Next Generation Organic Solderability Preservatives (OSP) for Lead-free Soldering and Mixed Metal Finish PWBs and BGA Substrates

by MICHAEL CARANO AND KOJI SAEKI

The documentation relating to the requirements for alternative surface finishes have been well publicized at many industry forums. Pressure to eliminate lead in electronics assemblies is forcing fabricators and OEMs to reevaluate their surface finish and joint attachment procedures. Many of the requirements, in fact, are obvious. Regardless, the PWB fabrication industry needs to work closely with contract manufacturers and end users to fully appreciate the true impact of technology trends. These trends are significant and include:

- Surface mount continues to increase at the expense of through-hole with finer and finer features.
- The use of non-tin/lead coatings and surface finishes will increase. Surface finishes such as electroless nickel/immersion gold, OSP and immersion tin will be utilized.
- With political movements toward banning lead in all electronic assemblies gaining significant momentum, lead-free solder pastes and wave solder materials will be adopted.
- The alternative surface finishes must perform through multiple thermal cycles with less active pastes and fluxes.
- The use of multiple metal finishes on the same bare board will place new emphasis on the compatibility of coating with each other, and the actual assembly module.
- Increased I/O demand and reduced lead pitch will require much tighter controls over the processes used to fabricate the bare board. High I/O packages will test the process limitations in imaging, etching, solder mask and surface finishes.
- Chip scale packages and BGA will find increased use as an interconnect medium
- Assemblies are becoming harder to inspect rework.

The trends listed above are only a snapshot of the many issues that fabricators and assembly companies face. However, those listed are the ones that most closely reflect the trends influencing the solderability of components and the bare board surface. This fact relates mostly to the actual selection and performance of the surface finish. Regardless, the finish must be able to perform under a variety of conditions, consistently and reliably.

In recent years, in order to achieve high-density surface mounting on printed wiring boards, the number of terminals of circuit components have been increasing, and the pitch of the terminals has been significantly reduced. With the trend for increased packaging density has come the use of COB (chip on board), flip chip and TAB (Tape Automated Bonding).

TRENDS TOWARDS MIXED METAL FINISH

In recent years, in order to achieve high-density surface mounting on PWBs, the number of terminals of circuit components have been increasing, and the pitch of the terminals has been significantly reduced. With the trend for increased packaging density has come the use of COB (chip on board), flip chip and TAB (Tape Automated Bonding).

In many instances, the surface mounting of such components may be required on PWBs with copper pads and other features plated with gold, silver, tin or solder. These mixed metal finish boards are becoming very common today and the surface treatment of such circuits will continue to grow in importance. The demand was such that a water soluble surface-treating agent, that was capable of protecting the bare copper form oxidation without leaving a film on the other metals, needed to be developed and implemented. In other words, the need for an OSP that selectively bonds to the copper without adversely affecting other metals such as gold or solder was established.

Conventional OSP processes based on long chain alkylimidazole compounds and substituted benzimidazole compounds functioned adequately to protect the bare copper. However, these materials also deposited a significant film on the other metals such as gold, tin and solder. This additional film interfered with subsequent operations such as wire bonding, and surface mounting of Quad Flat Packs on solder surfaces. In addition, the contact resistance on the gold increased to unacceptable levels. Thus, when PWBs are fabricated with multiple metal finishes, the metals such as gold or solder would have to be masked to prevent the OSP film formation on their surfaces. In some instances, the coating would have to be removed with alcohol, adding additional labor and cost to the fabrication process. A factor in promoting this film formation on the metal surfaces is the copper contained in many organic solderability formulations. The copper ions form a complex with the active azole ingredient in the OSP chemistry and actually helps to promote film growth. When a copper-solder mixed metal board is processed through such a process, the OSP forms on the solder and has the affect of discoloring the solder, making long-term solderability literally impossible to achieve.

