TECHNICAL PAPER

Application Guidelines on IR Reflow of Surface Mount Solid Tantalum Capacitors

Steve Warden & John Gill

KYOCERA AVX Components Corporation
Paignton, England

Abstract:
This paper tries to explain the factors which influence the ability of surface mount solid Tantalum capacitors to withstand present industry standard reflow technologies, and explores the peak temperature trends of industry IR reflow systems.

*To assist you with the terminology used within this document a glossary is available through the AVX worldwide sales office.

APPLICATION GUIDELINES ON IR REFLOW OF SURFACE MOUNT SOLID TANTALUM CAPACITORS

by Steve Warden & John Gill
KYOCERA AVX Components Corporation
Paignton, England

1.0 Introduction

When considering the IR reflow performance of a tantalum capacitor, it is first important to consider the affects that IR reflow can have on all electronic components, and also to fully understand the process of reflow.

Figure 2, shows AVX's recommended IR reflow profile, this illustrates the four phases of reflow. First of all there is the raising of the temperature from ambient to an elevated level. During this rise in temperature solvents within the solder paste evaporate. If the temperature gradient is too high, that is the temperature rises too quickly, solder balls can be produced due to "mini explosions" in the solder as the solvents are driven off too quickly [1]. A ramp rate between 1C/s and 3C/s is recommended [1, 2, 3] for this region. Too high a gradient can also lead to cracking of some components [1, 2].

The next phase in the reflow process is to hold the temperature at a steady value. This period is known as the "soak time" and is needed to activate the flux in the solder paste. The soak temperature can vary from 130C to 180C. Typical soak times are between 30 and 120 seconds [2]. If the soak time is too long, excessive growth of tin-copper intermetallics can occur which leads to tin depletion. The effect of tin depletion is the creation of brittle solder joints.

Sometimes more than one soak is used, as in the example shown in Figure 2, to try and ensure that all components on a board reach equilibrium before the temperature is increased further. This keeps the thermal stress on the components to a minimum.

The third phase in the IR reflow process is the ramp up to the peak reflow temperature. Again, a ramp rate between 1C/s and 3C/s is recommended to prevent damage to ceramic and silicon components.

1 or 2 seconds is all that is required over 200C to ensure a good solder contact fillet. The time above 200C should be kept to a minimum as this can cause undue stress to many electronic components. If the time over 200C is too long, poor solder fillets can result as too much flux is evaporated. The maximum reflow temperature should be between 220C and 230C, temperatures above 230C are known to cause damage to the internal silicon dies in semiconductor ICs [2].

IR reflow heating depends to a great extent on heat absorption, and the conditions experienced by an electronic component are thus sensitive to the mass of the component, the type of reflow system used and, in the case of IR reflow systems, the wavelength of the energy wave used to achieve reflow.

There are two types of IR reflow system commonly in use. The first uses area source or panel emitters as the heat source. These sources emit energy in the medium to far frequency range, 3.5 to 7.0 µm [3]. The second system uses lamp emitters, and uses wavelengths in the near end of the spectrum, 0.3 to 3.0 µm [3]. Whatever the source, the heat is transferred from the emitters to the components by a combination of radiation, conduction and convection.

Both heat sources described above are difficult to accurately control. Pulsing the emitters on and off, and changing the belt speed are the normal methods used to control the reflow conditions [1]. Because of the difficulty in accurately controlling the profile the minimum reflow temperature at which a good solder fillet is formed should be used to prevent the danger of over stressing a component.

The depth at which heating inside of the component occurs depends on the wavelength of the heat source, and it is thus clear that different sources will give a different stress level on components with different heights. Measurements of IR profiles at the top face of a component, as well as at board level should be made when considering the level of stress a component may be subjected to during reflow. This subject will be discussed again later in this paper (6.2.2).

