Authored by David Bao Ph.D.

Tombstoning Explained

Tombstoning，also known as Manhattan Effect or Chip Lifting，is a common defect in modern surface mount technology (SMT) processes relating to small passive chip components (0805, 0603, 0402 and 0201) used on printed circuit boards (PCBs). When tombstoning occurs, one end of the chip component will be detached from the copper pad of the PCB and stand on the other end of the chip component (Fig 1). The root causes of tombstoning are a) unbalanced torque on two sides of the chip components due to the surface tension of the molten solder, b) upward push by solvent vapors from flux or PCB during the reflow process, or c) by the floating effect of chip component on the molten solder. Once the possible root causes are identified, corrective actions can be made to minimize or solve the problem.

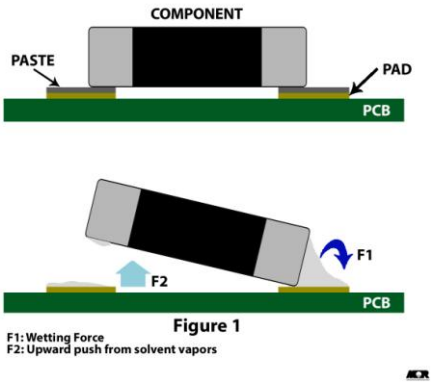

Figure 1
F1: Wetting Force
F2: Upward push from solvent vapors

Variables that Cause Unbalanced Torque

i) Solder Paste: Differences in the solder paste formulations cause different wetting speed. Fast wetting solder paste will enhance the uneven torque on two sides of the chip components. Solder powder melting behavior also plays an important part in this tombstoning phenomenon. Solder powder with a longer pasty range or a mixture of two types of powders (such as Sn63Pb37 melting Temperature 183°C mixed with Sn62Pb36Ag2 melting Temperature 179°C), will reduce the tendency of tombstoning. However mixing alloys will usually make the solder joints have duller appearances and sometimes causes poor wetting and solder balling.

ii) Component Geometry: Thicker components such as capacitors and inductors are more prone to tombstoning than thinner components such as resistors (Fig 2). When molten solder wets to the higher part of a thick component, it provides more leverage to pull the component to stand upright.

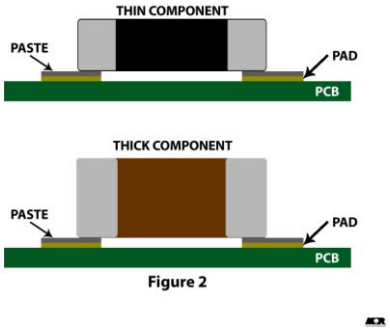

Figure 2

iii) Board Design: When the layout of the copper pads connect to a circuit that has heat sinking elements,

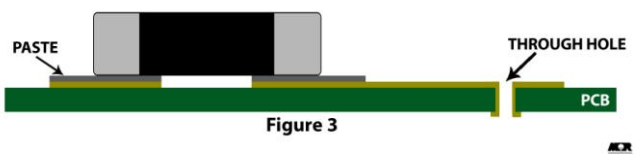

Figure 3

such as a via hole or wide trace, it will create a temperature difference (△T) on two sides of the component and cause tombstoning (Fig 3).

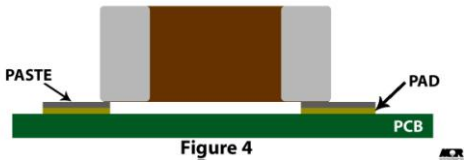

Figure 4

iv) Pad Design: If two pads are too far apart any component misalignment will cause an uneven wetting force during the reflow that will result in tombstoning. (Fig 4). When the pad is too large relative to the component, the pulling force applied by the toe fillet will increase making the component easier to stand up right.

v) Component and Board Oxidation: Oxidation on either the component or board will cause degradation on the solderability. When this happens, usually the wetting time on two sides of the component become more uneven, which will cause the component to tombstone.

vi) Pick & Place Accuracy: Component pick-and-place accuracy will cause unbalanced wetting force on two sides of the component during the reflow. This is one of the reasons that the smaller the chip component becomes the more easily the component will tombostone.

vii) Paste Deposition Consistency: If an unequal amount of solder paste has been deposited on the copper pads there will be two factors which will make the component have a higher tendency of tombstoning. In some cases, the difference in the thermal mass will cause the melting time of the solder paste to have a slight difference. As a consequence, the side that reaches complete wetting first will exert a greater pulling force than the other. In the other cases, if the wetting time difference is negligible, the side that has a larger amount of molten solder will have greater pulling force. In both cases, it may eventually cause tombstoning.

viii) Reflow Profile: Insufficient preheating or a fast ramp up rate immediately before reflow may cause a temperature difference on the two sides of the component, especially when one end of the component has a heat sink element. As mentioned before, any significant △T on two sides of a component may lead to a tombstoning problem.

Variables that Cause or Increase Upward Vapor Push

i) Solder Paste: At the reflow temperature some of the high boiling point solvents start to evaporate. The vapor underneath the component will push upward and cause a horizontal drifting which will play a significant role in the tombstoning phenomenon. The out-gassing effect varies from paste to paste depending upon the formulation

chemistry system; consequently there will be different tombstoning tendencies.

ii) Reflow Profile: A fast temperature ramp up rate right before the reflow zone not only causes a △T on two sides of the component as mentioned before; it will also aggravate out-gassing of the flux vehicle. In an accelerated experiment on a hot plate, one can observe the component moves up and down like the lid of a boiling water pot, before it eventually stands upright on one end. A slower ramp up rate before reaching the liquidus temperature is one of the key factors to minimize tombstone defects.

iii) Board or Solder Mask Quality: Sometimes solvent in the PCB or solder mask escapes from the pad area during the reflow, which can also contribute to tombstoning.

Variables that Cause Chip Components Float on the Molten Solder

i) Paste Deposition: If the solder paste printed on the pad is too thick the chip components will float on the molten solder. This floating of the component will cause an unbalanced pulling force and results in tombstoning. Various factors can affect the printing thickness such as stencil pressure, squeegee pressure, solder powder underneath the stencil, etc. House-plate or U-shaped aperture designs are used to solve solder beading problems by reducing the amount of solder paste printed on the pad. These aperture designs also help to eliminate tombstoning problems, which are caused by component floating (Fig. 5).

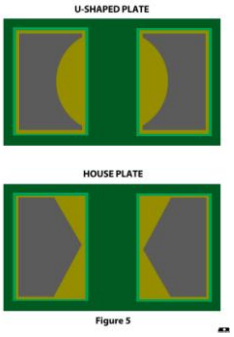

Figure 5

ii) Pad Design: If two pads are too close to each other (Fig. 6), components may also float on the molten solder due to the extra solder paste printed under the chip component before reflow.

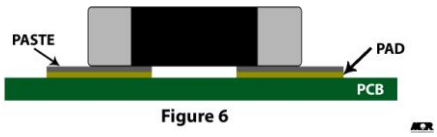

Figure 6

David Bao has more than fifteen years of experience in developing new solder paste, wave soldering fluxes and other SMT consumables. David has conducted Research and Development work at Indium Corp. and currently serves as the Director of New Product Development at Metallic Resources Inc. He received a Ph.D. in Chemistry at Oklahoma State University. Email dbao@metallicresources.com.