Soldering to Gold- A Practical Guide

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Background/History

Gold has always seemed to find a place in electronic applications because of the very versatile characteristics it possesses. Historically, it has been used as an etch resist, contact surface finish, protective coating, wire bondable surface finish, die attach surface, and solderable coating.

It has been in the role of a solderable coating where some confusion and misconception has always existed. The misunderstandings have been with respect to the impact of Au on the soldering processes, along with the resultant effects on the properties of the solder connections created.

In the past, the average thicknesses of applied Au deposits were much greater than those currently being applied. In most cases, this was specifically related to the particular application and plating solution. Some applications required harder, fine grained deposits where the use of codeposited hardening elements, grain refining additives, and brighteners were necessary. In these applications, smooth, shiny, thinner coatings were generally applied ($\leq 30\mu$-inches). These types of coatings were generally applied to contact surfaces and to areas requiring overall environmental protection. In other applications, Au deposits with either no additives, or low levels of additives, were required in order to attain the required properties for the specific application. The rougher, duller, matte finish of such Au deposits was found to be an advantage in direct die attach and wire bonding to devices utilizing leadframes in their construction. In situations such as these, the Au thicknesses were sometimes fairly substantial ($\geq 30\mu$-inches).

In most of the aforementioned applications, very little consideration was given to the subsequent soldering operations to which these components would be subjected. As a consequence, these relatively thick Au coatings would not only be deposited in the areas required for the specific application, but also to areas to which solder connections would afterward be made. Even when applied as a solderability preservative coating, thicker layers were necessary to ensure adequate solderability protection, due to the inherent porosity of the deposits.

Consequently, soldering to these thick Au deposits, generally in the 30 μ-inch to 100 μ-inch range (Figure1), resulted in some commonly associated problems. ‘Poor solderability’ and

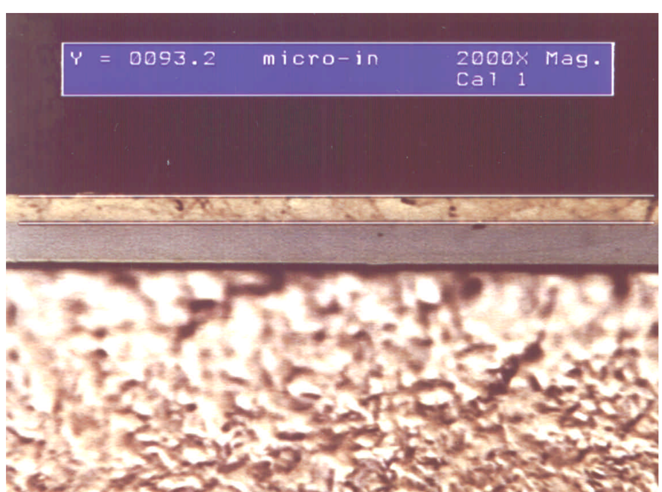

Figure 1-Very thick Au deposit which will undoubtedly result in poor solder connection.

'embrittlement' became very commonly used terms, when soldering to these Au deposits. It was these undesirable characteristics, along with the swiftly rising market price of Au that ultimately resulted in it's demise, until recently, as a popular electronic finish.

Resurgence in the Use of Au

Due to the expanding use of Au over past several years, it has become clear that the troublesome issues previously described, require some clarification. This is especially important for those faced with the task of creating solder connections to surfaces possessing Au finishes, as well as those who specify, design and deposit the Au finishes.

The intended objective of this paper is as follows:

- To bring some clarification to many of the issues surrounding the process of soldering to Au
- To bring about a better understanding of the process and the connections thereby produced
- Lastly, to propose some helpful considerations and guidelines that will result in more reliable, functional solder connections with greater longevity

Thickness is the Key

After many years of performing metallographic failure analyses of solder connections involving Au coatings, it has become clear that ***thickness*** is the most influential characteristic of the Au deposit as it relates to the ultimate integrity of the solder connections.

Fortunately, most current applications use very thin deposits, in the range of 5 μ-inch to 15 μ-inch thicknesses (Figure2). The emergence of plating processes that produce denser, less porous deposits, along with the reduction of time between application of the deposits and actual assembly soldering, have allowed processors to attain adequate solderability protection.

