

Ag plating in HBLED packaging improves reflectivity and lowers costs

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Various types of Ag plating technology along with the advantages and limitations of each plating approach are discussed. Potential issues with Ag as a packaging metallization, and some of the steps that need to be taken to mitigate risks, are also reviewed.

HBLED packaging is becoming one of the new, high volume applications for Ag metallization. Traditionally used in power semiconductors, plated Ag is rapidly replacing Au in all levels of HBLED packaging, including first level ceramic packages and second level IMS materials. The replacement of Au is driven by two clear advantages of Ag for the HBLED application: much lower material cost and higher reflectivity in the visible spectrum. Other advantages of Ag include higher electrical conductivity, higher thermal conductivity and no tendency to work-harden under repeated mechanical stress. Table 1 shows a comparison between Au and Ag for a number of key properties.

But Ag also has some disadvantages that must be carefully considered. Ag plating often involves higher free cyanide concentration plating solutions that require more safety controls (and thus more cost). And autocatalytic electroless plating baths for Ag are much less mature, and have fewer vendors, than autocatalytic Au. Another area of concern for device reliability is Ag migration. If a thin film of water absorbs on the surface between two

Ag pads at different voltage, Ag dendrites can rapidly form effectively shorting out the two pads. This is particularly a problem in the presence of halide contamination. Last is the well know phenomena of Ag sulfide formation which can greatly reduce reflectivity as well as solder wetting and wirebond ability of a Ag surface. Ag₂S forms when Ag metal is exposed to sulfur containing gases such

Property	Ag	Au
Metal Cost (per tr. oz)	15	863
Electrical conductivity (S/m)	6.3 x 10 ⁷	4.1 x 10 ⁷
Thermal conductivity (w/m-K)	429	318
Density (g/cm³)	10.49	19.3
Reflectivity 500nm %	>90	<40

TABLE 1. Comparison of Ag and Au.

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Bath Type	Source of Oxidation/ Reduction Reaction	Key Deposit Characteristics
Immersion Silver	Oxidation/dissolution of the pad or circuit line metal surface	Very thin Ag layer. Deposits wherever metal is present. Requires pad material to be less noble than Ag (Cu, Ni)
Autocatalytic Silver	Oxidation and reduction of chemical species in the bath	Can be a thick deposit. Deposits wherever metal is present. Can deposit on more or less noble metals. Requires rigorous control over plating process. Bath lifetime a few metal turn-overs.
Electrolytic Silver	Plating is driven by an external electrical current with an applied voltage	Only deposits on pads connected to the external circuit. Can be very thick. Very mature plating technology for Ag. Many parameters to adjust deposit properties.

TABLE 2. Comparison of basic plating processes.

as H₂S, a component in air pollution. Special precautions must be taken to protect Ag surfaces from H₂S and other sulfur containing chemicals. Ag surfaces also passivate when exposed to chlorides, so limiting chloride exposure is also necessary to keep the Ag surface metallic.

The purpose of this article will be first to discuss the different types of Ag plating technology, and how each plating approach fits in the HBLED application. The second focus will be to discuss both the advantages and dis-advantages of Ag with respect to HBLED device performance as well as short and long term reliability.

Ag plating technology

There are two broad categories of plating technology: electrolytic and electroless plating. For electrolytic plating, the metal surface to be plated is biased as the cathode in an electrochemical cell which contains dissolved metal ions (Ag⁺). The plating solution acts as the (ion conducting) electrolyte and an external Ag electrode in the plating bath acts as the anode. When the substrate to be plated is cathodically biased, and electrical current is applied, Ag ions from solution will plate out on the cathode (reduction reaction), and Ag metal from the anode will dissolve into solution (oxidation reaction). The critical requirement for electrolytic plating is that all of the circuit features that need

to be plated are electrically connected and can be easily contacted with an external connector (typically a pin in a plating rack).

