Wafer Bumping

- A Comparative Technologies Study

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Introduction

Modern semiconductor packaging strives to shorten electron pathways for increased speed, lower power, better device functionality and lower cost. Flip chip technology meets these demands and was introduced by IBM in the late 60's, known as Controlled Collapse Chip Connection (C4). Rapid growth and cost reduction has forced several revolutions, from ceramic to plastic package, high lead to eutectic 63Sn/Pb and presently, lead free. Flip chip involves several sequential steps: wafer bumping, attaching the bump die to the board or substrate and then completing the assembly with an adhesive underfill. Wafer bumping comprises step one: to create a solderable metal surface for each of the input / output interface, and step two: to deposit solder ball which provides mechanical and electrical connection between the die and the substrate. In the flip chip package, under bump metallurgy (UBM) determines the solder ball compatibility and cost. This paper discusses each of the UBM deposition technologies in meeting market demands.

UBM Deposition

i. Evaporated UBM and Solder Bump

This method has ceramic packages utilizing Cr/Cr-Cu/Cu/Au or TiW/Cu/Au as the UBM. A cleaning process removes oxides or photoresists (PR) prior to metal deposition and roughens the wafer passivation and bond pad surface which promotes better UBM adhesion. Cr/Cr-Cu/Cu/Au layers are sequentially evaporatively deposited, forming a multilayer thin film UBM. A thick layer of 97Pb/Sn or 95Pb/Sn is deposited and reflowed to form a spherical solder ball. During both processes a metal mask is used for patterning. The low vapor pressure of eutectic Pb/Sn solder makes this process suitable

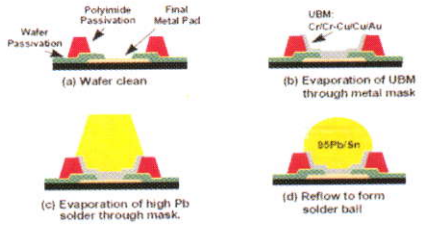

Figure 1: Evaporation UBM and Solder Bumping Process

only for high lead solder, which is ductile and allows the bump to be collapsible upon exposure to temperatures above 300° C, inherently unsuitable for plastic or organic packages. The modified 'Evaporated, Extended Eutectic' (E3), where a tin layer is deposited separately prior to reflow process, allows melting at lower temperatures. Alternatively, eutectic solder could also be used, as in Intel processors. However, both methods incur additional cost and eliminate the special 'controlled collapse' which results in planarization issues and non-self-aligned bumps.

ii. Electroplated UBM and Solder Bump

Electroplating UBM is an alternative process due to lower equipment costs and utilization of several material plating processes. The traditional solder bump plating process uses a Cr/Cr-Cu/Cu UBM with a high lead solder (3-5% Sn content). For eutectic 63Sn/Pb solder, a TiW layer is followed by a thick solder wettable layer such as Cu, called a 'minibump' or 'stud'. A schematic representation of this process is shown in Figure 2.

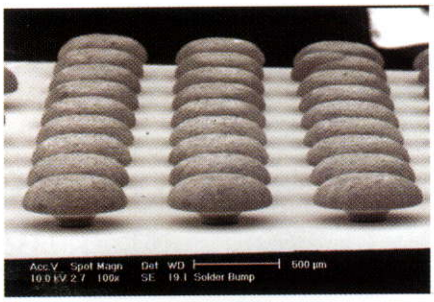

Figure 2: Micrograph image of 'mushroom' shape electroplated UBM and solder bump prior to reflow (Source : Ricky Lee, Presentation Slide – Leadfree and WLCSP)

The process starts with wafer cleaning prior to metal deposition where the multilayer UBM, consisting of TiW, Cu and Au, are sequentially sputtered. The UBM adheres to the wafer passivation layer as well as to the bond pads. A copper layer is plated over the bond pad to a height as determined by patterned PR for the creation of the minibump structure. A second mask forms a plated solder bump and the PR is stripped after bump formation, exposing the UBM on the wafer, which is removed in one of two ways. In the first approach, a wet etch is used to remove the UBM from the wafer with some undercutting. The solder is then reflowed into a sphere. In the second approach, the solder bumps are reflowed first, so that any intermetallics formed within the bump structure will protect the bump by minimizing undercuts during subsequent etching processes. The UBM / minibump enables application of high lead or eutectic 63Sn/Pb solder bump. Electroplating is less expensive than evaporated wafer bumping but bump uniformity is degraded due to non-uniform current density distribution, electric field between anode plate and wafer, and plating solution flow. The thick copper minibump that develops during electroplating may, however, induce unnecessary, excessive stress to the silicon underneath and cause cratering.