Also, because of the high level of heat transferred by absorption, variations in board density across a board can lead to significant differences in peak temperature across the board [1] leading to localized "hot spots". Components mounted in these areas can receive far greater stress levels than other components mounted on the same circuit board. This subject will be discussed in more detail later (6.2.1).

Color has little influence on the performance of a component with regard to IR reflow, this is because color is an attribute of energy in the visible wavelengths, and IR is in the invisible region.

The final stage in the reflow process is cooling the board and components back to ambient temperature. Forced air cooling should be avoided as this leads to very large levels of stress, instead boards should be left to cool at their own pace.

2.0 Tantalum Capacitors

Now let us consider how IR reflow affects tantalum capacitors. Tantalum capacitors are constructed using a great many different materials. The anode element is a sponge like structure of sintered tantalum powder. Tantalum is a valve metal whose oxide closely couples to the metal surface. The dielectric in a tantalum capacitor is produced by electrolysis, to produce tantalum pentoxide. The counter electrode is manganese dioxide, which covers the dielectric surface. It is applied by dipping the anode into varying concentrations of manganese nitrate, and then heating. This causes the manganese nitrate to decompose to manganese dioxide. Good electrical connection to the counter electrode is ensured by dipping the anode into a graphite, followed by a silver paste.

In a surface mount package, the capacitive element is attached to a leadframe by welding of the anode riser wire, and a silver epoxy paste attachment for the cathode connection. The whole assembly is then encapsulated in an epoxy resin. Figure 1 shows a stylized representation of a solid SMT tantalum capacitor.

For further details please refer to the AVX publication, “Basic Tantalum Technology” or the product catalog.

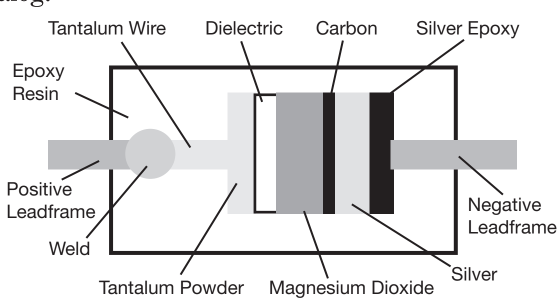

Figure 1. Stylized Surface Mount Capacitor - TAJ Range

Attempts have been made to ensure that the thermal expansion coefficients for all these materials are as closely matched as possible, but there are of course differences. When the capacitor is subjected to a temperature shock, as would occur if the capacitor were subjected to an immersion solder system, or subjected to absorption heating, as occurs during IR reflow, these thermal expansion differences can cause the build up of stress inside the capacitors structure. In extreme cases this can lead to rupturing of the dielectric tantalum pentoxide layer which is under very high tensile and compressive forces during the reflow process. Such ruptures can lead to an increase in the capacitor’s leakage current. With excessive temperatures, the movement created can lead to the capacitor becoming a short circuit.

If we consider a population of parts exposed to an aggressive IR reflow profile, then damage may occur to some parts at a ppm level. However, these can be diagnosed easily at the first stage of PCB testing because failures are detected during the opens and shorts check of an in circuit or “bed-of-nails” tester. However, if the short circuit threshold (the DC resistance limit used to define a component as being a short circuit on such a tester) is set very low, at say 1Ω, or there is no opens and shorts check performed on the board, then any residual short circuit failures may pass on to the power up stage and then fail. Typically tantalum capacitors which are short circuit range in resistance from 0. 1Ω to 20Ω. The failures can then sometimes be wrongly diagnosed as surge or current in rush failures, see the AVX publication “Surge in Solid Tantalum Capacitors”. Only a copy of the IR reflow supplied by the assembly board manufacturer can then help correctly diagnose the cause of failures.

3.0 Manufacturers IR Reflow Recommendations

AVX have a recommended solder profile which is published in the AVX surface mount guidelines manual, it is reprinted in Figure 2. This falls in line with the recommendations for good reflow discussed in the introduction [1, 2]. It, also, broadly falls in line with the recommendations given by other tantalum capacitor manufacturers [6, 7].

