New surface finishes are being sought by both structural and electronics marketplaces to improve the solderability of common and advanced base materials as well as to address environmental regulations that restrict the use of lead (Pb). Ideally, any new surface finish would be compatible with either conventional Sn-Pb or Pb-free solder applications. It is necessary to test the solderability behavior of these alternative finishes prior to their use on materials for assembly operations. One such surface finish that is currently capturing industry interest is Electroless Nickel (Ni)-Electroless Palladium (Pd)-Immersion Gold (Au) or ENEPIG. In this layer stack, the Ni layer is the solderable finish to which the solder joint is actually formed at the completion of the soldering process. The Pd layer is a protective finish to maintain the solderability of the Ni layer. The thin Au layer is a protective finish, as well, maintaining the solderability of the Pd layer because the latter forms a very thin oxide layer that slows the wetting and spreading of tin (Sn)-based solders.

The ENEPIG finish improves upon the good solderability of the original electroless nickel-immersion gold (ENIG), but with two benefits provided by the Pd addition. First, Pd eliminates the black pad solder joint defect (Ref. 1). The term “Black Pad” was first used in the late 1990s to describe a specific kind of nickel corrosion on ENIG surface finishes. This corroded nickel compromises the solderability of the part. In cross sections of the failed joint, Ni₃Sn₄ (for Sn-Pb solder joints) or (Cu,Ni)₆Sn₅ (for SAC alloy solder joints) intermetallic (IMC) is found on the solder side, and a phosphorous (P) content higher than that of the bulk Ni(P) plating is detected on the pad side (Ref. 1). Secondly, Pd slows the diffusion of Ni into the Au layer, resulting in longer shelf life and higher reliability for printed wiring assemblies exposed to harsh operating environments.

Experimental/Discussion

In the study reported here, the solderability of the ENEPIG finish was evaluated on oxygen-free-electronic (OFE) grade copper (Cu) coupons. The coupons were tested in the as-fabricated condition and after exposure to two accelerated storage environments. The two accelerated storage environments included the following: 1) Exposure to a Battelle Class 2 environment and; 2) steam aging per ANSI J-STD-002C, Solderability Tests for Component Leads, Terminations, Lugs, Terminals, and Wire (2007) (Ref. 2). The Battelle Class 2 test is a mixed flowing gas test containing 10 ppb H₂S; 200 ppb NO₂; 10 ppb Cl₂; 70% relative humidity (RH); at 30°C. The Battelle Class 2 accelerated environment was selected because it represents long-term storage under the conditions of a light industrial/manufacturing environment (Ref. 2). The length of the Class 2 accelerated aging test represents the equivalent of 3 months to 10 years for contact materials such as copper and silver. As such, the test is designed to accentuate plating defects. Steam-aged test coupons were exposed for 8 and 24 h within an atmosphere of 90% RH and temperature of 85°C. For brevity, the discussion below focuses only on the solderability behavior after exposure to the Battelle Class 2 environment.

The ENEPIG finish was obtained from two vendors denoted “1” and “2.” Copper coupons plated by Vendor 1 had nominal layer thicknesses shown below:

Vendor 1:

The second supplier, Vendor 2, pro-
provided two variants of the ENEPIG finish with the following thicknesses:
Vendor 2:

The difference between the two Vendor 2 variants was the thickness of the Pd layer: 6–7 μin. ("thick") and 2–4 μin. ("thin"). A thin Pd layer reduces the material cost of the ENEPIG finish; however, the potential tradeoff is a reduced barrier function between the Ni and Au layers. The solderability of the test specimens was evaluated using a rosin-based, mildly activated (RMA) flux with an eutectic 63Sn-37Pb (wt-%) solder. The solder bath was held at 245 °C.

The metric of solderability was the contact angle, $\theta_c$. The lower the contact angle, the better is the solderability. The value of $\theta_c$ was determined by the combination of two test methods. The first method is the meniscometer test. This test measures the meniscus height, $H$, or vertical movement of a solder meniscus up the side of the coupon. The meniscus height, $H$, is the vertical movement of the meniscus up the side of the coupon. Once these measurements have been obtained, the mean value for $H$ and standard deviation were determined from the wetting balance test is the wetting rate. The wetting rate indicates the speed with which the molten solder meniscus climbs the coupon. Although this parameter is not used within industry standards, testing at Sandia National Laboratories has determined that it provides a correlation between the laboratory test and performance in fielded processes.

Test Results — Contact Angle $\theta_c$

The contact angle data for Vendors 1 and 2 are plotted in Fig. 2 as a function of the exposure time in the Battelle Class 2 environment. If the actual storage environment is a Class 2 environment, the following correlation between the accelerated test exposure time and the actual storage lifetimes is as follows:

- 8.4 h corresponds to ~3 months;
- 33.6 h ~1 yr;
- 168 h ~5 yrs; and
- 336 h ~10 yrs.

It is clear that the ENEPIG finishes, used in conjunction with the Sn-Pb solder and RMA flux, exhibited excellent solderability that was not degraded by even the longest exposure to the Class 2 conditions. In fact, the contact angles of the Vendor 1 finish actually decreased slightly after exposure to the Battelle Class 2 conditions. Although both “thick” and “thin” variants from Vendor 2 have only been aged for 168 h (~5 yrs), the contact angles remained very low and unaffected by the Class 2 exposure. More importantly, it is also apparent that the two Pd thicknesses...
of these ENEPIG finishes provided comparable solderability performances, which opens the door to using the less-expensive, thinner Pd layer.

**Test Results — Wetting Rate (WR)**

The wetting rate behavior was also assessed for these finishes. Generally speaking, there were only small decreases in the wetting rate as a function of increased aging time in the Class 2 environment. The same trend was observed across all three candidate ENEPIG finishes — Fig. 3. Auger Electron Spectroscopy (AES) was used to determine the source of the slower wetting behavior. The primary cause was attributed to a small amount of Pd that had diffused through the Au to the surface. The driving force for that diffusion is a combination of the elevated temperatures and oxidation potential established by the air environment above the sample. The Pd proceeded to oxidize, thus, slowing the wetting and spreading process. A secondary factor may be a slight buildup of carbon compounds detected by AES on the Au surface. The small decreases in wetting rate would not impact an actual manufacturing process.

**Summary**

The electroless Ni, electroless Pd, and immersion Au (ENEPiG) surface finish is capturing the attention of both the structural and electronics soldering communities as a means to enhance the solderability of common base materials for a range of applications. Solderability testing has illustrated the robustness of this finish after simulated storage aging using the Battelle Class 2 environment. For the various ENEPIG finishes in this study, the excellent performance was sensitive to supplier but not to the thickness of the Pd layer. Only a slight decrease in wetting rate was observed after exposure to the Battelle Class 2 conditions. Auger electron spectroscopy identified two possible sources of the reduced wetting rate: a) Pd diffusion to the Au surface and its oxidation and; b) the small buildup of carbon compounds that are attracted to the Au layer.

**References**