iii. Sputtered UBM and Printed Solder Paste Bumping

As usual, the process starts with cleaning, prior to metal deposition. Then Al is sputtered, followed by Ni and Cu. The Al adheres strongly to the wafer passivation as well as to the Al bond pads. Cu prevents the Ni from oxidizing and does not need the solder bump to adhere to the UBM. The Cu layer will be consumed by the eutectic solder during reflow. The Ni serves to provide a solder diffusion layer and also as a solder wettable surface after Cu is consumed. Later PR is applied, patterned and developed and the Al/Ni/Cu layers are etched away except at the bond pad opening. The PR is removed, leaving the multilayer UBM on the bond pad. Finally, solder paste is printed onto the UBM and reflowed to form a spherical solder ball. This is cheaper than evaporation and competitive with electroplated bumping technology. Additional costs are not incurred at the board level because the UBM composition is compatible with eutectic 63Sn/Pb solder which is robust enough to withstand more than 10 reflow cycles. It also reported to be compatible with lead free solder.

iv. Electroless UBM

Electroless deposition is a promising technology and a low cost solution. Electroless bumping is selective autocatalytic metal deposition on activated Al pads without any costly equipment such as plating base and lithography. Ni, Co, Pd, Pt, Cu, Ag and a variety of alloys involving one of more of these metals can be deposited with this technology. Electroless Ni and Cu is the most established deposition solution. Electroless Ni bump acts as a UBM and as a foundation for the solder bump, or with a slight thickness increase it can be a stand alone minibump that can be used with conductive adhesives because electroless nickel is isotropic, allowing the bumps to grow evenly in all directions, and when above the passivation level, spread over it and sealing the bond pads. The process starts with a wafer back-side coating to prevent Ni from plating it and followed by a cleaning process. A second cleaning process removes thick Al oxides and prepares the surface for metal deposition. Next is the zincation process which activates the Al bond pad surface for Ni deposition. A thin Zn layer is deposited over the Al and will be substituted by Ni. Finally, a thin Au layer is deposited on the Ni from a gold immersion bath to prevent the oxidation of Ni before soldering and also help to improve solderability. Figure 3(a) shows the sequence of the Ni bumping process and Figure 3(b) shows the micrograph of electroless nickel UBM.

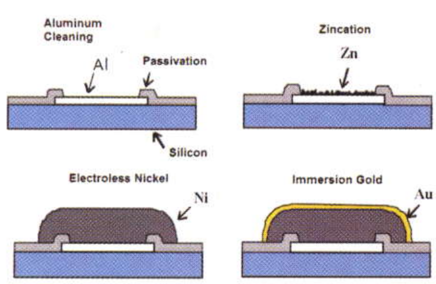

Figure 3 (a) : The schematic of electroless nickel bumping process

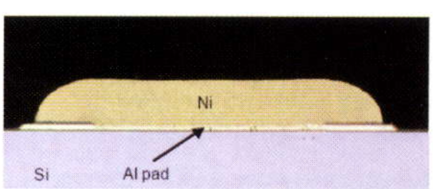

Figure 3 (b) : Micrograph of electroless nickel under bump metallurgy (UBM)

The major advantage of electroless Ni is its compatibility with a wide variety of solder balls, from high lead (90Pb/10Sn), eutectic solder (63Sn/37Pb) and also lead/ free (95.5Sn/3.8Ag/0.7Cu).

Conclusion

The solder bumping of silicon wafer requires a bump technology that is extremely reliable and robust in order to increase bumping yield and also compatible with a wide range of solder ball characteristics. Electroless technology has not yet seen wide deployment by the industry, however this technology is important as the growth of low cost Flip Chip technology becomes a major driving factor.

Several research papers about electroless nickel immersion gold (ENiG) bumping process have been published/submitted for publication in selected Journals.

1. **M.K Md Arshad**, I. Ahmad, A. Jalar, G. Omar, "The surface characteristics of under bump metallurgy (UBM) in electroless nickel immersion gold (ENIG) deposition", Journal Microelectronics Reliability, Vol. 46, Issues 2-4. pp. 367-379.

2. **M.K. Md Arshad**, I. Ahmad, A. Jalar, G.Omar, U. Hashim, "The effects of multiple zincation process on aluminum bond pa surfaces for electroless nickel immersion gold (ENIG) deposition", Accepted for publication in Journal Electronic Packaging, August 2006

3. **M.K. Md Arshad**, A. Jalar, I. Ahmad, "Characterization of Parasitic Residual Deposition on Passivation Layer in Electroless Nickel Immersion Gold Process", Accepted for publication at Journal Microelectronics Reliability.

4. **M.K. Md Arshad**, A. Jalar, I. Ahmad, G. Omar, "The Charaterization of Bond Pad Sureface Treatment in Electroless Nickel Immersion Gold (ENiG) Deposition for Under Bump Metallurgy (UBM)", 2nd Review for possible publication in IEEE Transactions on Components and Packaging Technologies