It has also been determined that the copper ions that are part of the OSP protective film contribute to ionic contamination, a situation being constantly scrutinized by assembly houses and end users. It is desired to keep ionic residues as low as possible. It has been demonstrated that the copper contributes to the staining/darkening of the solder and causes undo build-up of residue on the gold.

Therefore, it was imperative to develop an OSP process that would selectively deposit on the bare copper surface only, with low residual ionics. However, a film formed on the copper must have sufficient ability to maintain the solderability of the base copper through multiple thermal excursions and with a variety of low activity wave soldering fluxes and pastes.

HIGH TEMPERATURE OSP FOR LEAD-FREE SOLDERING

No discussion concerning OSP is complete without investigating its performance under the strenuous temperatures and soldering times for lead-free processing. A key consideration for the high temperature OSP is the coating's stability under very high temperatures. If the OSP film decomposes or undergoes any structural changes including evaporation, the coating's ability to preserve solderability is greatly compromised. One must understand that OSP technology has evolved from the basic benzotriazole through more complex and more robust formulations (Figure 1). The arylphenylimidazole represents the latest in new OSP technology

The latest generation based on a novel Arylphenylimidazole (Figure 2) shows much higher heat stability and can easily withstand the peak temperature of reflow for typical lead-free solders. TG (Thermogravimetry) curve indicates the weight increase and decrease, and DTA (Differential Thermal Analysis) curve indicates the exothermic and endothermic reaction of OSP coating itself. An OSP coating composed of an Alkyl benzimidazole compounds, which are still widely used in the market (figure 3) begins to decompose around 250 degrees C. This is the typical peak temperature for lead-free soldering. However, the latest OSP composed of Aryl-phenylimidazole technology shows much higher decomposition temper-

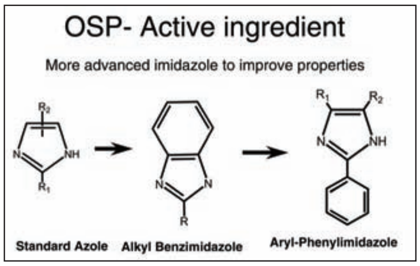

Figure 1. The evolution of Imidazole Chemistry for use as Organic Solderability Preservatives.

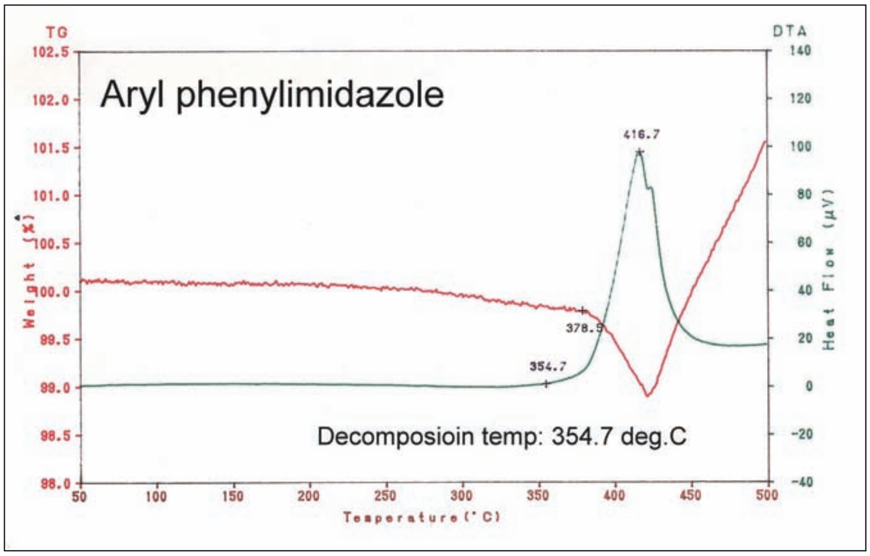

Figure 2. Thermal Stability of the Aryl-phenylimidazole compound.

