

TECH JOURNAL

Conductive Resin Terminal Type

Multilayer Ceramic Chip Capacitor



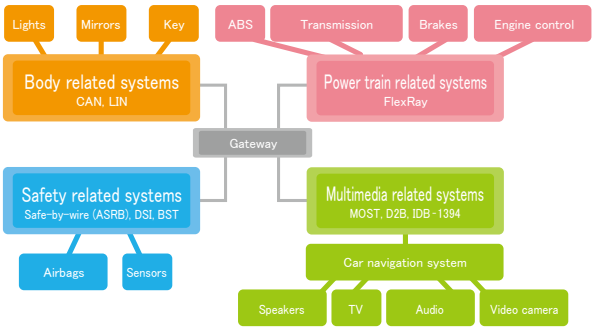
"Joint Reliability" Supports Safe and Pleasant Driving

Electronics are used more and more in current automobiles, where the components are exposed to extremely harsh conditions. While driving, the temperature in the engine compartment can reach 125 degrees centigrade, and as much as 150 degrees in close proximity to the engine. In addition, strong shocks and vibrations are also very common. Electronic parts and components used in a car must not only be rated for high reliability on their own, they must also have good "joint reliability" when mounted on a circuit board in an actual unit. Multilayer ceramic chip capacitors with conductive resin terminals are a new product from TDK, featuring a layer of conductive resin between the copper base and the nickel plated layer of the terminal electrode. The conductive resin layer serves to absorb and soften bending stress of the circuit board, caused by factors such as high temperature and shocks. This drastically reduces the risk of cracks developing at solder joints and in the ceramic elements.

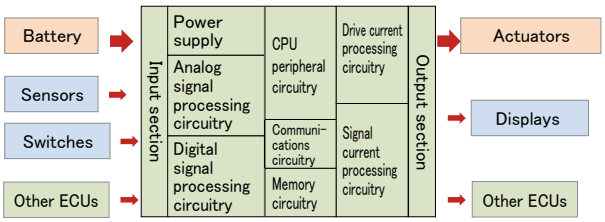
Automotive LAN Combines Multiple ECUs (Electronic Control Units) in a Network

Going far beyond the basic mobility functions of "running, stopping, turning", modern automobiles also are highly sophisticated electronic devices that incorporate numerous sub systems for areas such as ABS, power steering, air bag control, car navigation etc. A single car can have dozens of Electronic Control Units (ECUs), each of which is a type of onboard computer. These are linked by means of LANs dedicated to the power train, body, safety, multimedia and other function areas. Together, they help to ensure safe and pleasant driving.
In total, the electric and electronic equipment in a car is made up of as many as twenty to thirty thousand individual components, including about a thousand or more multilayer ceramic chip capacitors. Multilayer ceramic chip capacitors are renowned for long life and high reliability, but the environment to which automotive electronic devices are exposed is particularly severe. It is characterized by high temperatures, vibrations, humidity from outside air, and many other adverse conditions. In addition, there is the requirement to use lead-free solder for joining the components to the substrate, in keeping with the move to eliminate environment-damaging substances such as lead. Compared to conventional lead-based soldering which uses an alloy of tin and lead, lead-free solder joints are harder and tend to be more brittle. Therefore, when the substrate bends or flexes due to thermal shock or mechanical influences, solder cracks can develop at the joints. Overcoming this problem is a major goal for improving joint reliability.

