

Device Attachment Methods and Wirebonding Notes for RT/duroid® and RO4000® Series High Frequency Laminates

Volume production of microwave circuit assemblies requires fast, reliable and efficient methods of attaching discrete microwave components to the circuit board. These could include simple two-lead devices such as resistors or diodes, or complex multi-lead MICs. Bonding techniques used for conventional epoxy glass grade laminates have been used with limited success on PTFE based laminates. However, conventional epoxy glass grade parameters are generally acceptable for the Rogers RO4000® series high frequency laminates. This application note is intended to present a general guide for device attachment to RT/duroid® and RO4000 high frequency laminates.

RT/duroid Laminate Characteristics

RT/duroid laminates are random glass fiber reinforced PTFE or ceramic filled PTFE materials. PTFE is a soft, waxy, thermoplastic fluoropolymer. The glass or ceramic reinforcement adds dimensional stability and increases the hardness but the laminates are in general much softer than the low frequency hardboards, such as glass/epoxy. PTFE is a thermoplastic rather than a thermosetting resin. At elevated temperatures the substrate will readily deform and take a permanent set. Therefore, lead attachment methods must minimize the pressure applied to the dielectric, particularly at elevated temperatures.

RO4000® High Frequency Laminate Characteristics

RO4350B™ and RO4003C™ high frequency laminates are glass reinforced hydrocarbon/ceramic materials. The laminate is a rigid highly filled thermoset resin system which has a $T_g > 280^\circ\text{C}$ (536°F). The high T_g helps to maintain the expansion characteristics over a wide range of temperatures. Lead attachment methods are similar to what is practiced with conventional FR4 epoxy grade laminates.

Lead Bonding Methods

The methods employed to achieve low resistance electrical connections and good mechanical integrity fall into two categories: true fusion welding where the metals of the lead and the circuit pad are melted, and a form of diffusion where the joint is made without melting.

Welded Bonds:

- 1) Resistance Welding — The lead and circuit conductor are pressed together and a high current pulse (usually from a capacitor) passed between the two. Heat caused by the passage of the current through the resistance of the joint melts and welds the metal.
- 2) Parallel Gap Welding — This is a specialized form of resistance welding. In this case the electrical energy is supplied to a pair of parallel electrodes, which are in contact with device lead. The weld depends upon conduction of heat generated in the lead to the circuit pad to melt and fuse them together
- 3) Percussive Arc Welding — The lead and pad are held a small distance apart and an arc generated by applying a short pulse of RF energy to ionize the gap, followed by a discharge from the capacitor. As the arc decays, a mechanical device forces the two heated surfaces together and completes the weld.
- 4) Electron Beam Welding — A beam of high-speed electrons is focused in a vacuum on the lead and pad held together. The energy of the electrons is absorbed, raising the temperature to the melting point of the metals.
- 5) Laser Welding — Energy is focused on the work piece by an intense, collimated, monochromatic light beam that is absorbed and raises the temperature to the fusion point.
- 6) Soldering — The lead and pad are coated with a low melting point alloy and pressed together. Heat is applied either locally (by a heating tool) or generally (by infrared or oven heating) to melt the solder and weld the two components together.

Diffusion Bonding:

- 1) Ultrasonic Welding — Diffusion of metal between the lead and pad is induced by clamping the two together and applying mechanical energy in the form of ultrasonic sound vibration. The metal surfaces are cleaned by friction, which also heats them, aiding in the diffusion process, but temperatures do not reach the melting point.
- 2) Thermal Compression Bonding — Metal diffusion in this method is accomplished by heat and pressure applied to the cleaned surfaces of the lead and pad. The temperature is insufficient to give a true fusion weld.
- 3) Thermosonic Bonding — This method is a combination of ultrasonic and thermal compression bonding. The work is preheated, and ultrasonic energy is supplied through a gold capillary. Again, the weld is achieved at temperatures below the fusion point of the metal.

The methods most suitable for attaching devices to circuit boards made with RT/duroid laminates are: ultrasonic wire bonding, thermosonic bonding, parallel gap welding, thermal compression bonding and solder reflow. These are discussed in detail.

Ultrasonic Wire Bonding:

This method relies on the "scrubbing" action of the lead wire against the pad to expose nascent metal surfaces and deformation caused by the mechanical clamping to allow diffusion of the metals. Aluminum wires with their coating of abrasive oxide are particularly effective in forming this type of diffusion bond. For example, prior cleaning of copper pads is not necessary as any oxide contamination of the pad surface is rapidly removed by the motion of the wire to expose clean fresh copper.