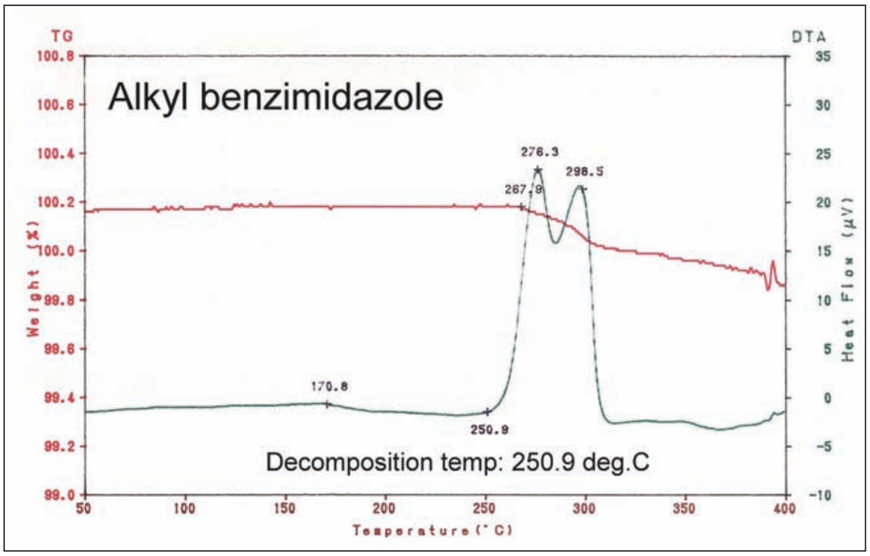

Figure 3. Thermal Stability of the substituted (alkyl) benzimidazole compound.

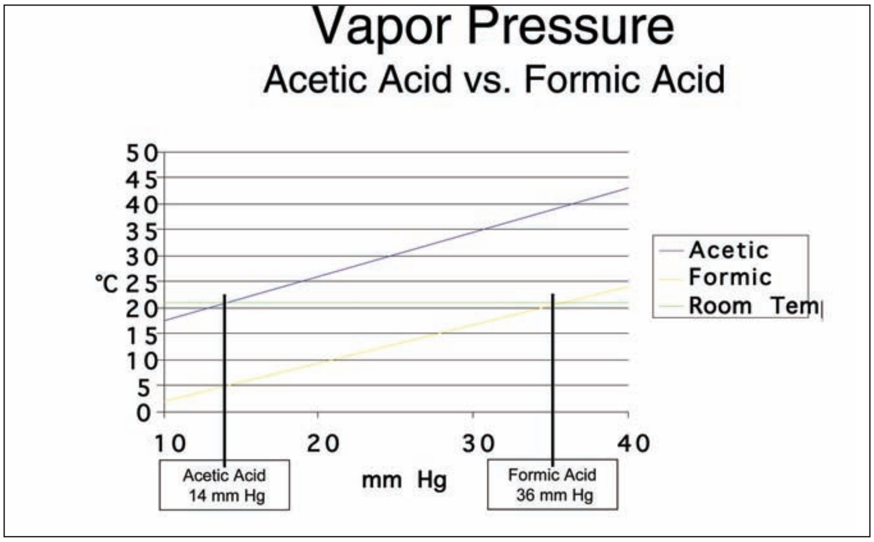

Figure 4. Vapor Pressure versus volatility of Acetic Acid and Formic Acid.

ature. (around 350 deg.C) Temperature stability of the OSP is a most critical factor in determining the solderabilty preservation of the coating.