☐ Automotive LANs with linked ECUs



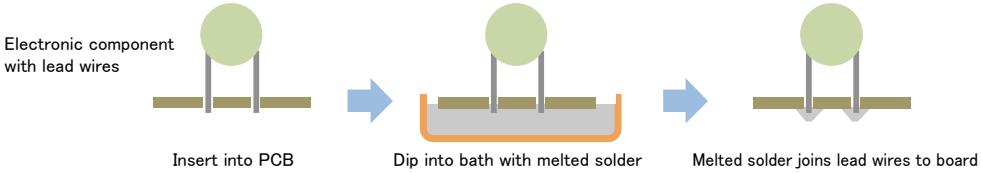
☐ Sample ECU circuit block diagram



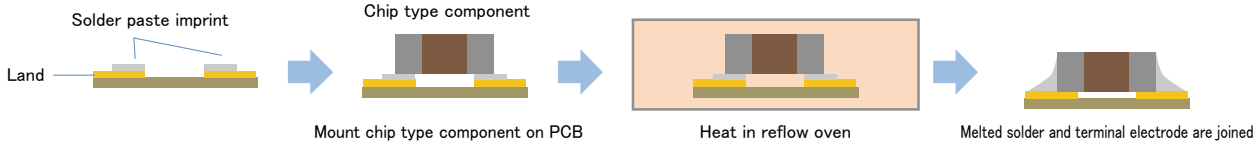
Evolution of Component Mounting Technology and Soldering Techniques

The techniques for mounting electronic components on a printed circuit board have evolved and changed drastically over the years, along with the spread of chip type components. In the past, when most electronic components had "legs" (lead wires), these were usually inserted into corresponding holes on the printed circuit board and then soldered. This is called THT (Through Hole Technology). By contrast, chip type components that have no lead wires are mounted directly on the board, using a technique known as SMT (Surface Mount Technology). This type of component is called SMD (Surface Mount Device).
The changes in mounting technology also brought with them changes in soldering techniques. There are two basic soldering principles, namely the flow method and the reflow method. The former involves placing components on the board, provisionally fixing them by means of an adhesive, and then dipping the board in a bath of liquid solder to create the joints. Flow soldering was used primarily for electronic components with legs. Along with the changeover to SMD type components, the reflow method became the dominant technique. For reflow soldering, solder paste is applied to the so-called lands on the printed circuit board (the spots where joints are to be established), and the components are mounted on top. The board is then subjected to controlled heat using a reflow oven, infrared radiation, hot air or similar to melt the solder paste and permanently connect the joints.

☐ Soldering using through hole technology and flow method



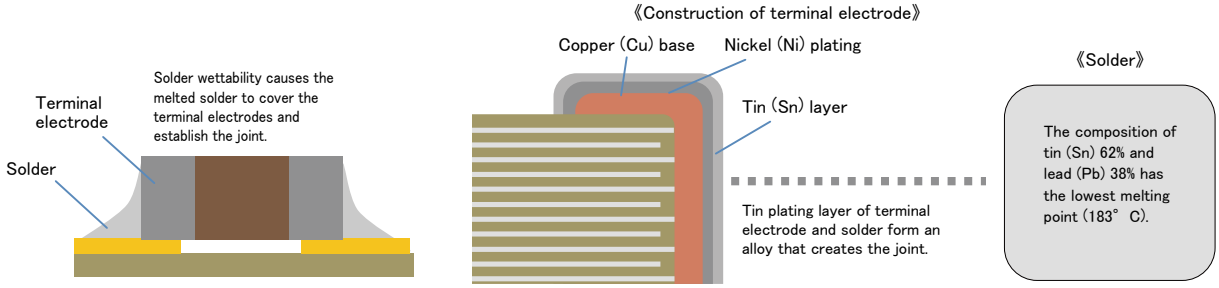
☐ Soldering using surface mount technology and reflow method



Solder Forms an Alloy with Metal of Terminal Electrode to Establish a Joint

Standard type multilayer ceramic chip capacitors have triple layer terminal electrodes using nickel (Ni) and tin (Sn) plating on a copper (Cu) base. The copper base electrically connects to the multiple layers of internal electrodes. This is covered by nickel plating, and further by tin plating to enhance the so-called "solder wettability".
Solder wettability refers to the condition where the melted solder flows easily around the electrode, thereby creating a new alloy on the surface. Because solder is an alloy of tin and lead, the tin plating on the terminal electrode facilitates this process.
If there is an oxidized layer on the surface, the alloy will be harder to form, resulting in a degradation of solder wettability. The use of soldering flux such as rosin is intended to remove oxidization from the surface. Soldering in a reflow oven with a nitrogen environment has the same purpose, i.e. the prevention of solder oxidization. Soldering is a process that involves a number of quite complex physical phenomena.

