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Diffusion Barrier Plating in Electronics

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Introduction

Diffusion barriers have been used in electronics manufacturing for several decades. Nevertheless, we occasionally see cases where no barrier layer is used when perhaps it should be. The addition of a plating step to create a diffusion barrier adds cost to the end product. This is the likely reason that we find cases where no barrier layer is used. Nevertheless, the cost of the diffusion barrier may well be offset by improved soldering process quality and solder joint reliability.

This document attempts to chronicle the reasons for using diffusion barriers and identify opportunities for applications where they have apparently been overlooked. The following is a series of examples illustrating the use of diffusion barriers in electronics manufacturing.

Silver-based Terminations on MLCCs

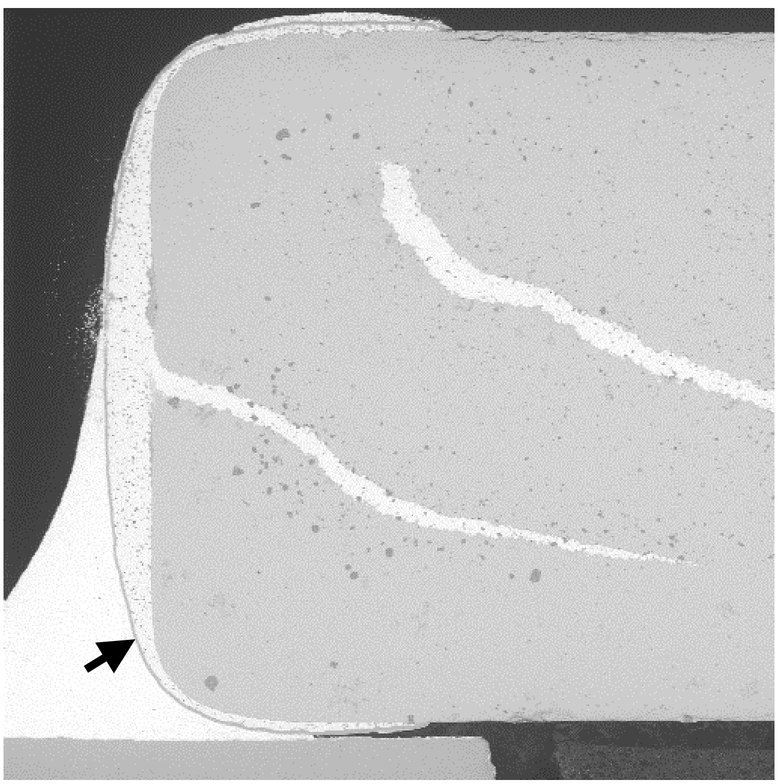

Fig. 1 – Nickel barrier layer on soldered MLCC termination [100X BSE SEM image].

Nickel barrier plating is routinely used on Ag-thickfilm terminations to prevent leaching of the termination into the molten solder during reflow. Fig. 1 shows a nickel barrier layer ~100 microinches thick on a MLCC in cross-section. Silver dissolves rapidly in molten Sn-Pb solder. Bader [1] measured dissolution rates of Au, Ag, Pd, Pt, Cu and Ni in a molten Sn-Pb solder four decades ago. His data shows that silver dissolves approximately ten times faster than does copper in Sn-Pb solder at typical soldering temperatures (260ºC). In extreme cases, the entire capacitor termination can be dissolved into the solder joint causing an open-circuited condition. Nickel dissolves at a much slower rate than does copper (in fact the dissolution rate was only measurable at temperatures above 400ºC). This is the reason that nickel is used as diffusion barrier over silver on MLCC capacitor terminations.

Alloy-42, Alloy-52, and Kovar

Alloy 42 (58Fe-42Ni), Alloy 52 (48Fe-52Ni), and Kovar (29Ni-17Co-53Fe-1trace) are low thermal expansion alloys used to minimize thermal expansion mismatch in silicon devices and glass-to-metal seals [2]. It is generally advisable to use a nickel diffusion barrier for soldering applications because iron (Fe) is known to be problematic as an impurity in solder. Fig. 2 is an example of a Fe-Ni alloy IC lead with no Ni-barrier plating. The solder on the pad failed to wet the lead due to exposed Fe-Sn intermetallic compounds that had oxidized on the Sn-Pb surface finish of the lead.