THE CHEMISTRY OF THE PROCESS

U.S. Patent # 5,795,409 describes the unique organic azole compound developed for lead-free soldering. This unique compound is solubilized in water and a nominal of amount of acetic acid. Acetic acid was chosen over such other acids as formic. The main reason is that acetic acid is less volatile than formic acid due to lower vapor pressure (Figure 4). This attribute contributes to maintaining a very stable pH range, which is necessary in building a uniform and sufficiently thick organic coating for solderability protection. When acids such as formic acid volatilize, the concentration of the active ingredient can increase, causing the organic material to build the film abnormally thick and in a rather non-uniform fashion. This leads to solderability problems ranging from poor solder paste spread to heavy organic residue being deposited onto other metals and laminate surfaces.

In addition to providing excellent protection for the copper under high temperature soldering conditions, this process is designed to deposit 1000–2000 angstrom thick coating. Other commercially available OSPs deposit 4000–6000 angstroms thick films that can interfere with solder paste spreadability. One of the key developments of this process is its ability to grow a film thickness (as uniform as possible) without the need for the addition of copper ions to the OSP solution. Most commercially available OSPs cannot maintain a sufficient film thickness in the absence of copper. The unique aryl-phenylimidazole compound, however, (Figure 5) provides sufficient film thickness without the added copper ions. Other commercially available processes will also deposit organic film on other metals such as gold or silver, due mainly to the added copper ions in the OSP solution. The aryl-phenylimidazole process negates this issue.

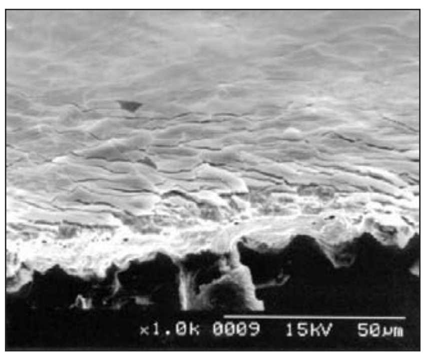

Figure 5. Uniformity of the OSP film from Aryl-phenyl imidazole chemistry-1500 angstrom thick.

OSP POPULARITY WITH BGA SUBSTRATES

Ever since the issues with black pad, many BGA and substrate manufacturers have adopted high-temperature stability OSP processes. Any concerns with galvanic reactions or hyper-corrosion of the nickel due to the action of the immersion gold are eliminated with OSP. Superior solder joint strength is the prime reason that most mobile phone manufacturers have moved to adopt OSP as the primary finish for their PWBs.

Fundamentally for past several years, BGA substrate manufacturers have shown interest in evaluating OSP as an alternative of ENIG. However, the assembling process prior to solder ball attach is totally different from normal printed wiring boards. Generally, the process includes several high heat incursions, including a long curing process for EMC (Epoxy Molding Compound). The process (detailed below) certainly can affect solder paste spreadability:

1. 120–130°C for a few hours to remove the moisture in the substrate
2. Mount the chip and cure the adhesive around 170-180° for 10-20 min.
3. Plasma irradiation to clean the gold surface prior to wire bonding, as well as make the solder mask surface rough in order to improve the adhesion with EMC.
4. Cure EMC around 170-180°C for several hours.
5. Solder ball attach with unique soldering flux on the bottom side of BGA substrate

On the other hand, the prolonged and strenuous heat conditions could compromise the solderability of the copper by increasing the extent of oxygen penetration under the OSP film as well as promoting nickel oxidation underneath gold plating. This will undoubtedly affect the solder joint strength. However, this newer generation OSP material displays a significant resilience to such thermal excursions. Today several large and well recognized BGA substrate manufacturers utilize high temperature resistant OSP for their chip packaging substrates.