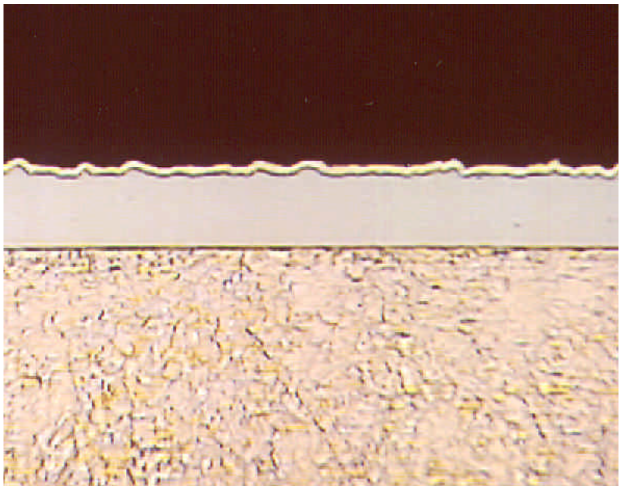

Figure 2- Thin Au deposit that is in the range currently most acceptable for minimization of soldering problems.

These thinner, less porous Au deposits are extremely important for several reasons.

1. Adequate solderability protection at a lower cost

2. Lower probability of solder connection embrittlement

3. Reduced voiding in solder connections

4. Reduced localized Sn depletion

Each of the aforementioned reasons is individually significant and will therefore be addressed separately.

Solderability Protection

Since the actual solder bond is being made to the underlying layer (typically Ni) following the rapid dissolution of the Au, the good solderability of that layer (assuming it was originally present) will be preserved by the thinner, denser, lower porosity Au coating.

Because of the very rapid dissolution of the thin Au coating, and the subsequent formation of the solder bond to the Ni, it is of paramount importance that the Ni surface be made active and solderable immediately prior to application of the Au deposit. If the Ni surface was not solderable at that point, deposition of the Au solderability preservative coating will have been made in vain (Figure 3). It is amazing how this seemingly obvious point can be overlooked due to either misunderstanding, or lack of communication with those responsible for the electroplating process (see the following "Plating Practices" section). It is important to make it understood that solderability must be initially present, if it is to be preserved by a protective coating. This is not only true in this situation, but in all those where a solderability preservative coating is being applied.

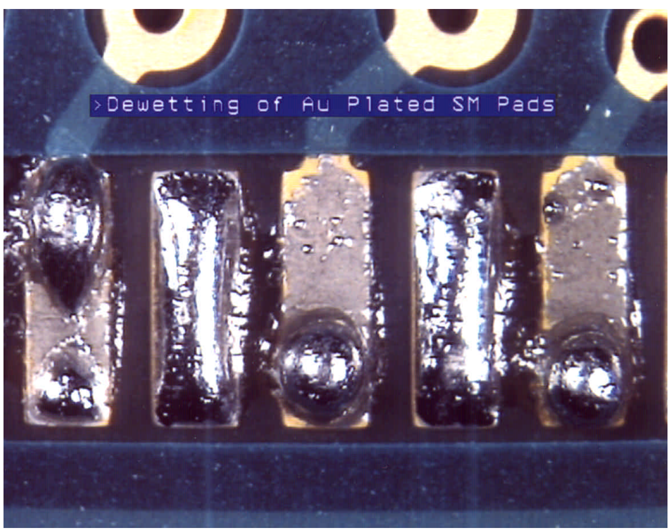

Figure 3- Dewetting of Au plated SM attachment sites due to poor solderability of underlying Ni.

Being aware that the solder connection is being made to the Ni, it is also important to be aware that, even when solderable, Ni reacts much slower with solder than Cu [1], therefore, requiring more energy to create an adequate bond. This is important to understand when considering a solder paste reflow profile for SM attach. Additional time above solder alloy liquidus temperature must be factored into the operation [2] in order to achieve the required reaction between the Ni and the Sn in the solder.

As with most materials to which solder connections are created, the Ni must also react sufficiently with the Sn in the solder, to form a continuous intermetallic compound (IMC) layer at their interface. The necessary Ni-Sn IMC reaction layer formation is essential to create a solder connection with sufficient strength to withstand the required service rigors encountered in it's role as part of the complete assembly.

