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OOOH Colors, It Must Be Lead Free

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Lead free reflow solder presents users with a myriad of new experiences including matte/dull/grainy solder joints instead of shiny smooth ones, higher reflow temperatures, board de-lamination/blisters, increased plastic package cracking, potential tin whiskers and chip terminations changing color after reflow soldering.

It was unusual to see chip terminations change colors when tin lead solders were used but with the introduction of lead free reflow soldering and the corresponding increases in reflow temperatures terminations are now changing colors. Two conditions are present when reflow temperatures are increased for lead free solder alloys that leads to discoloration. Reflow temperatures are above the melting point of tin (Sn MP is 232^{o}C). Air temperatures commonly used in forced convection reflow systems are high enough to both melt the tin plating on the termination allowing it to be pulled into the solder joint due to solder joint liquid solder surface tension leaving behind the exposed nickel barrier. Now those metal oxide colors will be visible due to high air temperatures during reflow.

Metal colors are due to thin oxide films, the higher the temperature or longer the exposure during soldering, colors will change. Colors may change at lower temperatures than those listed if metals are exposed for long periods of time (minutes). Table 1 lists oxide temperatures used for tempering tool steel from an old edition of Machinist's Handbook that are commonly encountered as set points in forced convection reflow ovens. Those same colors are used for tempering stainless steel alloys that are made with high nickel content and only cobalt separates iron (Fe) from nickel (Ni) in the periodic table. These colors can be used as a guide for temperatures that chip terminations have been exposed to. We can use this table as a guide in understanding why chip terminations are changing colors after lead free reflow soldering and or rework.

Table 1. Colors for Tempering from an old Edition of Machinist's Handbook

Temperature ^{o}F	Temperature ^{o}C	Colors
430	221.11	Very Pale Yellow
440	226.67	Light Yellow
450	232.22	Pale Straw Yellow
460	237.78	Straw Yellow
470	243.33	Deep Straw Yellow
480	248.89	Dark Yellow
490	254.44	Yellow Brown
500	260.00	Brown Yellow
510	265.56	Spotted Red Brown
520	271.11	Brown Purple
530	276.67	Light Purple
540	282.22	Purple
550	287.78	Dark Purple
560	293.33	Blue
570	298.89	Dark Blue

Most chip termination base metals can change color including both nickel and palladium silver. A chip cross section drawing is in Figure 1 showing the termination structure. The tin plated on the termination has no where to go and stays in place if just the chip is heated. But if the parts are reflow soldered to an assembly then colors become visible especially when assemblies undergo double sided reflow or if rework is performed on an assembly. This is due to the surface tension of the liquid solder during reflow pulling the tin plating from the top of the chip terminations as shown in Figure 2.

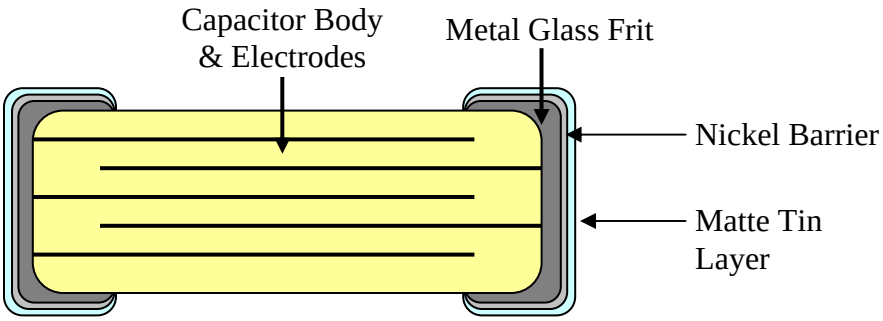

Figure 1. Cross Section of a Chip Capacitor Termination

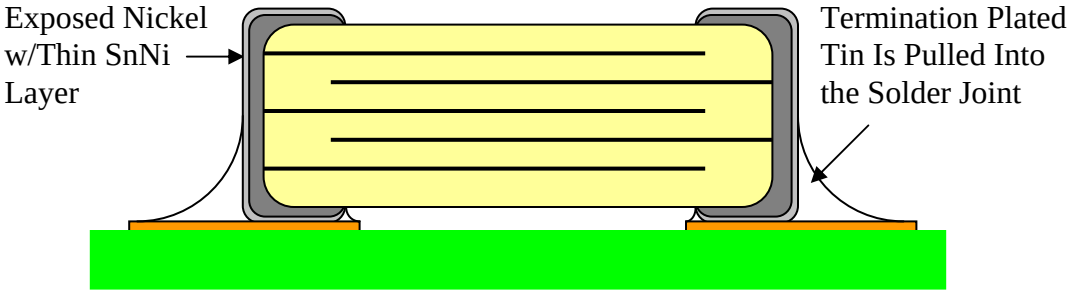

Figure 2. Tin Plating Pulled from Termination during Lead Free Reflow

Discoloration is observed even when tin lead solders are used after multiple exposures to reflow or rework. These colors are more pronounced when lead free solder alloys are used due higher temperatures. The matte tin plated on terminations and leads melts and is pulled into the solder joint leaving behind a thin tin/nickel intermallic layer. This layer readily oxidizes resulting in discolored terminations. Even parts reflow soldered in nitrogen blanket reflow systems can be discolored due to the presence of oxygen. These systems are not oxygen free but have enough residual oxygen to discolor the exposed nickel. The discoloration is not as pronounced as those systems that do not use a nitrogen blanket but is still present.

Solder joint reliability is not affected as only the exposed portion of the termination oxidizes. Metallurgical bonding occurs where the solder fillet is in contact with the component termination and solder pad resulting in a reliable solder joint. What does occur is that solder joints may be difficult to rework due to oxidation on the exposed termination due to stable nickel passivation.

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