In the tantalum capacitor’s technical summary, there are recommended maximum guidelines for total time above specific temperatures, the graph is reprinted in Figure 3, and again it falls broadly in line with the recommendations given by other tantalum capacitor manufacturers [4, 5, 7, 8].

It should be noted, however, that these temperatures are maximum time-temperature characteristics and that AVX recommend that peak temperatures below these levels are used during IR reflow. It is good practice to use the minimum temperature to allow a good solder joint to form, so as not to unduly stress the electronic components on the circuit board, and temperatures above 230C should be avoided as they can lead to damage of silicon dies and some ceramic or plastic materials [1, 2, 3].

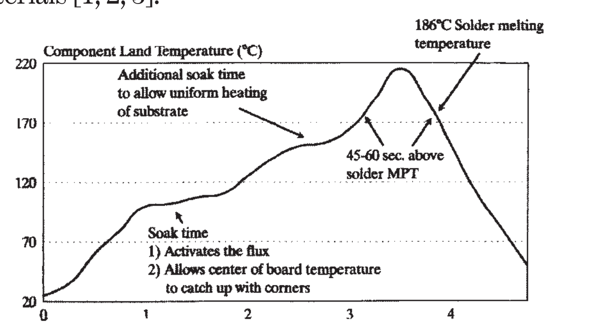

Figure 2. Recommended IR Profile

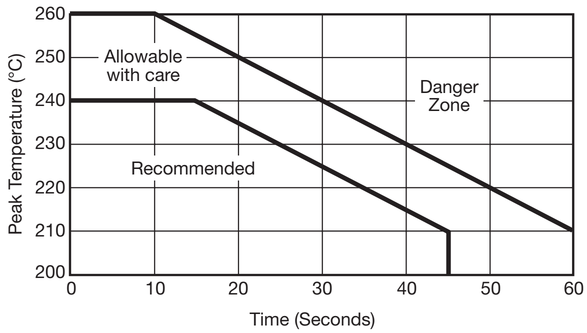

Figure 3. Maximum Time vs. Temperature Guidelines

4.0 International Standards

There are many guides and standards appertaining to surface mount capacitors. Two of these are CECC 00 802 - Standard method for specification of surface mounting components (SMDs) of assessed quality, and IEC 68-2-58 - Solderability, resistance to dissolution of metalization and to soldering heat of surface mounting devices (SMDs).

The CECC 00 802 specification states that "The heating rate in an IR-furnace depends on the absorption coefficients of the material surfaces and on the different component thermal masses, related to the surface area that is accessible to IR radiation". So it can be seen that the thermal mass of a tantalum capacitor, which is large, is going to cause that component to heat up far more than some of the smaller components on the circuit board. It also concedes that "the temperature of components in an IR-furnace .... is ill-defined", and recommends that a temperature measurement be made on the components as they pass through the IR oven. The CECC specification show a "typical" IR reflow profile measured on several circuit boards and is for guidance only and should not be used for the determination of any maximum parameters.

The 00 802 specification uses the IEC 68-2-58 specification when referencing the ability of a component to withstand soldering heat by using a test method of immersing the component in a solder bath and determining the level of shift of the electrical parameters post test. As AVX tantalum capacitors are class A components and they are immersed in the bath at 260 ± 5C for 10 ± seconds. This test causes a different type of stress to that involved in IR reflow, and more closely simulates solder wave systems.

To produce a test specification for a surface mount device, which could be used to test their ability to withstand IR reflow, would be extremely difficult because of the variety of reflow source wavelengths, the variability of the belt speed, and the differences in thermal mass not only between components but also between different types of substrate. A two layer FR4 board, has a very different thermal mass to an FR4 board with four layers, two of which are power planes.

It is therefore important that real measurements are made when setting up a reflow profile for a new board, to ensure that none of the components on the board receive an overly large stress level.