Iron causes a significant number of problems for electronics grade solder joints. Manko [3] suggests that "the presence of iron in solders at low levels such as 0.1 percent shows grittiness and is rather detrimental." The Fe-Sn binary alloy phase diagram [4] shows the important Fe-Sn intermetallic compounds in this binary system that are stable at temperatures below 232ºC are $FeSn_2$ and FeSn. The $FeSn_2$ is the most likely intermetallic to form since there is and excess of Sn available from the Sn-Pb solder.

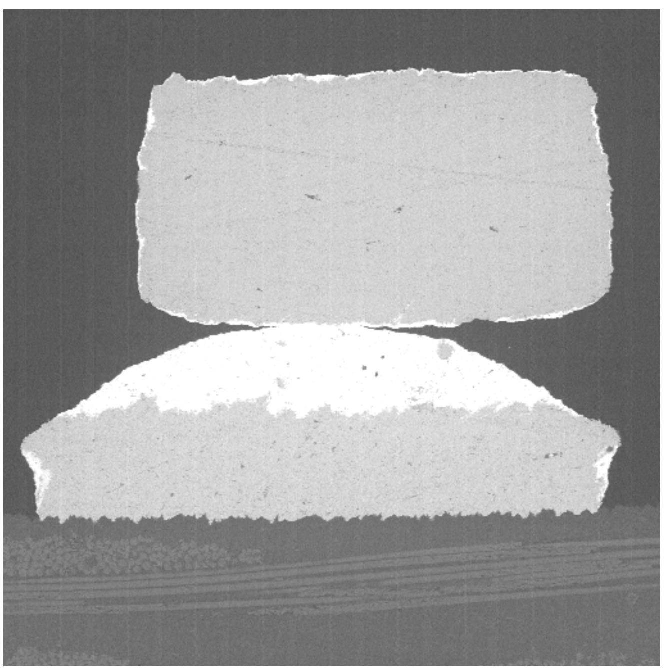

Fig. 2 – Solderability problem on Fe-Ni alloy IC lead with no apparent Ni-barrier [243X BSE SEM] [ref. SLI-168]. The solder from the pad did not wet the lead.

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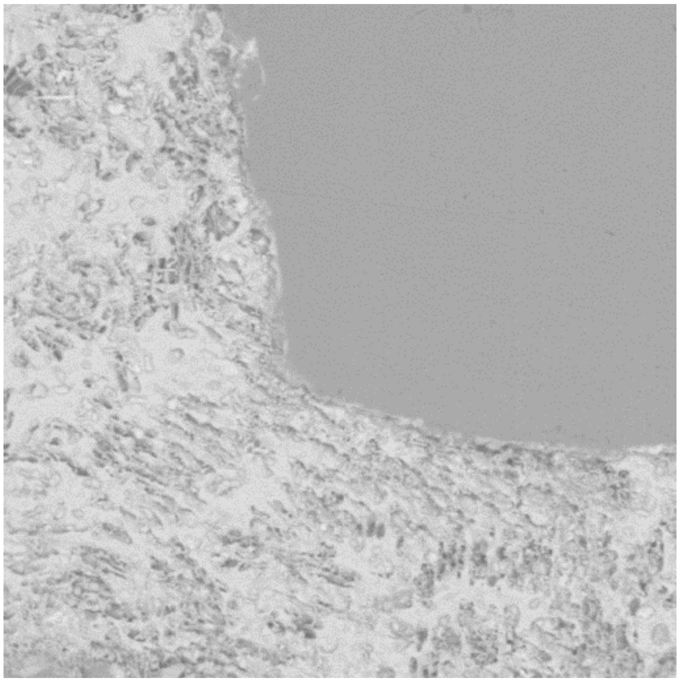

Fig. 3a – [994X, ref. SLI-1110]. Iron (Fe) from this Alloy 42 IC lead appears to have a significant impact on the microstructure of the bulk SAC solder alloy.

