Tips for Preventing 'Tombstoning' of Chip Components

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The familiar "tombstoning" action of passive chip components during the mass reflow soldering process is still with us. Increasingly smaller, lighter components have not helped eliminate the problem. Tombstoning results in costly rework.
Despite advances in reflow soldering technology and process improvements, tombstoning as a problem never went away completely, and has returned in greater incidence with the decreasing sizes and mass of chip components, as well as the use of higher-temperature lead-free solders.

Tombstoning is most often encountered with greatest frequency when passive components become smaller; in vapor-phase reflow processes; in N_2-Reflow systems; and suddenly and unexpectedly with new batches of components and/or PCBs.
There are basically two primary causes of tombstoning; those related to the surface of the PCB and components (such as solderability, oxidation, physical damage of plating, etc.) and those related to temperature. There are areas where both causes have a combined effect, as in the choice of solder paste, where thermal stability issues and alloy choice must be considered in concert.

One cause involves differences in initial wetting of the solder, between both joints of a passive component. Ideally, both connections on either end of the component will reflow, wet, and form solder joints simultaneously. In this manner, the forces acting on the surface – wetting and solder surface tension, for example – will act in concert, canceling one another out. When this does not happen, the forces acting on that forming joint can lift the component up and on end before the solder on the other end has had the opportunity to melt and hold the end down through the strength of its own solder surface tension between the wetted end termination of the component and the wetted pad on the board.

The Role of Wetting
The mechanism of wetting consists of three important parameters: 1.Time of initial wetting; 2.Wetting force; and 3.Time of complete wetting. How soon complete wetting occurs has a direct bearing on tombstoning, because that is when the forces are greatest on the solder joint and the component. If one end of the component reaches complete wetting significantly before the other side does, the wetting forces have the potential to "pull" the component upright due to force exerted on the metallization on the perpendicular edge of the component and top side if there is an overabundance of solder.

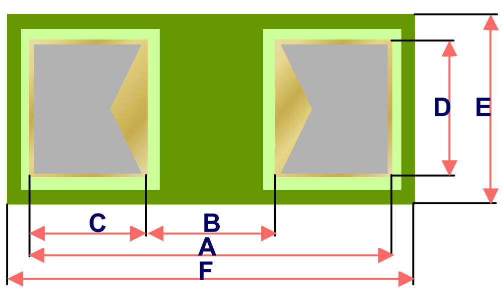
Thermal Mass
Unequal thermal masses of solder are a certain recipe for tombstoning, since the lesser mass of solder will reflow sooner, wet sooner, and thus exert physical force on the component sooner. Differences in the thermal mass of both solder joints of a passive component are caused by tolerances in pad dimensions, component metallization, and in

the volume of printed solder paste; and by differences in heat dissipation through vias or inner layers.

The larger the pad dimension, the greater the surface area of molten solder and the greater the effect of surface tension. There is great variation in pad dimensions because although there are recommended pad dimensions for specific component types, the tolerances are not specified! Varying tolerances can have a tremendous effect on pad mass. These values are shown in the diagram and table of pad dimensions and recommended tolerances in **Figure 1.**

The varying thermal mass of terminals related to component types and outlines directly affects the rate of heating and time to reflow. Again, these tolerances are expressed as nominal values, but they should rather be relative because (naturally) the smaller the components get, the more important tolerances regarding dimensions become on pads,

Fig. 1: Thermal Mass of Pads



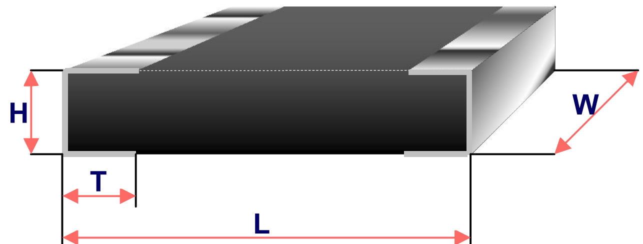
	Recommended Footprint [mm]						Placement
Type	A	B	C	D	E	F	accuracy
0201	0.75	0.23	0.26	0.31			+/- 0.15
0402	1.50	0.50	0.50	0.60	1.00	1.90	+/- 0.15
0603	2.10	0.90	0.60	0.90	1.45	2.35	+/- 0.25
0805	2.60	1.20	0.70	1.30	1.90	2.85	+/- 0.25
1206	3.80	2.00	0.90	1.80	2.25	4.05	+/- 0.25

metalizations and also with regard to placement accuracy. These values are shown in the diagram and table of terminal types and component outlines in **Figure 2.**

Less solder paste will reflow more quickly than an excess deposit. It's important no matter what type of application method is used – stencil printing, cartridge printing, or dispensing – that the amount of paste deposited be appropriate to form a good solder connection, and not excessive. More importantly, the amount must be uniform from pad to pad prior to reflow. 3-D imaging of the paste deposit helps the process engineer monitor the thermal mass of the solder paste to keep it under control.