5.0 Industry Trends

It was perceived by the engineering departments at AVX that the industry's IR reflow profiles have been increasing in recent years due to increasing board densities and higher throughputs, so a survey of major industrial manufacturer's profiles was carried out by AVX in the latter months of 1993. Some of the results are summarized in Table 1. As can be seen, there is quite a wide range of peak temperatures, from 200C to 235C. There is also a wide range of temperature gradients, from 0.75 C/sec to 3.5 C/sec.

	A	B	C	D	E	F	G
Peak Temperature (°C)	235	224	210	200	220	212	235
Max Gradient (°C)	1.35	3.5	0.83	1.3	0.75	2.68	1.9
Time to 180°C (Seconds)	164	180	180	120	170	170	180
Time to Peak (Seconds)	222	208	210	210	200	210	200
Time above 180°C (Seconds)	102	60	60	60	80	64	50

Table 1. Results of Customer IR Reflow Survey

When compared to the IR reflow profile recommended by AVX, which has the characteristics shown in Table 2, it can be seen that 4 out of the 7 profiles displayed in Table 1 had higher peak temperatures and 2 had higher ramp rates.

AVX expect the peak temperatures to continue to rise as manufacturers move towards using leadless solder pastes for reflow.

	Recommended Profile
Peak Temperature (°C)	220
Max Gradient (°C/s)	2.0
Time to 180°C (Seconds)	190
Time to Peak (Seconds)	220
Time above 180°C (Seconds)	45 to 60

Table 2 . Recommended Profile Characterization

6.0 Factors Which Influence Reflow Performance

6.1 Factors under the capacitor manufacturers control

The factors which are known to most influence the reflow stability of a Tantalum capacitor are the peak temperature, the time above 180C and the maximum gradient of temperature rise.

The reason the peak temperature has such an effect is that the higher the temperature the more expansion/ contraction will take place and thus the greater the stress on the capacitive element. Also, if higher temperatures are seen, then the time spent above the glass transition temperature of the molding compound (178C) is usually increased, which also increases the stress on the device. Obviously, the greater the stress, the more likely the probability of a dielectric rupture.

This dependency has been demonstrated internally at AVX by taking samples from several production batches and testing them to various IR reflow profiles with peak temperatures in the range 235C to 310C, measuring the leakage current of the parts before and after the cycles.

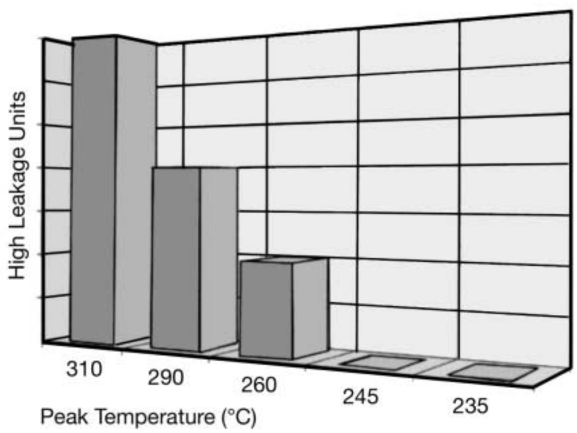

Figure 4. Reflow Trial Results

The time above 180C is also key to the reflow performance, because the longer the component is at high temperature the longer it is under stress, and the longer the component is subjected to a high stress condition, the more likely the dielectric will be breached. 180C is approximately the melting point of standard 60/40 solder, and is therefore the temperature above which the reflow takes place. (Note that this is also close to the glass transition temperature of the molding compound, as discussed above.)

The maximum temperature gradient is an important factor as this governs the rate at which the heat can be equally distributed throughout the capacitor's anode. If the rate is very high, the tantalum metal will heat much more quickly than the surrounding resin. Thus the anode is put under a large constrictive force, which under excessive conditions can lead to a rupture of the tantalum pentoxide dielectric, thus an increase in the capacitor's leakage current, or a short circuit.