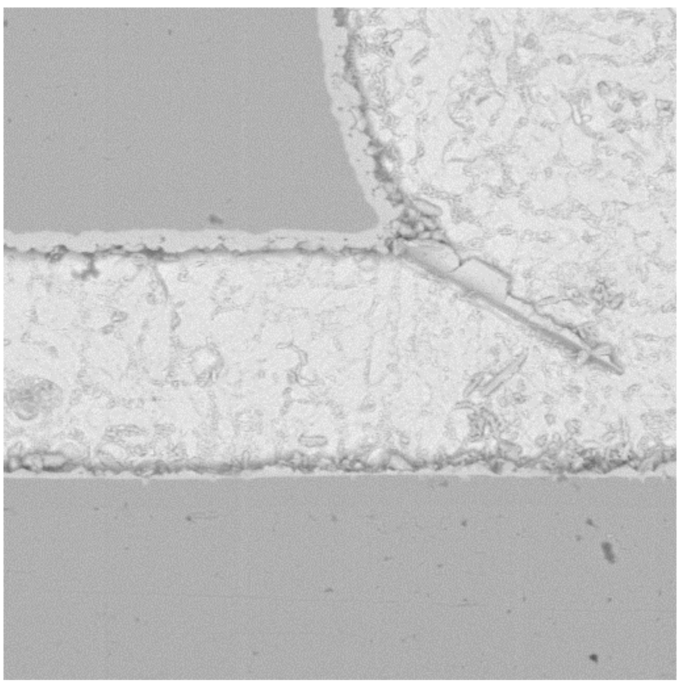

Fig. 3b – [796X, ref. SLI-1110]. This is considered a "normal" microstructure (compare with Fig. 3a) for lead-free 305 SAC alloy. The lead (top-left) is phosphor-bronze. The PWB mounting pad (bottom) is ENIG-finished copper.

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Fig. 3a shows a lead-free solder joint (SAC alloy) of an Alloy 42 IC lead that did not utilize a nickel barrier plate. The iron that diffused into the joint had a significant impact on the microstructure of the bulk SAC alloy (compared with Fig. 3b which is "typical"). The microstructural difference is likely to mean that the mechanical integrity of the solder joint is compromised.

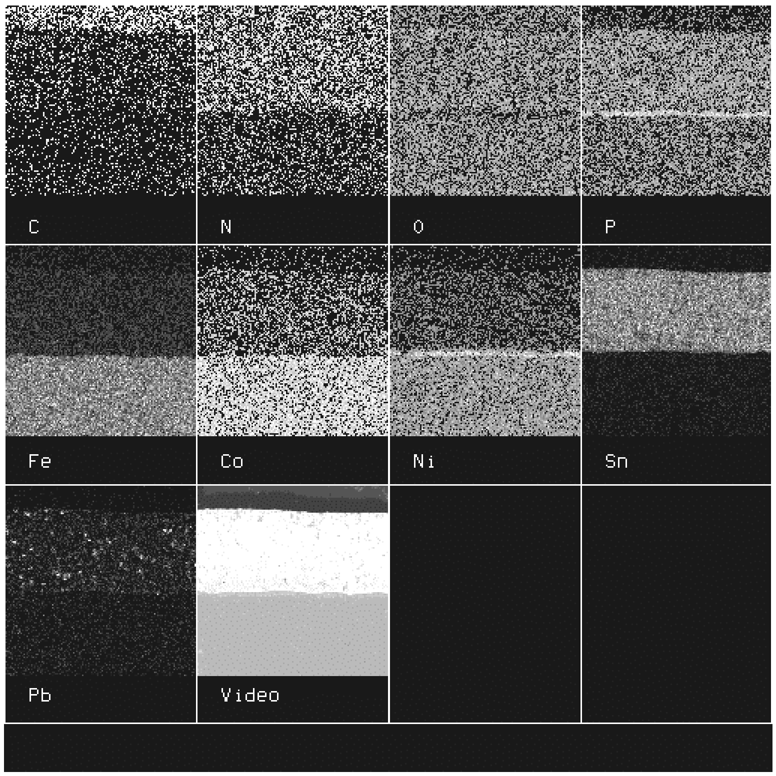

Fig. 4 - This is an elemental dot map of the lead finish/base metal. There is an electroless nickel (Ni-P) layer between the Kovar base metal (Fe-Ni-Co) and the tin-lead plating. [284X, ref. SLI-1076].