Plating Practices

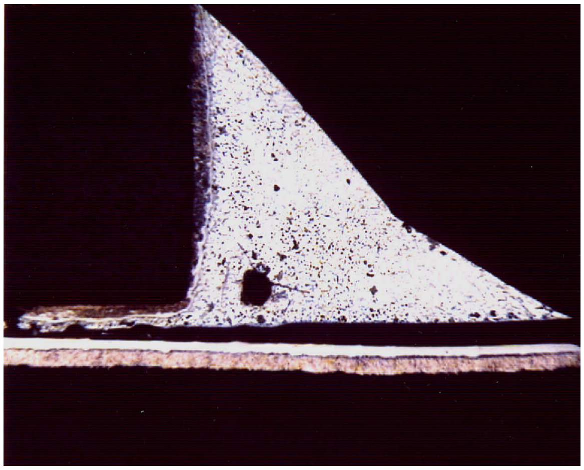

Figure 4- Failure within layered and impurity embrittled Ni deposit.

In addition to the obvious need for good solderability, the impurity levels in the Ni deposit should be kept as low as possible. This is important, even when P-Ni electroless deposits are used. Any impurities, either codeposited or occluded, that do not take part in the bonding reaction, could accumulate at one of the reaction interfaces, and interfere with the reaction, reducing the actual anchorage area created during the reaction. This clearly will reduce the overall strength of the bond being created and have an impact on it's service life and that of the assembly of which it is a integral member. It is therefore suggested that plating solutions be maintained and filtered regularly so as to minimize the codeposition and/or occlusion of unwanted contaminants. In the case of P in electroless P-Ni, keeping the P content nearer it's lower limit will be an advantage in this respect (Figure 5). Interruptions in the Ni deposition process, resulting in a layered deposit, will also create weaknesses that can eventually be failure sites (Figure 6).

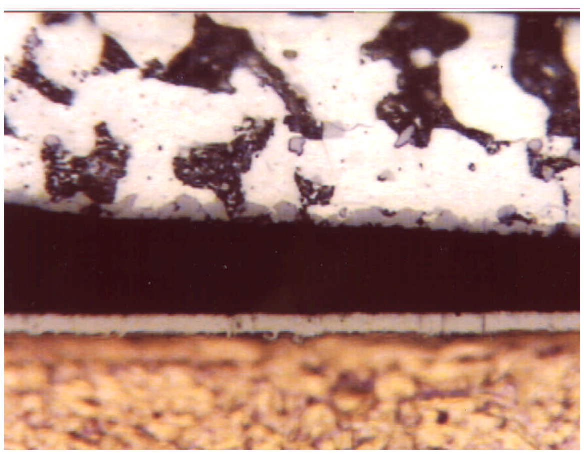

Figure 5- Failure due to separation at interface between Ni-Sn IMC layer and Ni deposit caused by accumulation of contaminants during reaction.

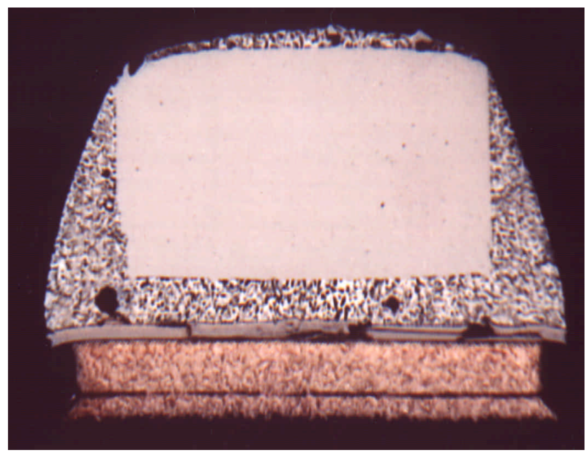

Figure 6- Failure initiating within layered and impurity embrittled Ni deposit.