PLASMA IRRADIATION

Plasma irradiation should be necessary only for the topside of BGA substrate to clean the gold surface and make the solder mask surface rough. However, the irradiation atmosphere is

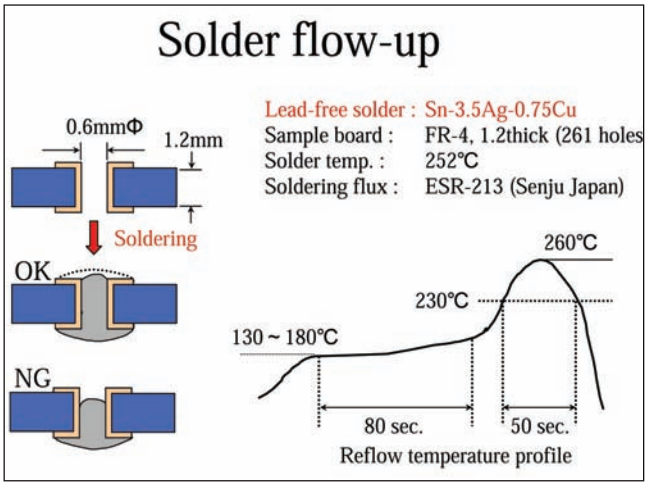

Figure 6a. Solder flow up testing parameters using standard through hole test vehicle and lead-free IR reflow profile to age surface prior to wave soldering. Acceptance criteria for hole fill is top side wet out of pad with solder and minimum of 75% of barrel of hole filled with solder.

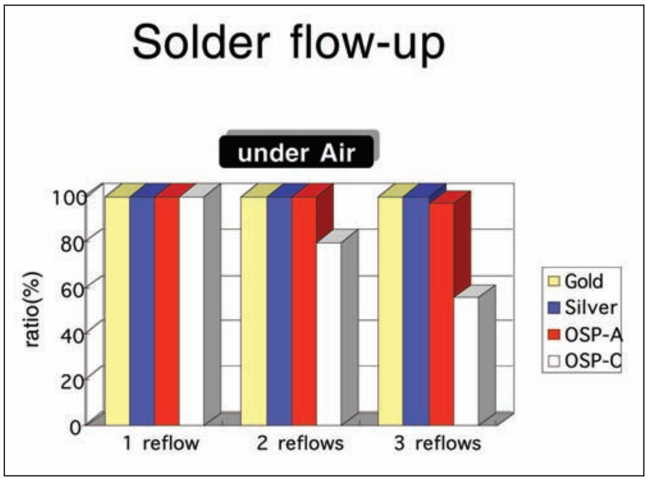

Figure 6b. Solder flow up measuring percentages of holes filled with lead free solder after a series of IR reflow cycles in air

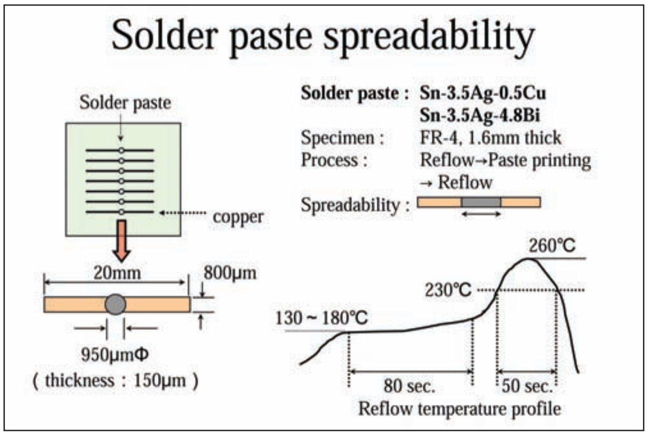

Figure 7. Solder paste spreadability test vehicle and protocol.

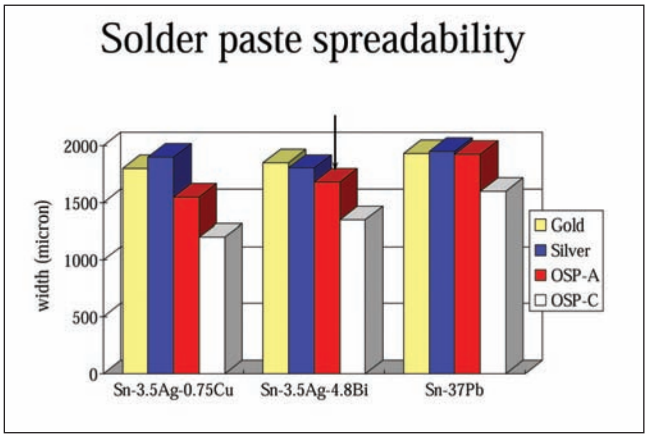

Figure 8. Results of solder paste spreadability testing.

