Using wet chemistry for etching under-bump metal

OVERVIEW Drawing on traditional front-end processing, wet chemical etching of under-bump metallurgy in the presence of solder bumps can now be successfully applied in back-end wafer level packaging applications. These methods resolve a unique set of problems and control issues.

Wafer level packaging takes advantage of IC manufacturing's front-end processes, including film deposition, photolithography, electroplating, solvent resist stripping, and metal etching. These processes, as applied to solder bumping, require some special techniques and considerations that are still fairly new territory. We have been focusing on wet etching of metal layers for the solder bump process flow.

Typically, solder bumps are placed on conventional peripheral aluminum bonding pads or on landing pads that have been redistributed to new locations above the chip circuitry. These redistribution lines and landing pads are usually copper, occasionally aluminum. The under-bump metallurgy (UBM) is a layer, or stack of layers, that provides an important foundation for the solder bumping process. UBM wet etch deals with processing steps to define isolated regions of the UBM beneath the solder bumps.

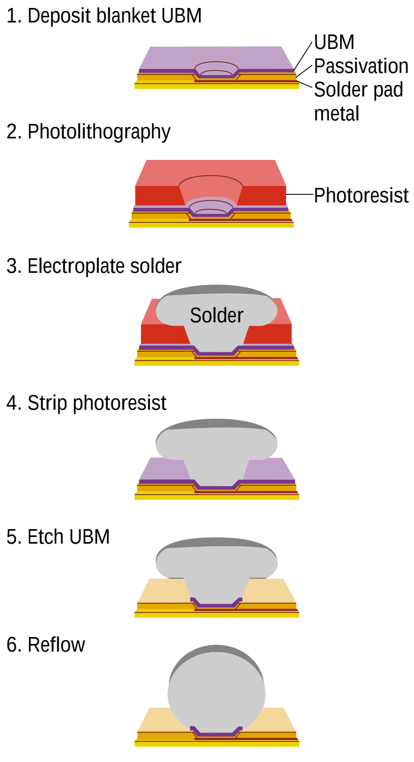

Figure 1. Electroplated solder bumping process.

Process flow

In a typical *electroplated solder bump process* flow (Fig. 1), after landing pads for the solder bump are defined and isolated with a dielectric film, UBM layers are applied via blanket film deposition. Then photolithography creates vias, in relatively thick photoresist, above the landing pads. Electrochemical deposition into the open areas produces electroplated solder bumps.

When eutectic solder (63% Sn-Pb) is used, a stud of copper or nickel is usually plated before the solder bump. Often the solder is allowed to plate over the top of the photoresist to create a mushroom-shape 80–120µm high. This allows a sufficient volume of solder to be deposited to achieve the desired standoff height when the bump is eventually reflowed. If photoresist thickness is high enough, the appropriate volume of solder may be contained within the via and there is no need to mushroom plate over the top of the resist. When the photoresist is stripped, the solder bump is left towering over the blanket UBM (Fig. 2).

The purpose of a UBM etch is to remove all metal from the area between solder bumps, thereby isolating them on top of UBM islands. When the solder is subsequently reflowed, it will not wet the dielectric and is thus limited to the UBM underneath the as-plated bump. In this state, the surface tension of molten solder pulls it into the desired shape of a truncated sphere.

The alternate *solder paste process flow* differs in several ways: First, UBM pads are defined by photolithography after blanket deposition of UBM. The UBM etch uses the photoresist rather than the electroplated solder bumps as the metal-etch mask. Next, a solder paste mask is applied using a metal stencil or photoresist. The solder paste is applied to select areas where the isolated UBM pads remain. Finally, with the stencil or photoresist removed, the solder is reflowed.

UBM technology

The UBM layers provide: an adhesion layer that holds upper layers and solder bumps to landing pads; a barrier to diffusion of upper layer metals into underlying interconnect and circuitry; and a wetting layer for connection and reflow of solder bumps. For electroplated solder bumps, the top layer of the blanket UBM also serves as the electrical conduction layer (i.e., the seed layer) that acts as the cathode in the electrolytic cell.

Currently, the industry is using a wide variety of metal layers in various UBM schemes, leading to some difficulty in generating a standard process for UBM etching. Most barrier layers combine barrier and adhesive properties by mixing materials. For example, tungsten — a good barrier — mixed with 10% titanium improves adhesion. Barrier layers include chrome, titanium, tantalum, titanium-tungsten-nitride (TiWN), and nickel-vanadium (NiV). These are usually thin layers (250–2500Å). Deposition is generally by

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sputtering. The seed layer is usually ~5000Å of copper deposited by physical vapor deposition.

When final bump composition is gold instead of solder, a gold seed is used, and gold electrochemical etching is often used in place of wet etching to remove the seed layer. This is then followed by wet etching of the barrier layer.

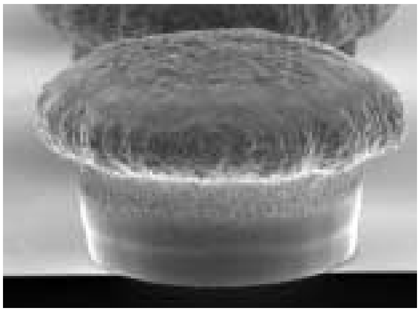

Figure 2. Solder bump after photoresist strip.

