ -CH_2\text{------------->}\ -CH_2-CH\ -CH_2\ -CH_2-$$
$$|$$
$$-CH_2\ -CH_2\qquad\text{------------------->}\ -CH_2\ -CH_2$$

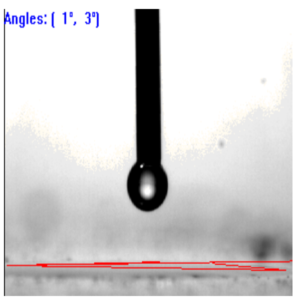
Based on the above situation it can be seen that the power density must be carefully monitored. Complete removal can be illustrated by the use of contact angle measurement.

The actual surface energy can be calculated using the same method and the application of three different liquids. The tests in all of the following cases were conducted using an Advanced Surface Technologies, Inc. model VCA 2500 contact angle measurement device.

Aluminum coupon organic contamination
Contact angle before of 57/54^0 using certified water



Contact angle after plasma treatment below readable limits.



Shear tests after plasma cleaning

Many hybrid manufacturers are shifting from the old traditional pull test to shear tests due to the increased area and mass of the weld area. Typical pull tests were ineffectual due to wire failure before bond failure. Shear tests, on the other hand, measure the actual strength of the ball bond joint itself. In reference to this manufacturers who were previously experiencing failure rates as high as 30 percent have seen failures reduced to less than 1 percent. The actual yield increase is directly related to the overall cleanliness of the process prior to plasma cleaning. If you are already experiencing yields in excess of 90% than the increase may be small but few have not seen some improvement.

Plasma Reactions

Reactions fall into two categories: chemical and mechanical. Chemical reactions are reactions as a result of an actual chemical interaction of the plasma with the surface of the product or contaminant. These reactions would include oxidation and ablating the surface with such gases as fluorine or chlorine. Mechanical reactions are generated with the use of noble gases such as argon or helium. Since these inert gases exists in their monatomic state the reaction is a kinetic energy transfer or, in simple terms, a sand blast. The dislodged contaminants can be swept away in the vacuum stream before they can redeposit on the product or allowed to recombine with the correct process parameters. These inert gas plasmas are used to remove organics and particulate from surfaces which might readily oxidize such as silver or copper. Because of the mechanical nature of inert gas plasmas the reaction must be in the direct path of the ions. This direct path is referred to as a primary plasma. Secondary plasmas are possible in chemical reactions such as oxygen but pose the oxidation possibility of silver and copper.

Plasma Damage Possibilities

Ceramic surfaces often exhibit a yellowing after treatment. This effect is a result of surface cross-linking and will disappear over time. If the hybrids can be annealed in a 300C the effect can be removed immediately. In either case the effect is both temporal and of no effect on performance.
Ion damage may be possible on un-passivated devices if improper power levels are utilized. Care must be used as in any cleaning method to insure correct parameters are established. Each manufacturer should be able to provide basic parameters for most applications and there is a large amount of printed material on plasma cleaning. One of the better references is produced by IMAPS titled, “Reliability and Yield Problems of Wire Bonding in Microelectronics”, by George Harman.

The Physical Equipment

All current plasma systems fall into the same basic configuration:

1. A chamber for the reaction.
2. An energy source for the gas ionization.
3. Control circuitry to regulate the time, gas flow and amount of energy.
4. A vacuum system to provide the low pressure environment.

The Chamber

Chambers are manufactured in either metal or glass depending on the application and the method of ionization. Quartz chambers are used in highly critical environments where submicron particulate generation is an issue. Quartz reactors can also be inductively coupled which will produce the most uniform results on populated devices. This is especially useful in removing contamination from even the underside of die edges.

For industrial applications, metal chambers are more prevalent and allow for the rougher handling environment accompanying that industry. Aluminum chambers offer an advantage over stainless steel chambers in that aluminum will develop a natural oxide layer which becomes a tough barrier to secondary reactions. Even the best stainless steel has been known to oxidize in a plasma environment and over time the oxidized surface can be a source of particulate which is undesirable. As in all vacuum processes there is some redeposition of removed material on the chamber walls. This is minimized with a quartz chamber and thus quartz chambers offer less maintenance and greater cleanliness of the reaction. The obvious trade off is in volume manufacturing. Aluminum chambers are necessary to process high volumes of parts as well as in-line applications.

Plasma Today

Plasma systems range from a small two inch chambers to ten foot walk-in chambers capable of processing as many as seven automobile bumpers at a time. Though there are standard sizes available, your needs should dictate the system.
High volume throughput has given rise to the in-line plasma system. These systems address the automated production line and, though batch processing is used, do use automated feed and robotics. Batch processing is still less expensive due to the robotics and handling requirements.
The following are actual case studies of plasma applications.

Case Study "A"

A controlled study to find the effectiveness of the removal of common oils such as 143AA, 5606, 24139 grease and 2190 TEP was conducted by a US Government agency in conjunction with Anatech LTD. Stainless steel coupons were cut 1" x 1" and weighed. A drop of oil between 10-12mg was applied to each coupon and then exposed to different plasmas. The following table illustrates the effectiveness of different gas combinations.

contaminate	**plasma gas**	**time in plasma**	**percentage of removal**
143AA OIL	Oxygen	15 min	100%
5606 OIL	Oxygen	8 min	100%
5606 OIL	Oxygen	5 min	100%
5606 OIL	Argon	15 min	70%
24139 GREASE	O_2/CF_4	15 min	100%
2190 TEP OIL	O_2/CF_4	15 min	100%
5606 OIL	room air	15 min	87%

The above chart shows the general effect of chemical over mechanical processes in relation to the time for total removal.

Case Study “B”

Glass panels with organic contamination were received with contact angle measurements of 60 - 75 degrees. Less than a one minute plasma process produced contact angles of one to three degrees.

Conclusions

From the above studies, it can be seen that plasma processing can be an effective final cleaning organic contaminant removal prior to wire-bonding. It can also be illustrated that plasma can be used before die attach to reduce the amount of epoxy necessary for good adhesion.
Plasma can be applicable to any geometry making it especially useful in cleaning populated hybrids and closely attached dies. As the geometry of hybrids decrease the need for surface preparation and complete cleaning processes will increase.

Plasma cleaning prior to wire-bonding will continue to grow as a cost effective and environmentally friendly alternative to wet or chemical processes. It has also shown itself to be especially effective in molecular level cleaning of small and irregular shaped components regardless of the minuteness of the critical dimensions.