There are a number of key advantages of electrolytic plating if this circuit continuity can be achieved:

- Plating is directly controlled by the applied electrical current. The higher the current, the faster the plating rate (within limits, if the rate is too fast other competing reactions can occur)
- There is no intrinsic limit to the thickness of the deposit
- There are many adjustable parameters including current density, metal ion concentration, voltage profile, temperature, and degree and type of agitation. These parameters can be used to adjust and optimize deposit ductility, thickness uniformity, density, roughness and pad adhesion.
- If properly maintained, the lifetime of the plating bath can be very long, on the scale of many months. In addition, electrolytic plating chemistry is significantly less expensive than electroless plating baths. Both of these factors lower plating costs.

For electroless plating, the oxidation and reduction occurs within the plating bath, not driven by an external

circuit. This allows plating to be accomplished on metal features that are electrically isolated from each other, which is a common feature of many types of circuits. There are two basic types of electroless plating technologies. One is “immersion plating” and the other is “autocatalytic plating.”

Immersion plating is accomplished by depositing a “more noble” metal onto a pad of “less noble” metal. The reaction is very simple. The oxidation reaction is the dissolution of the “less noble” pad metal into the plating solution. The reduction reaction is deposition of “more noble” metal ions in solution onto the pad material. This is essentially a controlled galvanic corrosion process. In the case of Ag, deposition can occur on metals such as Cu or Ni which are less noble. The limitation of immersion plating is that the process stops or slows dramatically once the pad surface is covered with the depositing metal since corrosion of the underlying pad material can no longer occur (oxidation reaction is shut down). Consequently, immersion plated layers tend to be very thin.

Auto-catalytic electroless plating is much more complex. In this case, specific species are added to the plating bath which drive continuous oxidation and reduction reactions. Small levels of catalyst are first deposited on the surface to be plated to favor reduction reactions (plating) on the surface of the pad versus in

the solution. Auto-catalytic plating baths require high levels of chemical sophistication to develop, because there is a very fine balance that must be achieved. If the oxidation/reduction reactions are too aggressive, plating will occur in solution or on surfaces that are not metal. If the oxidation/reduction reactions are too passive, then plating cannot be easily initiated on all metal surfaces. Because chemical reactions are very sensitive to impurities, chemical uniformity and temperature, the plating process must be very tightly controlled so that impurities do not build up in the bath, and temperature across the part being plated is extremely uniform. However, an advantage of auto-catalytic baths compared to immersion baths is that much thicker plated layers can be achieved. These basic plating processes are compared in **TABLE 2**.

For the HBLED application, there are a number of potential requirements for the Ag plated layer which impact which type of plating chemistry is utilized. Some of these various requirements are summarized in **TABLE 3**.

From a development standpoint, immersion Ag and high cyanide (CN) electrolytic Ag plating baths are well established technologies. Auto-catalytic Ag and lower free CN Ag electrolytic plating baths are newer technologies that are less established in high volume applications.

Ag Layer Function	Conditions	Comments	Candidate Baths
Solder Pad	SAC 305 Solder	Ag layer should be thin to limit Ag dissolution in the solder	Immersion Ag, autocatalytic Ag, electrolytic Ag
High reflectivity pad or conductor	Maintain reflectivity after heat exposure for die attach, wirebonding, silicone curing cycles	Underlying metals such as Ni or Cu diffuse in Ag during thermal cycles. On the Ag surface these metals form oxides and they can hurt die attach and wirebonding reliability as well as reducing Ag reflectivity. Thicker Ag layers reduce this effect.	Auto catalytic Ag, electrolytic Ag. If plating with a white solder mask or dry film present, then only low CN, lower pH electrolytic Ag is stable

TABLE 3. Summary of HBLED Ag layer requirements.

Critical issues for Ag plating

For most HBLED applications, electrolytic Ag plating is preferred if this can be accomplished with the circuit design. This allows use of a very mature plating technology and can be used to deposit thick Ag layers. If thick Ag is required to maintain high reflectivity, good wirebonding and die attach after thermal exposure, and electrolytic plating is not possible, then the less mature autocatalytic Ag is the only real option. In addition to being less proven in high volume manufacturing, this plating technology is also more expensive to implement due to higher plating bath costs and shorter bath lifetime (few metal-turn-overs or MTO) and the need for very tight control over the plating environment.