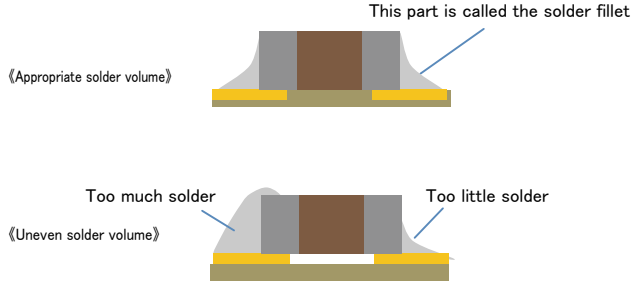
□Solder creating a joint for a multilayer ceramic chip capacitor



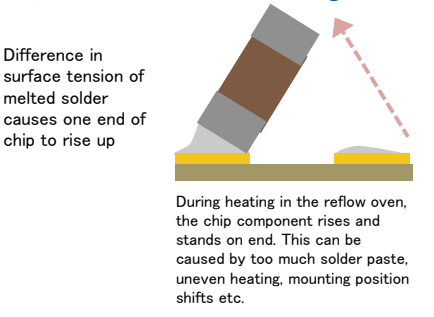
Improved Reflow Technology Conquers the "Manhattan Effect"

The miniaturization of electronic devices in recent years has been made possible by factors such as ever smaller components and higher mounting density, but the evolution of reflow technology has also played an important role. When the printed circuit board with the mounted chip components is moved into the reflow oven, the solder paste melts and wets the terminal electrodes, thereby creating the joint when the solder subsequently cools and solidifies. The section where the solder accumulates against the terminal electrode is called the fillet. If the fillet is of the proper size, i.e. when there is a proper amount of solder, the fillets of the terminal electrodes on both sides show a smooth slope rising from left and right towards the chip. However, if the solder volume is too small, the fillet may be malformed, leading to a reduction of cohesion force.
Another phenomenon that can occur is that one side of the chip component rises up during the heating process in the reflow oven. Because the vertical chip then resembles the shape of a skyscraper, the phenomenon is called the Manhattan effect, and it is also referred to by other names such as Tombstoning effect.
The surface tension of the melted solder acts on the terminal electrodes, but when the amount of solder differs between the two sides of the chip component, or if the heating temperature distribution is uneven, the difference in surface tension may cause one side of the component to break free and rise up.
At the time when reflow ovens first came to be used, the Manhattan effect was noticed in particular with multilayer ceramic chip capacitors. Subsequently, improvements to the shape and dimension precision of the lands, better control over solder volume and quality, purpose-built solder printing equipment, more accurate reflow oven temperature control (including preheating and temperature rise profile), and similar measures helped to solve the problem. However, in recent years, the changeover to lead-free soldering has brought new problems with it, in particular a decrease in joint reliability.

□Solder volume and fillet shape



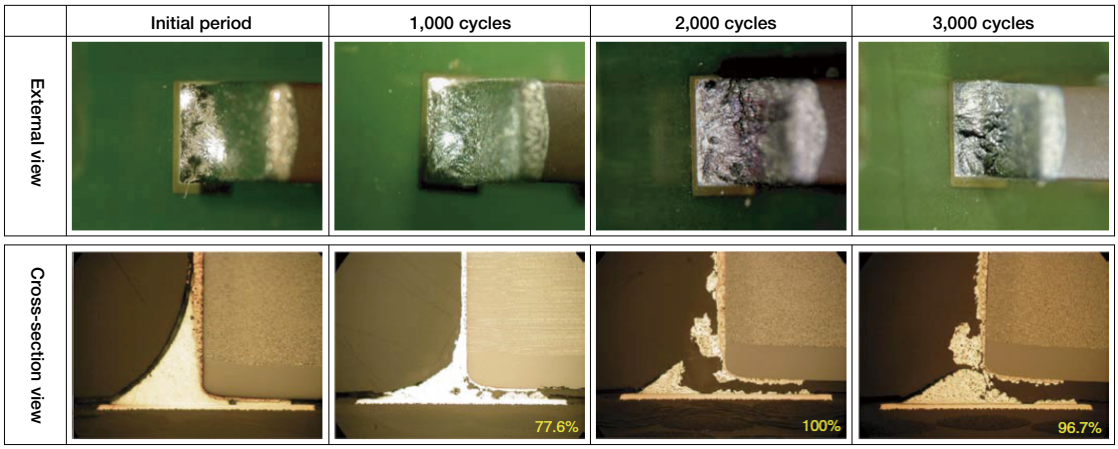
□Manhattan effect (also called Tombstoning effect)