usually filled with certain amount of argon gas to diffuse the plasma ray efficiently, so that OSP coating on the bottom side also could be exposed and removed. Finally, the thickness is quite important to keep the copper from oxidation during the heat conditions. The arylphenylimidazole based OSP is able to withstand the plasma irradiation, even though a minor amount of the OSP is removed.

RELIABILITY TESTING

With the advent of lead-free assembly parameters, the question is: how well does the OSP coating maintain solderability? Typical measurements for this important attribute include solder paste spreadability, solder flow-up and solder joint strength. In Figures 6–12, the reliability testing is performed on four surface finishes: Electroless Nickel-Immersion gold, Immersion silver, an OSP based on substituted benzimidazole and the OSP based on aryl phenyl-imidazole. The test vehicles and the conditions under which the testing was performed are shown with each respective test. OSP A is the aryl-phenyimidazole and OSP-C is the alkyl-benzimidazle. Lead-free solder based on a SAC alloy was used for each of the testing protocols.

SUMMARY AND CONCLUSIONS

The active ingredient is one of the most important ingredients of OSP to improve the heat-resistance, which becomes important much more in conjunction with lead-free solder. The latest OSP shows excellent stability even more than the peak temperature of reflow for lead-free solder.

The heat conditions for BGA substrates due to adhesive and molding compound curing are significant when compared to standard PWB soldering conditions. In addition, BGA substrates typically under go a plasma irradiation prior to BGA placement and soldering. While the majority of

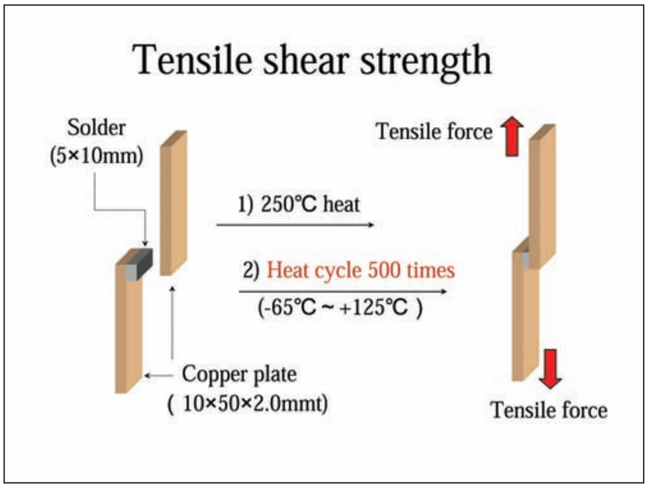

Figure 9. Tensile shear testing-copper coupons are processed with each of three different finishes. Solder paste is printed on one coupon-then joined to the other. Heat treatment and thermal cycles follow. Then Instron Tensile Tester used to perform tensile shear tests.

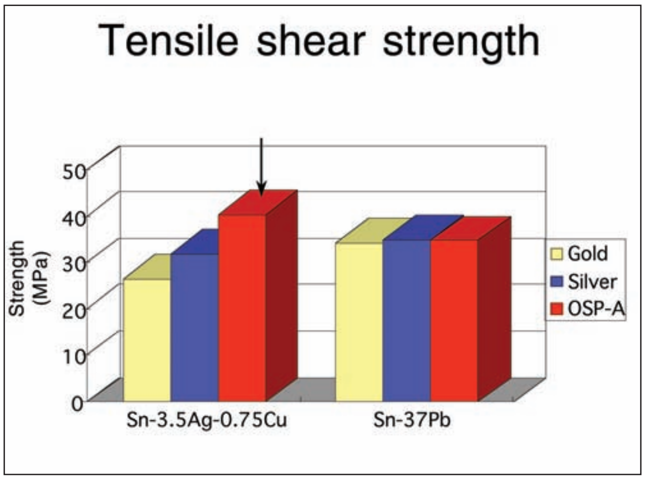

Figure 10. Results of tensile shear testing.