UBM etch processing

Although UBM layers may be dry-etched successfully, wet etching is generally used because no additional cleaning of etch residues is required. Whether performed as a batch process or a single wafer process, wet etching costs are significantly less than dry etching. Additionally, wet etching more efficiently etches beneath the caps of mushroom plated bumps.

UBM etching removes exposed metal layers that are masked either by photoresist (in the solder paste process) or that are masked by the solder bump (electroplated solder process). Two issues that must be addressed for a successful UBM etch are complete film removal and controlled undercut.

The etch time must be long enough to ensure all the target metal is removed from areas not covered by the mask. Extra etch time might be used to ensure that the film clears in areas where metal might have been slightly thicker or where metal removal rate is slightly slower, such as in a tight pattern corner. Depending on the process, 10–50% over-etch time is common. For example, a 1µm-thick film that etches at 1000Å/min would clear in 10 min.

With wet etching, metal etch is typically isotropic (i.e., lateral etch under the mask occurs at roughly the same rate as vertical etch through the film). Therefore, undercut dimensions will be about the same as the film thicknesses. With longer etching time, more metal beneath the mask will be removed. Thus, with no over-etch, the finished metal feature width of a 1µm-thick film will be decreased by 2µm (i.e., 1µm on each side). Mask sizing may be adjusted to compensate for undercut produced by wet etching.

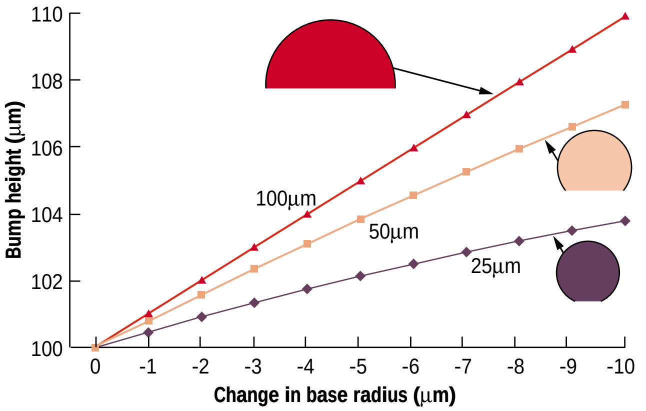

Figure 3. Spherical bump height vs. change in base radius for three different pad radii (i.e., 25, 50 and 100µm). Bump silhouettes are examples of reflowed bump cross-sections.

With an isotropic etch process using no over-etch time, the angle of the metal wall will be ~45° and widest at the base. The top of the film is where etching has had maximum time for lateral etching. With longer over-etch times, as undercut increases, the sidewall profile becomes more vertical. With UBM etching with solder bumps masking the UBM, the mask for each layer is not photoresist, but the adjacent vertical layer (i.e., the base of the solder bump masks the seed layer and the seed masks the barrier layer). With extreme undercut, mechanical adhesion of the bump is a concern because rinsing or handling may break bumps from the wafer. For this reason, UBM layer uniformity is critical, particularly on bumps with smaller base diameters where even slight undercut removes a proportionally larger amount of adhesion area compared to that still holding the bump in place. Undercut values are commonly specified to be <2–5µm. Undercut of 1–3µm can be routinely accomplished using either a spin-spray wafer-batch processor or a single wafer spray processor.

The importance of controlling UBM undercut translates directly to reflowed bump height. As the base area of the bump is reduced, the height of the truncated sphere formed at reflow will increase. Variations in undercut or UBM base become variations in bump heights across a die and wafer. For example, the data in Fig. 3 show the relationship of how the height of a truncated sphere increases with the reduction of base radii for three base areas. The nominal bump height is 100µm in all three cases.

The varying dependence of bump height on changes in base area allows different specifications for UBM etch undercut. Different bump geometries will have proportionately different contributions of undercut to overall bump height variation. Once this is understood, uniform control of undercut becomes more important for manufacturing success.

With short etch times, there can be problems with run-to-run repeatability due to initiation of the etch and variations in system configurations as the etch begins. Slowing the etch rate, even slightly, opens the window of process variations that still produce acceptable results. With batch processing, a one-minute etch time helps provide reasonable etch control.

Because of tighter controls possible in single-wafer processing, etch times in a single wafer tool are often much less than batch processing. Orientation of the wafer and spraying directly toward its face can also provide process advantages over introducing the etchant from the side. Throughput typically is lower and costs are higher compared to batch processing, but in some cases the identical "individual attention" offered each wafer in single-wafer processing can be a significant advantage.

The most critical process parameter is etch time for both single-wafer and batch processing tools. In some cases, it is possible to physically observe the film clear through a window in the process chamber. This allows a specific, fixed over-etch time to be implemented by advancing the recipe step when the film clears. An electronic endpoint detection system can provide attentiveness and accuracy to endpoint determination that can far exceed that of a human operator.