New Problems Caused by Lead-free Solder

Conventional solder, which is an alloy of tin and lead, has a low melting point, is inexpensive and easy to work with, but it is also an environmental pollutant that is harmful to humans. Therefore different types of lead-free solder composed of tin (Sn), silver (Ag), and Copper (Cu) or similar but no lead are now being used as a replacement. However, lead-free solder has a higher Young's modulus than conventional lead-based solder, making it more susceptible to expansion and contraction, and it is also harder and more brittle. Therefore, when the printed circuit board on which the chip components are mounted is subject to bending stress due to warping or other influences, the solder joint deteriorates and cracks can appear. This phenomenon is called solder cracking.
Another defect that can occur with lead-free soldering is the so-called Kirkendall voids which are microscopic cavities, also causing reduced cohesion. When two different types of metal that are in close contact are heated, atomic dispersion occurs. After the name of the scientist who discovered it, the effect is known as the Kirkendall effect. As the speed of the dispersion differs depending on the type of atom, repeated thermal cycling involving heating and cooling tends to cause the formation of voids which eventually lead to solder cracks. The temperature in the engine compartment of a running car regularly reaches 100 degrees centigrade and higher. This causes populated circuit boards to expand and contract, leading to bending stress that can result in cracks and voids in solder joints, thereby lowering the joint reliability.

□Growth patterns of solder cracks in thermal shock (temperature cycling) test



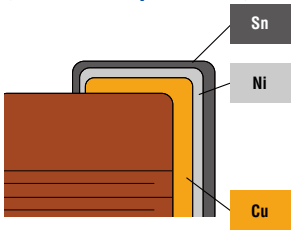
Numbers in cross-section photographs refer to crack ratio

Temperature cycle: -55°C to +125°C
Lead-free solder: 96.5 Sn (tin)/3.0 Ag (silver)/0.5 Cu (copper)

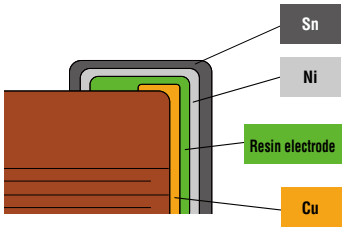
Conductive Resin Terminals Solving the Solder Crack Problem

The problem of joint reliability for multilayer ceramic chip capacitor boards can be ameliorated by measures such as improving the physical properties of the lead-free solder, reducing the size of parts etc., but these do not represent a fundamental solution.
In order to ensure joint reliability, TDK developed multilayer ceramic chip capacitors with conductive resin terminals. A resin electrode layer between the copper base and the nickel plating of the terminal electrode absorbs bending stress from the board and suppresses the forming of solder cracks. Conductive resin is made of epoxy or other synthetic resins mixed with a filler of conducting particles (silver or similar). To increase conductivity, flat rather than spherical filler particles are also sometimes used.