On examining the results of the IR reflow survey, as party of AVX's commitment to continuous product improvement, AVX embarked on an investigation into what could be done to improve the capacitor's reflow performance. Since it is obvious that the peak reflow temperature is increasing, and that the reflow time is decreasing thus increasing all temperature gradients, as shown by customers A, B and G in Table 4, AVX decided to improve the performance of the capacitor under the increasingly more aggressive IR reflow conditions.

One of the results of this investigation, has been that AVX has implemented a program of increasing the manganese layer on all its C, D and E case surface mount tantalum capacitors, to enhance their performance under the increasingly hostile IR reflow conditions used by industry. The manganese acts as a buffer layer between the encapsulating resin and the dielectric.

The smaller A and B case parts are not as susceptible to IR reflow because they contain very much less metal, and therefore do not heat as quickly or have as great a temperature differential through out the package.

The analysis also included an investigation into ways of reducing the internal tensile and compressive forces which can act on the capacitor element during IR reflow.

This analysis included the development of a computer based finite element array model for a tantalum capacitor. Some of the results from the analysis are shown in Figures 5 and 6. In Figure 5, the results for the tensile forces are shown. These clearly indicate the points which are likely to suffer the greatest stress levels.

Figure 6, which shows the compression forces under the same conditions, also locates points under the greatest stress.

This analysis enabled the significant characteristics which contribute to the level of stress to be identified and engineering programs to be established to reduce the stresses within the capacitor's constructional geometry.

Many of the technology features discovered have been progressively incorporated into capacitor designs as a part of AVX's continuous product improvement program.

6.2 Factors under the control of the assembly manufacturer

PCB manufacturers can themselves minimize the effect of IR reflow on the solid tantalum capacitor by:

6.2.1 Prevent "Hot Spots"

Avoiding high concentrations of capacitors, which may lead to localized heating effects. In a great many designs, the circuit board includes several tantalum capacitors in parallel to acting as bulk energy storage and decoupling capacitors. These capacitors are generally the larger case sizes, C, D or E. If these capacitors are mounted in close proximity to one another, then because of the large amount of metal inside the capacitors, this area of the board will heat preferentially to the surrounding areas. The temper- ature difference can be as great as 20C compared with an area only 2 cm away. This creates a ‘localized hot spot’ around the capacitors.

Components mounted in this area will therefore be subjected to a greater thermal stress than parts mounted on other areas of the circuit board. It is therefore important for the capacitors to be spread out over the board. This also has the advantage that the electrical performance of the product, with particular regard to noise suppression, will be improved, as the stored charge energy is now evenly distributed throughout the board close to each integrated circuit, rather than grouped in one site.

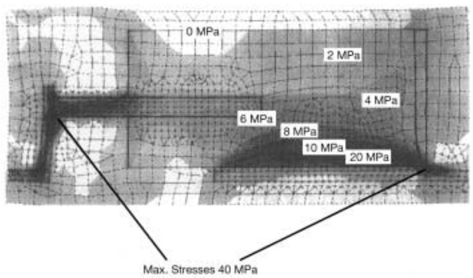

Figure 7. Localized Hot Spots

6.2.2 Keep thermal differentials across the component to a minimum

IR profiles create large temperature differentials between the top face of the capacitor, and the PCB board. With large case size or extended range parts the temperature difference between the top surface of the capacitor and the PCB, can be as great as 20C. Another cause of temperature differential is the very large volumes of metal used in the “super-extended” range products, which during reflow causes a great deal of internal stress to the capacitor. These parts when heated can therefore be more susceptible than standard parts to reflow damage. Care should be taken when using these parts to ensure that the temperature differential between the top surface and the circuit board is kept to a minimum. Figure 8 shows the best method for determining the solder profile of a tantalum capacitor.