Embrittlement

The advantage of thinner Au deposits is also important from the standpoint of solder connection embrittlement. The thinner Au deposits minimize Au-Sn IMC formation, and in almost all instances, its concentration along the reaction interface (Figure7). In situations where thick Au deposits (>20 μ-inches) are present, the larger quantity of Au-Sn IMC that forms, usually segregates and cannot disperse uniformly through the solder connection. The elevated concentrations of Au in the areas of segregation greatly degrade the integrity of the solder connections, especially where cyclic thermal environments are encountered in service [3, 4]. This is especially critical in the confined spaces between flat mating surfaces, such as those between SM attachment pads and chip components or gull wing leaded components [5].

Figure 7- Concentration of Au-Sn and Ni-Sn IMC at reaction interface with Solder.

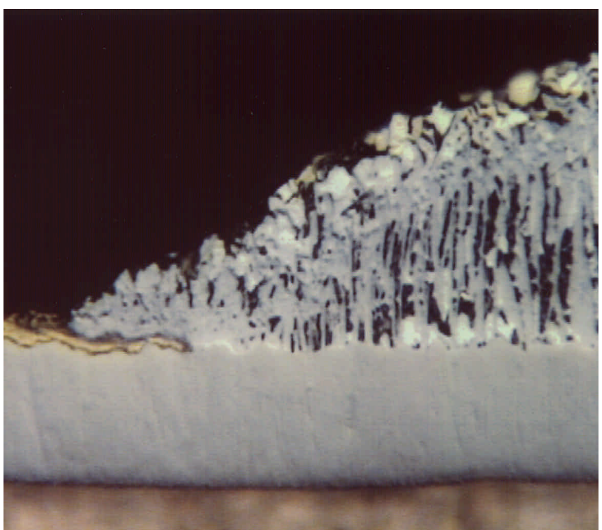

Figure 8-Concentrated Au-Sn IMC at leading edge of Solder as it reacts with Au deposit.

Very thick Au coatings (>40 μ-inches) can even have a significant impact on larger fillet areas that are not as confined as those just described. Concentrations are usually observed at the leading edge of the solder, as it reacts and flows out along the Au plated surface (Figure8). Au-Sn IMC formed during the reaction between the solder in SM connections and thicker Au coatings, can easily result in almost complete saturation of confined connection spaces. The greatest incidence of solder connection failure due to Au-Sn IMC embrittlement has been with crack initiation and propagation through the areas between the SM component connections having flat to flat mating members. These areas are usually very thin with respect to solder, much of the solder having been displaced during component placement. In a sometimes overzealous attempt to ensure good adherence of the component prior to solder paste reflow, excessive placement pressures are occasionally used, thereby dislocating much of the needed solder from the connection site. The resulting minimal solder in these regions can very easily become saturated with IMC reaction products, not only those of Au-Sn, but of any others formed during solder reaction with other connection surfaces. Thus, the impact is even greater when other IMC reaction products are being formed with Pd and Ag containing thick film terminations on chip components, and much worse, Au plated component leads (Figure 9). In any case, adequate solder thickness is most important in this critical region of the solder connection.

Additionally, the Sn in the small amount of remaining solder is easily consumed during reaction with the Au, thereby resulting in a very soft, weak Pb rich zone between two very hard and brittle IMC layers (Figure 10). This is obviously not the most desirable microstructure when cyclic thermal excursions are to be encountered.

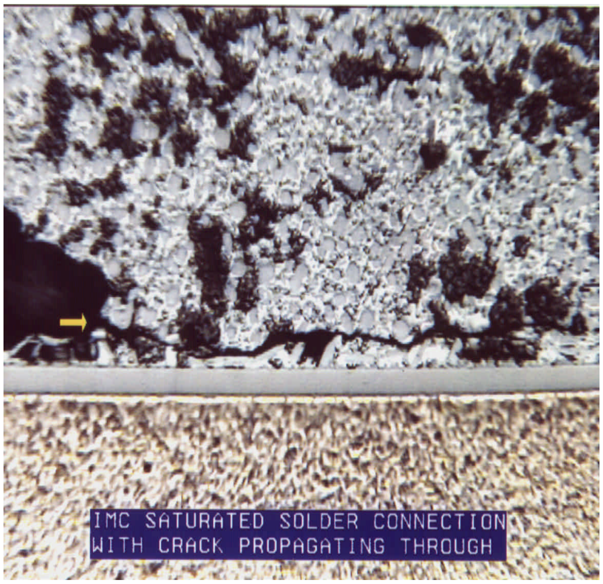

Figure 10- Crack propagating through IMC saturated solder connection.