Test bonds were made using a Mullen Equipment Corporation Ultrasonic Wire Bonding Machine 8-166 on RT/duroid® 5880 and 6010 materials clad with 1 ounce and ½ ounce copper, and dielectric thickness from 0.010" to 0.125". Some samples were pumice scrubbed before bonding; others were left with oxide on the copper surface. The wire was 0.001" aluminum alloy with 1% silica. Machine settings were:

	Channel #1	Channel #2	Channel #3
Time	38.2	18.4	Low
Power	50.5	88.5	Low



Figure 1. Ultrasonic Wire Bonded Joint. 0.001" aluminum wire bonded to ½ ounce electrodeposited copper on RT/duroid 6010. No attempt to clean the copper foil surface was made, but the result is still a good joint.

Pull strengths of the wire bonds were greater than 4 grams minimum, and usually greater than 5.5 grams (Acceptable values for 0.001" aluminum wire bonded to copper coated alumina are 3

grams minimum, with 6 grams considered "good".) Pull strengths were independent of the type and thickness of the dielectric, and no difference between pumice scrubbed and uncleaned samples was noted. No distortion of the copper foil or dielectric was seen in any of the samples bonded. Gold or nickel/gold plating on the copper shows similar results.

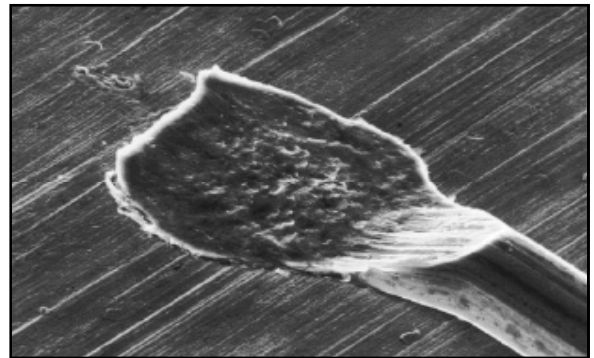


Figure 2: Ultrasonic Wire Bonded Joint. A similar joint to the one shown in Figure 1. No distortion of the copper surface can be seen.

Thermosonic (Ball) Bonding:

In this method, a gold capillary wire is agitated by an ultrasonic generator and pressed against the preheated circuit pad. A ball of gold is formed at the protruding tip of the wire by a gas flame or electrical heater, and forms the initial contact with the pad. Plastic deformation of the gold ball caused by the contact pressure results in a "nailhead" shape typical of this type of wire bond.

Gold does not have the abrasive properties of the aluminum wire described above, and it is unable to break through the surface contaminants on the copper foil. Cleaning the copper before bonding does not help since preheating the work area (about 200°C) quickly oxidizes the surface.

Tests of thermosonic wire bonds on RT/duroid 6010 material clad with unprotected copper were unable to produce reliable bonds. However, when the copper was plated with 2 to 4 microns of gold, most of the wire joints were good. Failures were attributed to migration of copper to the surface of the gold plating (during the preheat

cycle), which assumed a salmon pink color. A nickel strike coat on the copper before gold plating produced good, reliable wire bonds with pull strengths of 5 grams using a Mullen 8-150 machine, with 0.001" gold wire on ½ ounce electrodeposited copper clad RT/duroid 6010 material. The work area was heated to 200°C.

Some small deformation of the conductor and substrate was seen in the test pieces, and in one instance, the copper foil at the edge of bond area was cracked. The use of the more ductile rolled copper foil on RT/duroid laminates is recommended when thermosonic bonding is planned, and contact pressure between the wire and the circuit pad should be kept to a minimum consistent with good pull test values.

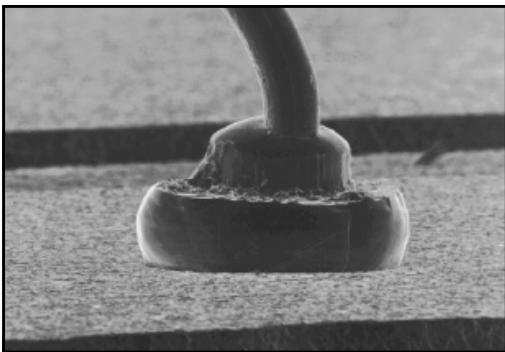


Figure 3: Thermosonic (Ball) Welded Joint. 0.001" gold wire welded to ½ ounce copper on RT/duroid 6010. Deformation of the gold ball due to the pressure against the conductor shows the typical "nailhead" shape. The etched edge of the conductor is seen in the foreground.