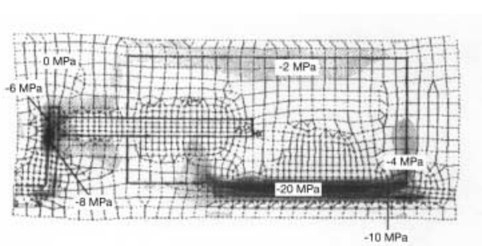

Figure 8. Determining Temperature Differentials

6.2.3 Keep IR reflow gradients in control

Avoid large temperature gradients during reflow which take components to peak reflow temperature or to the soak temperature too rapidly. Good practice is to ensure that the maximum ramp rate is around 2C/s [1, 2, 3].

6.2.4 Avoid high peak temperatures

Components with a large thermal mass, such as internal antennas in mobile phones, are often reflowed using very high temperatures. This unduly stresses all the other electrical and electronic components on the circuit board.

A reflow with a lower peak is preferable, and can be achieved simply by increasing the soak time [1, 2, 3].

7.0 Conclusions

In conclusion, it should be remembered that large case size tantalum capacitors contain a high volume of tantalum metal, which will preferentially heat compared to the surrounding circuit board. This causes stress within the constructional geometry of the capacitor. While there are several product enhancements the capacitor manufacturer can make, the board manufacturer can also reduce these stresses by preventing large concentrations of tantalum capacitors, which lead to hot spots, minimizing temperature gradients, temperature differentials and keeping the peak reflow temperature as low as possible. These are simply good production practices but they can dramatically improve the performance not only of tantalum capacitors on IR reflow, but also of all other electronic components on the board.

Acknowledgments

The authors wish to thank Mr. M. Stovin, Mr. I. Salisbury, Mr. W.A. Millman and Mr. A. Conibear all of AVX for their cooperation in the production of this paper.

Reference

1. “Soldering Surface Mount Assemblies”, C.L. Hutchins, EP&P, August 1992 Supplement, p 47-53
2. “Thermal Profiling Reflow Solder”, P.C. Kaziermowicz, Circuits Assembly, August 1992, p 59-62
3. “Reflow Soldering Process Considerations for Surface Mount Application”, J. Bergenthal, KEMET, 1989
4. “TMC series datasheet”, Hitachi Condensers Co.
5. “T491 - Solid Tantalum Chip Capacitor”, KEMET Electronics Corporation
6. “Panasonic - Technical Guide of Tantalum Electrolytic Capacitors”, Matsushita Electronic Components Co.
7. “293D - Molded Tantalum Chip Capacitors”, Sprague
8. “SVH series - Surface mount resin molded tantalum chip capacitors”, NEC Corporation

List of Other Publications Available From KYOCERA AVX

Analysis of solid tantalum capacitor leakage current
by R.W. Franklin

Reliability management of tantalum capacitors
by C. Reynolds

Ripple rating of tantalum chip capacitors
by R.W. Franklin

Investigation into the effects of connecting tantalum capacitors in series
by J.A. Gill

Equivalent series resistance of tantalum capacitors
by R.W. Franklin

Surge current testing of resin dipped tantalum capacitors
by R.W. Franklin

Analysis of fusing technology for tantalum capacitors
by Ian Salisbury

Surface mount tantalum capacitor applications information
by John Maxwell

An exploration of leakage current
by R.W. Franklin

Surge in solid tantalum capacitors
by John Gill

Thermal management of surface mounted tantalum capacitors
by Ian Salisbury

Application specific SMD tantalum capacitors
by William A. Millman

Molded surface mount tantalum capacitors vs conformally coated capacitors
by John Stroud

Glossary of terms used in the tantalum industry
by John Gill

Basic tantalum capacitor technology
by John Gill

NORTH AMERICA
Tel: +1 864-967-2150

ASIA
Tel: +65 6286-7555

CENTRAL AMERICA
Tel: +55 11-46881960

EUROPE
Tel: +44 1276-697000

JAPAN
Tel: +81 740-321250

WWW.KYOCERA-AVX.COM