□Tin-plated product (standard product)



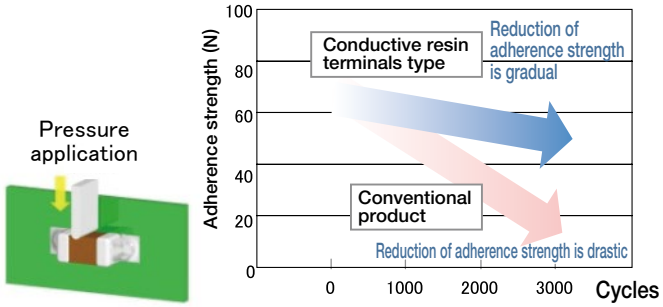
□Conductive resin terminal type product



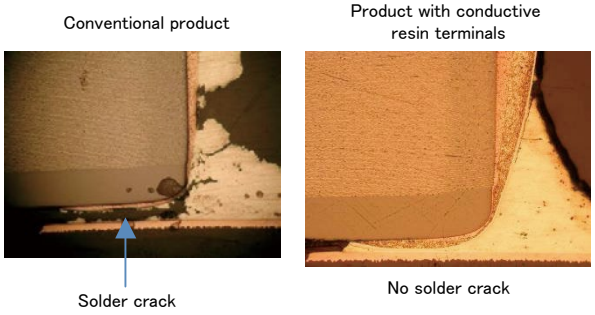
Conductive Resin Layer Ensures High Resistance against Thermal Shock and Board Flexing

JIS specifies various test methods for multilayer ceramic chip capacitors soldered to a printed circuit board, to determine characteristics such as resistance to thermal and mechanical influences. In an ECU located in the engine compartment of a car, vibrations and shocks reaching the PCB will cause it to flex. In addition, thermal shocks (temperature cycling) causing expansion and contraction also increase the risk of cracks. The top graph illustrates the data for thermal shock testing (3,000 cycles), with a temperature cycle of -55°C to +125°C. While the adherence strength of the conventional product has been reduced by 90 percent, the drop in the product with conductive resin terminals is only 50 percent. The conventional product shows cracks in the solder. By contrast, the product with conductive resin terminals only shows a partial separation of the nickel plating layer and the conductive resin layer.
The bottom graph illustrates the data for a board bending test (flexure limit). The conventional product already shows a crack in the ceramic element at a 4 mm deflection, while the product with conductive resin terminals can easily withstand more than twice the deflection amount. When excessive pressure is applied, the ceramic element of the conventional product develops a crack, while the product with conductive resin terminals only shows a separation of the nickel plating layer and the conductive resin layer, but no cracking. This demonstrates the superior cracking control achieved thanks to the conductive resin layer.

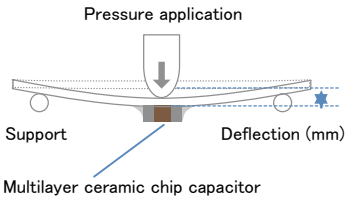
□Thermal shock (temperature cycling) test



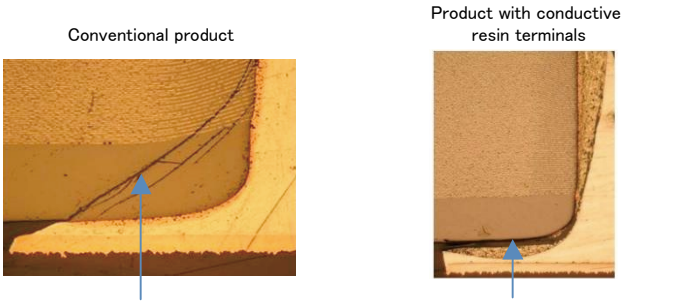
《Comparison of joint strength using applied pressure testing after thermal shock (temperature cycling)》



□PCB bending stress test



《Board bending test》



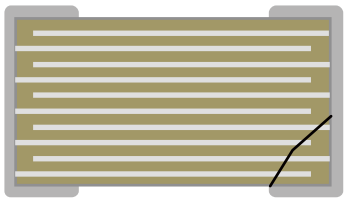
Also Suitable for Outdoor Use under Difficult Conditions

A more serious problem than solder cracks is cracks in the capacitor element itself. When the crack destroys the internal electrode, insulation breakdown may occur. The way a crack appears in the capacitor elements usually follows a certain pattern. When the terminal electrode is firmly joined by the solder, the bending stress will be concentrated on the joint section of the terminal electrode, and the crack will develop starting from the tip of the electrode and advancing through the ceramic element.