Fig. 4 shows an elemental dot map of a Kovar lead that has an electroless-nickel (EN) diffusion barrier. Electroless-nickel is actually Ni-P alloy, which is why there is a prominent phosphorous signal associated with the nickel barrier. Electroless-nickel diffusion barriers are generally only used on surfaces that are not subject to significant bending such as ENIG finished PWBs and Kovar headers for hybrid circuits. Electroplated-nickel is generally used form diffusion barriers on flexible component leads because it is more ductile than the Ni-P alloy and less likely to fracture in bending.

Brass Leads and Terminals

Brass is commonly used for component leads, cases, connector pins, terminals and other soldering applications. A nickel barrier layer is recommended for solderable surfaces due to the deleterious effect of zinc in solder. The Zn-Sn system is a binary eutectic system with no intermetallic compounds. The Zn-Pb system also has no intermetallic compounds and very little mutual solid solubility. Therefore, it is surprising that zinc has such a significant deleterious effect on Sn-Pb solder joints. Manko [3] states

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that "The addition of zinc is reported to be very detrimental to the solder alloy. As little as 0.005 percent of zinc is reported to cause lack of adhesion, grittiness, and/or susceptibility to failure during solidification."

Fig. 5 shows the elemental spectrum of a gold-plated brass lead that reportedly exhibited severe solderability problems. The elemental spectrum shows that there is oxidized copper and zinc on the gold surface, which explains the solderability problems reported on the device leads.

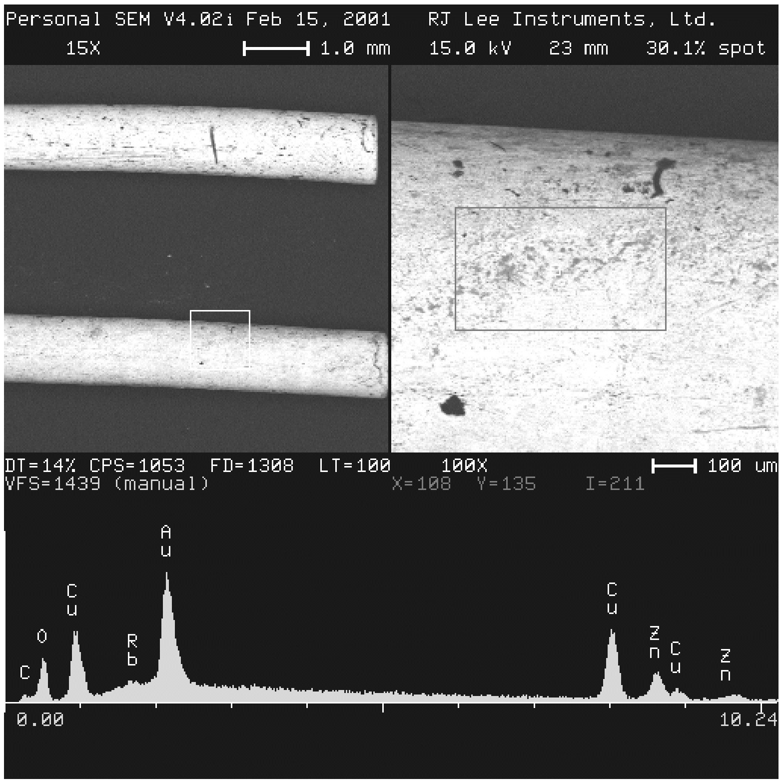

Fig. 5 – Elemental spectrum and BSE SEM images of gold-plated brass leads with no diffusion barrier [ref. SLI-475]. The elemental spectrum shows that there is oxidized copper and zinc on the lead surface, which explains the solderability problems reported on the device leads.

Conclusions

The use of diffusion barriers is essential to prevent diffusion of undesirable contamination from base materials into solder joints. This is especially true for Fe impurities from Fe-Ni or Kovar alloy and Zn impurity from brass alloys. SEM Lab, Inc. has documented significant numbers of solderability issues over the past decade that were directly attributed to the absence of a diffusion barrier.

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References

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[2] Electronic Materials Handbook - Volume 1 - Packaging, ASM International, Section 4 - Packages - Glass-to-Metal Seals, 1989, ISBN 0-87170-285-1.

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