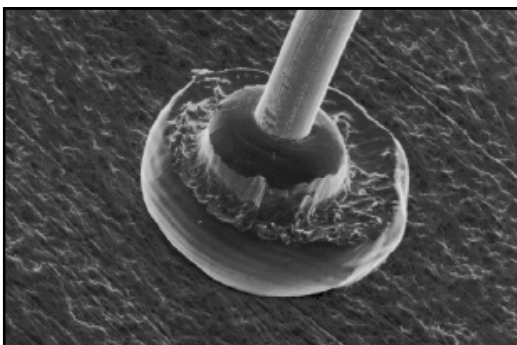


Figure 4: Thermosonic (Ball) Welded Joint. Another view of the joint shown in Figure 3. Above the flamed off gold ball can be seen a thicker section of wire where it has been forced back into the ultrasonic head.

Additional work was completed at the National Training Center for Microelectronics. As part of the study, sample boards were manufactured from various Rogers Microwave materials for use in establishing thermosonic gold wire bond parameters. The parameters generated are approximate and are offered for use as reference points based on the work completed. Parameters may vary based on device surface, metal finish, wire type, wire diameter, capillary configuration etc.

This information was generated using two types of equipment. A Panasonic automated wire bonder (HW27U-H) and a K&S manual wire bonder. The bond type practiced was a thermosonic bond using 0.001" diameter gold wire. The boards were plated with 50 micro-inch of nickel and 200 micro-inch of Type III grade A gold (99.9%). Typical industry plating thicknesses may vary from 50-100 micro-inch of gold over 50-250 micro-inch of nickel.

As noted, wire bonding to PTFE based products can be difficult when compared to thermoset material systems. The action of the capillary pressing on the PTFE surface can create a "bounce back" effect that makes it difficult to achieve a good bond. PTFE is a soft substrate and may slightly deform due to the pressure from the capillary. When bonding to PTFE based laminates, it is often necessary to increase the time and decrease the force to address the softness issue. An additional method used to offset this effect is to increase the plated nickel layer beneath the gold plated pad. There is some risk associated with this method. The increased nickel plating may become brittle resulting in cracking or micro fracturing upon the impact of the capillary. There is also increased risk of micro-fracturing of the Ni/Au plated traces or pad areas due to handling of the soft substrate materials. There often needs to be the right balance of plated metals unique to the material type, circuit design and equipment used.

When bonding to PTFE based Products, it was found that reducing stage temperature can minimize the materials expansion and contraction

due to the thermal exposure. A short stabilization period may be beneficial when placing PTFE parts on a heated stage. A stage temperature at or below 80°C may be necessary to help reduce the effects of material movement. This approach was found to be particularly effective with regard to the random glass fiber reinforced PTFE RT/duroid 5870 and 5880 laminates.

When bonding to thermoset materials like Rogers RO4000 products, conventional epoxy glass parameters should be used as a starting point and optimized based on pull test results.

Recommended starting parameters for thermosonic gold bonding would be as follows:

	Time	Power	Force	Stage Temperature
RT/duroid 5880	250	110	90	80
RT/duroid 6010	250	110	90	80
TMM	35	70	95	130
RO4000	35	70	100	130
FR4 as reference: Epoxy Glass	30	120	160	130

- Power is measured in watts.
- Time is measured in milliseconds.
- Force is measured in grams.
- Stage temperature in Celsius

Parallel Gap Welding

Fusion welds are formed in the method by the resistance heating of gold foil or gold plated leads on the device to be bonded. A short section of the lead is pressed against the conductor between two electrodes and a heavy current (typically 100 amperes) passed. Better control is achieved by confining the electrical contact to the lead rather than passing current between the lead and the conductor. The amount of energy (which appears as heat) is determined by the current and the duration.

Tests were conducted with copper clad RT/duroid laminates using a Unitek Phasemaster™ 3 machine. Gold foil leads of cross section 0.005" X 0.002" were parallel gap welded to copper pads. Machine settings used were 55% of maximum power and duration times of 0.8 to 1.3 seconds. Uncleaned pads would not produce good welds due to copper oxides interfering with the fusion of the metals, but on cleaned pads, pull strengths of 30 grams minimum and better than 35 grams were recorded. Gold or nickel/gold plating on the conductors would ensure freedom from oxide contamination. With the machine correctly set, no distortion of the conductors or dielectric was observed.