Cracks in the capacitor element often occur due to handling problems of the printed circuit board after component mounting. In order to achieve higher efficiency during production, the components are all placed on a long continuous board on the mounting line in one operation, and the board is later broken up into the individual boards. If the boards are broken off manually rather than by dicing or with special tools, bending stress may occur which can lead to cracks in the capacitor element. The illustration below shows that the crack occurrence ratio also depends on the orientation of the capacitor.

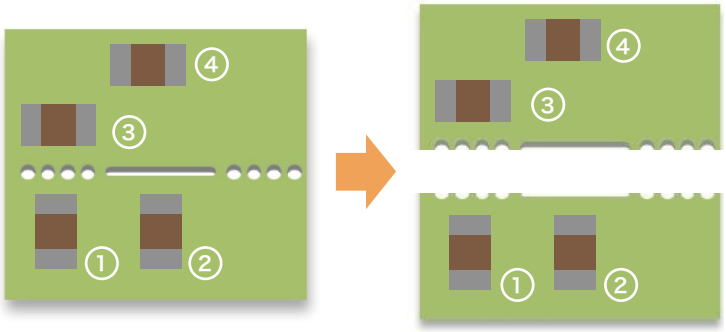
TDK succeeded in solving the joint reliability problems related to the use of lead-free solder by developing a multilayer ceramic chip capacitor with a conductive resin layer within the terminal electrode. This technique also lends itself to the production of large capacitors with high capacitance, thereby increasing the range of options available to unit designers. Application areas include not only automotive electronics equipment but also electronic equipment installed outdoors under demanding environment conditions.

□Crack development in capacitor element



Cracks in ceramic elements tend to occur from the tip of the terminal electrode. The destruction of the internal electrode can cause insulation breakdown.

□Crack occurrence when printed circuit boards are separated



When the printed circuit boards are broken off by hand without a special fixture, the bending stress can cause cracks in the multilayer ceramic chip capacitor.

The orientation is also significant. The crack occurrence ratio is decreasing in the order ①＞②＞③＞④.

Main Features

1. Conductive resin layer inside terminal electrode absorbs external stress from thermal or mechanical shocks
2. Improved board bending resistance and drop resistance keep crack occurrence in ceramic elements under control
3. Reduced risk of solder cracks due to thermal shock and temperature cycling, and improved adherence

Main applications

Engine control ECU, sensor module, HID, ABS units and other automotive electronic equipment

Products

- All ranges of 2-terminal products 6.3 V to 630 V DC
- All ranges of array capacitors (dual-element type)
- 150°C temperature resistant types (X8R characteristics etc.)

Type	C2012						C3216							C3225					C4532			C5750			
R.V.	2W 450V	2E 250V	2A 100V	1H 50V	1V 35V	1C 16V	2J 630V	2W 450V	2E 250V	2A 100V	1H 50V	1V 35V	1E 25V	2J 630V	2W 450V	2E 250V	2A 100V	1H 50V	2J 630V	2W 450V	2E 250V	2J 630V	2W 450V	2E 250V	2A 100V
103	X7T	X7R					X7R																		
223	X7T	X7R																							
473	X7T	X7T					X7T							X7R											
104		X7T						X7T	X7R					X7T		X7R									
224			X7S						X7T						X7T	X7R			X7T						
474			X7S	X7R						X7R										X7T	X7R	X7T			
105			X7S	X7R						X7R	X7R										X7T		X7T	X7R	
225					X7R					X7S	X7R						X7R							X7T	
475						X7R						X7R					X7S	X7T							
106													X7R					X7T							X7S

X7R series
X7S series
X7T series

Current as of August 2010

* Conductive resin terminal electrodes can also be implemented in other medium voltage products, C0G characteristics products, etc.