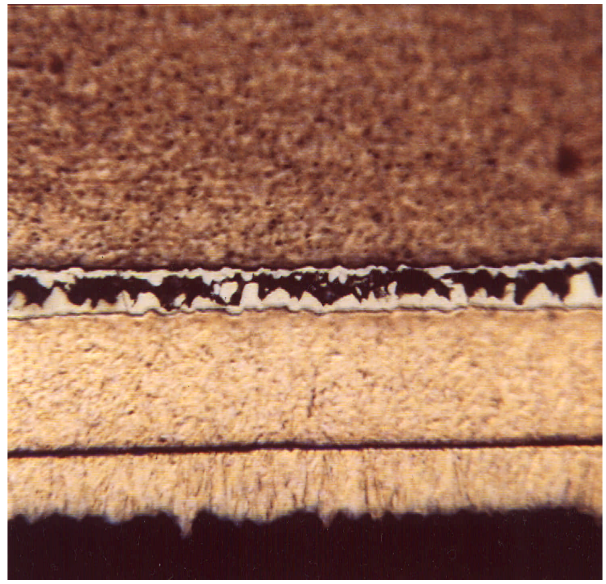

Figure 9- Buildup of weak Pb-rich phase (Dark areas in microstructure) as a result of Sn depletion through reaction with Au and Ni.

<u>Voiding</u>

The formation of voids due to outgassing is another significant issue relating to Au finishes. In addition to the other common causes of voids, such as shrinkage and unexpelled flux volatiles, large concentrations of voids can be created in connections during solder reaction to plated layers having organic materials occluded in the them. Occlusions can occur, either intentionally or unintentionally, with any plating process. Deliberate additions of additives, such as grain refiners, wetting agents and brighteners, or unintentionally introduced organic contaminants, can become occluded in the deposit. These can then be volatilized and released into the solder connections during reaction of the molten solder with the plated coating.

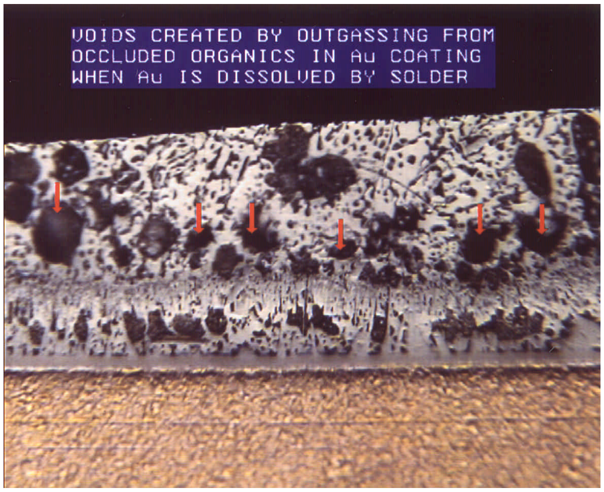

Figure 11-Voids in solder connection formed by volatilization of organic brighteners and contaminants occluded in the Au deposit.

Any bright plated deposit that is to be soldered, is therefore, very likely the source of varying degrees of outgassing, resulting in unwanted voids in the solder connections.

The formation of voids can be especially problematic when they are released into limited areas between flat mating surfaces, such as those previously described.

Entrapment of voids in these spaces is very probable even under normal conditions. This location now makes it extremely difficult for escape due to the very small quantity of sluggish and immobile IMC saturated solder in the area. In addition, voids formed in confined areas are more likely to be smaller and more aligned, since the limited space and limited mobility make it difficult for them to coalesce into larger ones (See Figure 12 and 13). This results in an additional weakness through which any crack initiated, can very easily and quickly propagate, resulting in rapid failure of the connection. Here we have a compound problem, frequently observed in solder connections where bright Au coatings are present, bringing to light yet another reason why care must be exercised when applying Au deposits.