The cleaner and more oxide-free the surface of the pad/terminal are, the lower the interfacial surface tension will be; the sooner initial wetting will occur; the stronger the wetting force will be; and ultimately, the sooner wetting will be completed. Consider that when surfaces in both joints are oxidized to the same degree, some oxidation will delay initial wetting. Delayed initial wetting provides more time for the temperature in the larger pad/terminal to rise, so that Δ-T is minimized. As a rule of thumb, the smaller the Δ-T, the smaller the time differential of initial wetting.When both terminals of a passive component do not have equivalent wettability, tombstoning can result, since the more solderable end will reach the complete wetting stage sooner. What factors can most commonly affect wettability? One example is when the metallization of component terminals can become damaged, or are improperly plated or contaminated, reducing the wettable surface area.

Figure 2: Thermal Mass of Terminals



	Component Outlines [mm]									
	L			W			H		T1	
Type	Spec	Tol -	Tol +	Spec	Tol -	Tol +	Min	Max	Min	Max
0201	0.60	0.03	0.03	0.30	0.03	0.03	0.30			
0402	1.00	0.02	0.10	0.5	0.02	0.10	0.30	0.40	0.15	0.30
0603	1.60	0.10	0.10	0.80	0.05	0.15	0.35	0.55	0.10	0.50
0805	2.00	0.15	0.15	1.25	1.15	1.15	0.50	1.70	0.20	0.60
1206	3.80	2.00	0.90	1.80	2.25	4.05	0.50	1.70	0.25	0.75

The reduction and elimination of tombstoning is supported by the following:

- The use of solder paste with a thermally stable flux system providing and maintaining tackiness;
- A paste with metal particles with 2 different eutectic points: 50 % melting at 217 °C (Sn95.5Ag3.8Cu0.7) and the balance at 221 °C. (Sn96Ag4).
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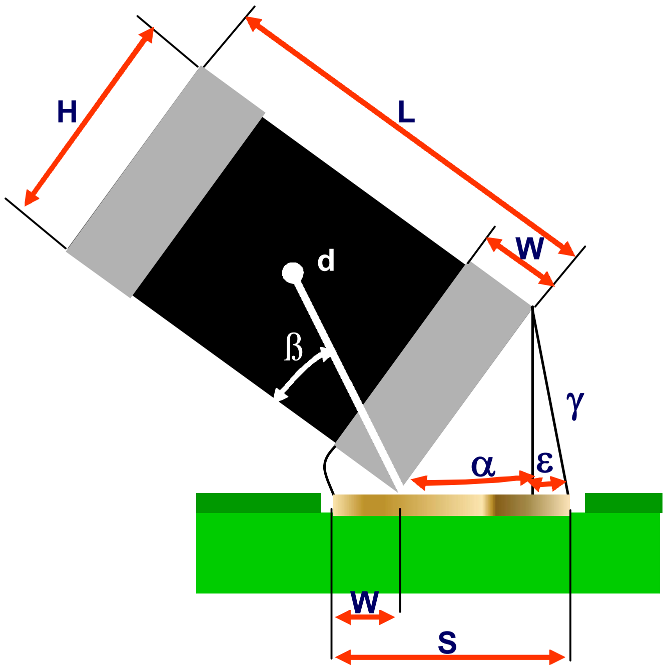
The angling effect caused by the force of faster initial wetting in one joint is mechanically hindered by the solid particles of the alloy that melts at 221° C. This provides the alloy that melts at 117 °C on the other pad with a fraction of a second more time to wet as well, and restores the equilibrium forces.

Klein Wassink[1] initially described the phenomenon of Tombstoning in a model wherein forces of surface tension play a dominant role. The model, however, ignores the impact of the viscosity of the solder paste during melting.

In the temperature range of 179 – 183°C, the solder paste in fact has become a suspension of solid Sn63 powder particles in the liquid Sn62. This suspension evidently has a substantially higher viscosity than a solder paste that has become liquid entirely! By theoretical conclusion and by practical experience we know that this higher viscosity balances out the surface tension forces by mechanically hindering the angling effect of the component. Therefore, we have added viscosity as a significant parameter to this model, which is shown in **Figure 3.**

Figure 3: Model for Tombstoning



Active forces:

Upward: $T_1 = M*g*d*\cos(\alpha+\beta)$

Surface tension of solder on pad:

$T_2 = \gamma*W*\cos(\alpha/2)$

Upward: $T_3 = \gamma*H*\sin(\alpha+\varepsilon)$

(Klein Wassink et all)*

Viscosity of Paste

$T4 = \eta$ @ $T = 179^{o}C$

Conclusion

In addition to using a solder paste with the abovementioned characteristics, tombstoning can in large part be prevented by following three basic rules of thumb, listed as follows:

- Minimize ΔT in the board through control of the thermal (reflow) processing profile;
- Control the tolerances on boards, components, and component placement;
- Control the O_2 ratio in N_2 systems (preferred level: 500 ppm).

Tombstoning is a preventable defect; attention to its causes and addressing each of them will reduce the incidence of tombstoning, resulting in higher yields, lower defect rates, and less rework overall.

Sources

1. 1. R.J. Klein Wassink - Second Edition (1998) Soldering in Electronics pp 609 - 616 "Drawbridging of Leadless Components", Electrochemical Publications Ltd, Isle of Man, British Isles.

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