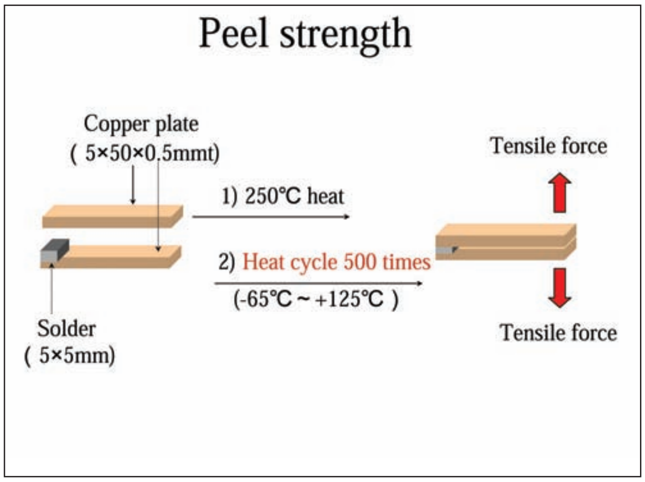

Figure 11. Peel strength of solder joint-same protocol as in Figure 9-Results generated from peel strength tests.

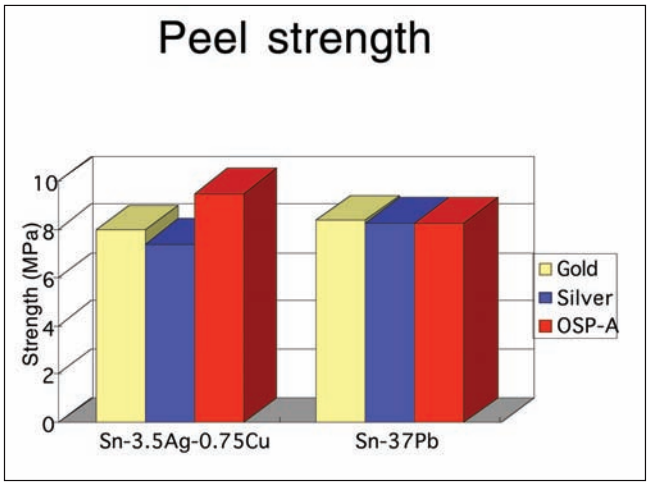

Figure 12. Results of peel strength testing.

OSPs based on alkyl-benzimidazole are unable to retain the solderability for lead-free soldering after these treatments, new generation aryl-phenylimidazole have been proven to resist oxidation and improve solder paste spreadability.

Since plasma irradiation could remove the coating significantly, the coating should be controlled to a greater thickness. However, OSP designed for selective gold plating does not make any deposit on gold, and could achieve good wire bonding without plasma irradiation.

OSP shows excellent solder pull strength especially in conjunction with tin-lead solder and lead-free solder, after heating, in comparison with ENIG. Performance against immersion silver is comparable.

Michael Carano

Michael Carano is vice-president Marketing and Business Development for Electrochemicals, Inc. where he has been employed since 1979. He is responsible for the company's global marketing and business development functions. Carano has published over 65 technical articles and has presented numerous other papers throughout the world. He was recently elected to the IPC Board of Directors and is serving his first term.

Electrochemicals Inc.
5630 Pioneer Creek Drive
Maple Plain, MN 55359
Tel: 763-479-2008
Mcarano@electrochemicals.com