Ag migration

From an HBLED reliability point-of-view, the most significant issue for Ag metallization (no matter how it is deposited) is Ag migration. If Ag migration forms a short between the diode anode and cathode, of course the device will no longer function. There are a number of critical requirements which must be met for Ag migration to initiate:

1. There must be two electrodes separated by a dielectric at different electrical bias
2. The electrode with an anodic bias must have some amount of exposed Ag
3. Between the two electrodes the surface of the dielectric must have a hydrophilic surface chemistry
4. There must be a source of humidity. The humidity level does not have to be very high since electro-

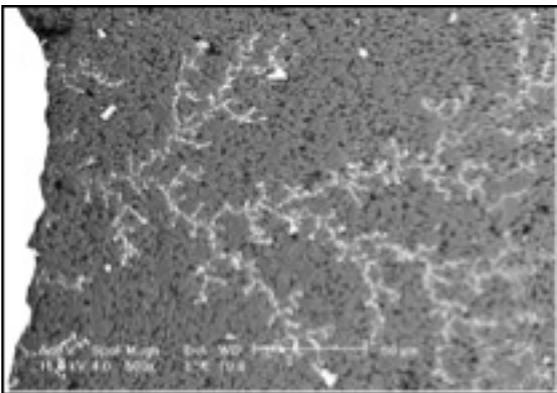


FIGURE 1. Dendrites growing across alumina dielectric. Ag electrodes on top and bottom (not shown).

chemical Ag migration can occur with a few monolayers of adsorbed water. RH above 30% have shown migration to occur in some cases.

5. There must be a source of ionic contamination, particularly chlorides. For chlorides the level should exceed 4 $\mu\text{grams}/\text{in}_2$. [1]

Typically an organic residue such as a flux residue on the dielectric surface results in a hydrophilic surface chemistry on FR4. Most ceramic materials, such as Al_2O_3 also have hydrophilic surfaces which will attract a water layer.

Once these conditions are met, the electrical bias difference between the two pads results in the electrochemical dissolution of the Ag from the anode and deposition of this dissolved Ag onto the cathode. Because of the low concentration of Ag in solution, the structure of the deposit is dendritic. Dendrites will continue to grow until they form a short between the anode and the cathode. Under the right set of conditions, dendrites can grow in a matter of minutes. **FIGURE 1** shows a Ag dendrite grown on an Al_2O_3 surface between two Ag pads (pads are not shown). Typically the first few dendrites that connect will burn out like a fuse due to the high current density, but over time a more stable short will develop with many dendritic fingers.

Studies have shown that the presence of a solder mask between the two biased pads can help reduce the probability of dendrite formation, as long as the solder mask

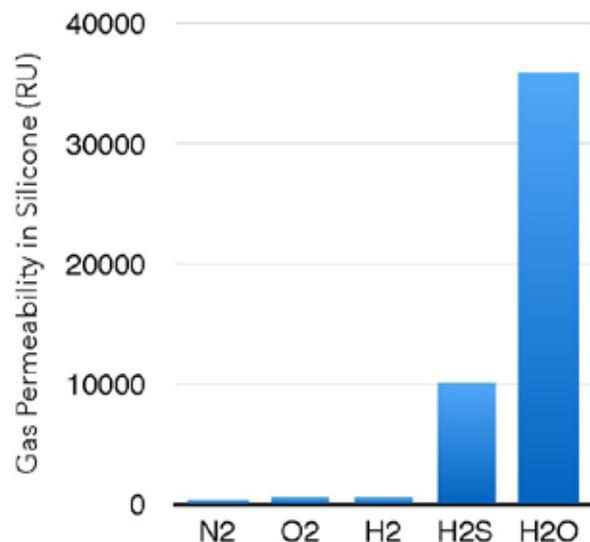


FIGURE 2. Gas permeation rates through silicone (relative).