Several endpoint detection systems are commercially available, offered as standalone systems or integrated within etching platforms. These generally consist of a light source and detector that sees the wafer, and a computer for signal processing to determine

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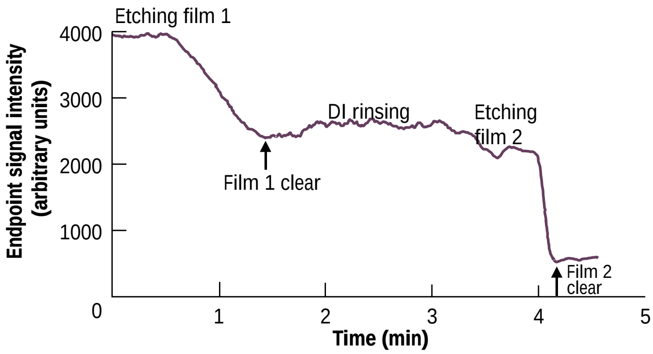

Figure 4. UBM endpoint signal.

endpoint. The wavelength of illumination and detection are optimized to see an intensity change from the wafer as the target film clears. A second recipe controls the etch tool for a subsequent layer etch. This real-time monitoring and signal processing can improve etch process control and extend bath life by allowing the use of a chemical bath as its decreasing activity requires slightly longer etch times. Various algorithms and limits allow more control of the etch process, over-etch time, and chemical bath lifetime.

Figure 4 shows an endpoint detection signal for a two-layer UBM etch with a water rinse between the etch steps. The first layer etch time is ~10 min; the second etch takes ~1 min.

Film etchant possibilities

Film	Etchant
Copper	Dilute sulfuric peroxide mixture (dSPM), ammonium persulfate, various ammonia chemistries
Gold	Iodine, cyanide-based chemistries
Chrome, Cr-Cu	HCl, ceric ammonium nitrate
Nickel vanadium	Nitric acid, dSPM, H_2O_2, HCl
Titanium, TiW(N)	H_2O_2, dilute SC1, dilute HFN

Process chemistry

The principal difficulty in UBM etching with solder as the mask, as compared to a photoresist patterned metal etch, is etching in the presence of the solder. It is not difficult to etch copper with a wide variety of chemistries. Unfortunately, the same is true for lead, and etching copper or TiW in the presence of exposed lead can be tricky. The problem is most prevalent for high lead (>90% Pb) bumps where peroxide or persulfate-based solutions will preferentially attack lead and liberate gases that prevent the etchant from uniformly contacting UBM layers. The result is a reasonable etch rate in areas without bumps, and nearly no etch (except Pb) in regions with higher bump density.

In worst cases, solder bumps are completely dissolved before there is any appreciable etch of the target film. Some chelating agents added to etchants seem to help moderate reactions with lead and have been used with good results. But even in these cases, prolonged contact of bumps with the etchant can oxidize bumps.

Better results have been achieved by taking promising chemistries and using more dilute concentrations for increased etch times. In cases with visible oxidation and gas evolution on bumps, it has also been helpful to quench the etch repeatedly with DI water and then allow it to reinitiate uniformly across the surface, etching only a few seconds until the reaction is quenched again. In this way a more aggressive etchant can remove the UBM layer stepwise with only minimal attack on the lead bumps.

With eutectic and lead-free solder bumps, the problem is greatly reduced. Certain etchants can still cause significant problems in bump degradation, but by moderating concentration and temperature, good results can be achieved. Peroxide-based chemistries generally work well to strip titanium-based layers in the presence of eutectic solder, where, if problems are encountered, a decrease in temperature is usually sufficient to decrease attack on the lead. The etch rate of many solutions, and particularly of peroxide-based solutions, is a very strong function of temperature. The breakdown of peroxide as it consumes lead (or titanium-based metal mixtures) can generate enough heat to cause noticeable bath heating during processing. This, of course, increases reaction rate further, causing more heating.

It is sometimes necessary to process with a single-use chemistry to maintain run-to-run control and provide the cleanest chemistry. This means spray application to wafers, routing this chemistry to the drain instead of reclaiming it back to the storage tank. Although this might seem wasteful, this method allows more dilute chemistries to be used at higher temperatures. Chemical usage/lot is the same, but DI water use increases.

This technique has been most successfully used on titanium based films in the presence of either high-lead or eutectic solder using dilute ammonia-peroxide-based chemistries (i.e., dilute SC1). The limitation here is that the etch recipe must be completed before the supply chemistry in the tank is exhausted. Any remaining chemistry after process completion is sent to the drain. Then a fresh bath is poured for each subsequent lot of wafers to be processed.

The table shows typical etch chemistries for common materials used in UBM. By making an appropriate choice of etch chemistries, UBM can be wet-etched with minimal attack of exposed bumps.

Conclusion

UBM must be etched to define isolated, wettable pads before solder bumps may be reflowed. Wet chemical etching UBM in the presence of solder bumps presents a unique set of problems and control issues. Our work has identified primary sources of variation in an integrated solder bumping process flow that affect UBM etching. Further, we have proposed and developed methods that help deliver a manufacturable UBM etch. What has been traditionally IC front-end processing has been successfully applied to the UBM etch steps in the wafer-level packaging process flow. ■

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