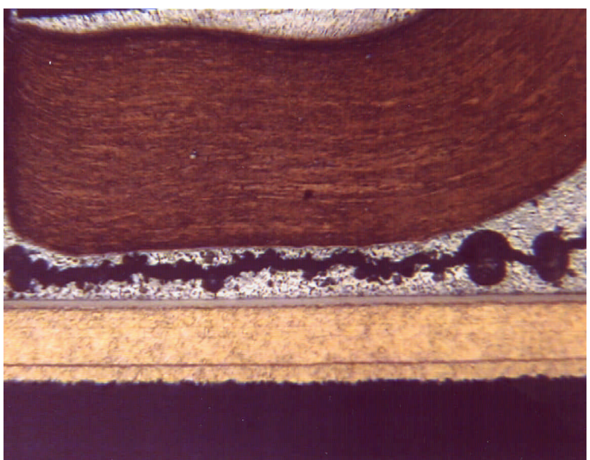
Figure 12-Outgassing from Au plating in confined space that has resulted in aligned voids between two flat mating surfaces.

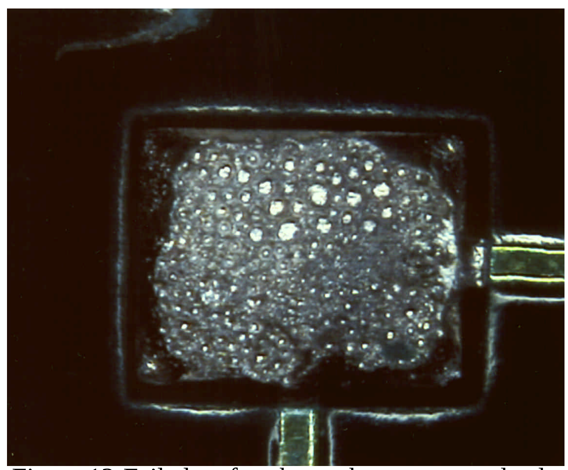
Figure 13-Failed surface beneath component lead revealing numerous entrapped voids.

This makes clear another advantage of thinner Au deposits. The application of thinner Au deposits results in a limitation of occluded organic materials and subsequent minimization of voiding created therefrom.

Sn Depletion

As noted earlier, and illustrated clearly in Figure 10, thick Au deposits result in the formation of more IMC reaction products, thereby consuming more of the available Sn at the location of reaction and creating weaker localized Pb rich regions.

Just as in the case of IMC concentrations and voids, this becomes a greater problem where solder availability is low, such as between closely spaced flat surfaces. The highly probable catastrophic consequences that can result from this additional weakness, along with embrittlement and voids, is easy to envision, and signals yet another reason why many precautions must be taken when dealing with Au plated surface finishes.

Even though not as critical as the situations involving Au, but still as important, similar precautions must be followed when creating solder connections with other types of electronic metallizations, owing to the reactivity of Sn with most electronic metals.

Summary of Important Considerations

The following is a summary of important factors to consider and always keep in mind when making solder connections to Au plated surfaces.

1. Specify Au thicknesses between 5 μ-inches and 15 μ-inches.

2. Make certain that the underlying Ni deposits are solderable.

a.) If electroless P-Ni is used, request P levels to be nearer the low end of the requirements.

b.) In general, request minimal impurity levels in the Ni deposit.

3. During SM reflow soldering, assure ample time above the liquidus temperature of the solder alloy such that sufficient reaction takes place between the solder and the Ni, allowing for the formation of an adequate solder bond.

4. Assure proper plating solution maintenance to minimize the possibility of occluded organic materials in the Au deposit. Filtration, Carbon treatment and additive control should be carefully and diligently performed.

Conclusion

It should be remembered that the formation of the Au-Sn IMC is only part of the group of occurrences that comprise the complex and potentially failure prone scenario, and that all of the consequential secondary reactions play just as significant a role in the failures that are likely to occur.

It is clear that producing solder connections on surfaces possessing Au finishes is a very complex task. This being stated, it is also clear that the task is also fairly easily accomplished when the critical issues are understood. If this were not the case, the successful assembly of the great multitude of functioning products which possess Au finishes as an integral part, could not have ever been possible.

It is also clear that process controls be put in place, and enforced diligently, such that the fabrication of the Au plated components, along with their ensuing processing during the soldering operation, be accomplished with the care necessary to provide maximum reliability with minimal risk of failure.

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