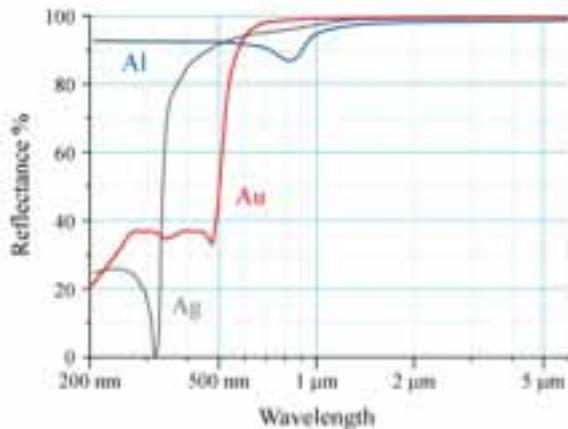


FIGURE 3. Reflectance % vs. wavelength through the visible for various metals.

is not a source of halide contamination. The presence of the mask makes it much more difficult for a continuous layer of water to form between the two pads. [2]

Ag sulfide formation

Ag does not readily form an oxide but will form a sulfide with exposure to sulfur containing gas species such as H_2S . This is an issue for HBLED for two reasons. First, a moderate level of Ag_2S will decrease visible light reflectivity hurting HBLED light output. For more severe Ag sulfide formation, Ag conductor lines can be corroded.

There are two main areas of focus in controlling the impact of Ag_2S formation. The first focus area begins after plating is complete and ends once the device is packaged and assembled. Since thin layers of Ag_2S passivation will impact assembly operations such as wirebonding, rigorous efforts must be made to keep the Ag surface very clean until assembly is complete. One option is to control exposure to sulfur containing gases by keeping plated parts in a controlled environment. Another option is to apply a thin organic coating, the way OSP is used to protect plated Cu from oxidation in the PCB industry. Many plating bath vendors who sell Ag formulations also sell proprietary organic coating baths.

The second area of concern is silver sulfide formation in the finished package. This can impact reflectivity, as discussed above, as well as conductor integrity in more extreme cases of exposure. Encapsulants such as silicone are typically not good barriers to H_2S and thus offer limited protection. Relative rates of gas permeation in

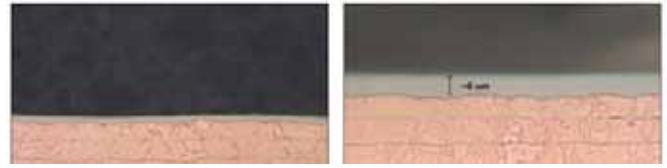


FIGURE 4. Cross section showing plated Cu with bright Ni smoothing layer to decrease surface scattering.

silicone is shown in **FIGURE 2**. [3]

Factors that influence Ag reflectivity

As shown in **FIGURE 3** [4], Ag intrinsically has very high reflectivity in the visible spectrum (wavelength from 350 to 750 nm). In addition, plating can be utilized to further enhance light reflection by decreasing surface roughness which can lead to surface scattering.

FIGURE 4 shows a cross section of a rough plated Cu surface that has been over-plated with an electrolytic bright Ni layer that has had organics added to the plating bath to promote leveling and smoothing of the surface. You can see from this cross section how dramatically smoother the surface texture is after the bright Ni layer. The peak-peak roughness factor, RP goes from $2.89 \mu m$ for the as-plated Cu, to $0.09 \mu m$ for the top of the bright Ni deposit. When this surface is then plated with Ag, a mirror finish results.

Assembly operations with Ag

Provided that there is no significant Ag_2S passivation, Ag is an excellent surface for both soldering and wirebonding. For wirebonding to Ag pads, typically Au wire is utilized. Because Au and Ag form a continuous solid solution, a diffusion bond is formed during wirebonding, very similar to a Au/Au wirebond. ◀

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