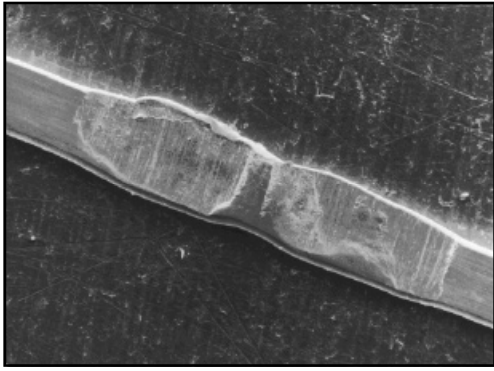


Figure 5: Parallel Gap Welded Joint. 0.005" X 0.002" gold taps welded to a cleaned but unplated copper surface. Note the indentations in the gold foil caused by the electrodes.

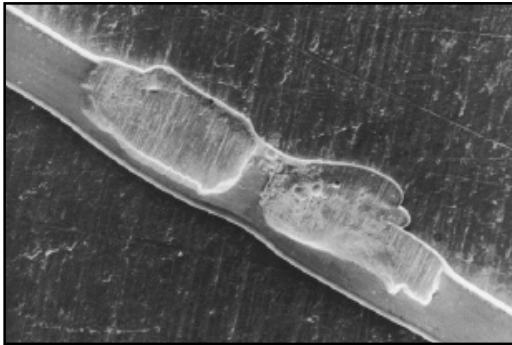


Figure 6: Parallel Gap Welded Joint. A joint similar to the one in Figure 5. In this instance, the electrodes have been slightly misaligned, resulting in a gold "smear" at the edge of joint area. However, the bond is still good.

Thermal Compression Bonding:

The device lead and the conductor pad are aligned and pressed together. Heat is supplied to the lead surface, and diffusion of the metal between the two components takes place, creating the bond. A modification of the parallel gap welder in which the electrodes are replaced with a resistance heated head is the equipment normally used. Power input, duration, and pressure control the quality of the bond. For RT/duroid laminates, pressure should be only high enough to ensure good thermal contact between the heating head, the device lead, and the conductor.

Very clean surfaces are necessary to ensure proper diffusion of the metals. Gold tape or gold plated leads on the device, and gold or nickel/gold

plating on the conductor are required for thermal compression bonds. The method is unsuitable for wire bonding — the device leads must be in the form of flat tapes to provide sufficient area in contact with the pads for efficient heat transfer.

Solder Reflow:

Tin/lead solders have been used in the Printed Circuit Board industry for many years to make electrical connections between copper conductors and discrete components. More recently, low melting point indium based solders have been used in special applications where severe temperature constraints exist. For microwave circuit boards and RT/duroid laminates, soldered joints are probably most commonly used for component mounting. Soldered connections have the advantage of being usable in low volume and prototype production with reasonable efficiency, rework capability, and low capital investment. Equipment is now available that can perform reliable, repeatable solder connections in the largely automated fashion at low cost, thus facilitating the transition from the lab and prototype shop to the factory floor.

The method requires that the device lead and the circuit trace are solder plated. Parallel gap welding equipment is modified by fitting a resistance heated head in place of the electrodes. The solder joint is made by simply pressing the two components together and heating sufficiently to melt or reflow the solder. The joint is allowed to cool until the solder refreezes. Minimal pressure is required — just enough to allow good thermal contact between the solder surfaces.

Lead Bonding Machines

All of the device attachment methods described above require specialized machines (with the exception of hand soldered joints). Equipment is available in a wide variety of degrees of sophistication from simple single head to multiple station machines which can make several bonded

connections simultaneously. Several equipment suppliers offer custom design systems that are microprocessor controlled, capable of locating, positioning, and bonding components in place from programmed X/Y coordinate data.

Multiple head machines are recommended for mounting components with more than two leads. This is not only for faster operation, but if multiple leads are bonded one at a time, then alignment of the later leads may become difficult. Forcing the leads into alignment (in both the vertical and horizontal planes) can break previously bonded joints, or even snap a brittle component.

Clearly, the review of lead bonding methods above cannot attempt to address, in a specific way, the large number of options and variables involved in mounting components on RT/duroid and RO4000 circuit board materials. The Process Engineer who has the task of implementing a lead bonding capability is advised to select reputable equipment suppliers and work closely with them to ensure that the machines he buys are appropriate to his needs. Most suppliers provide, at no cost, a comprehensive Customer Service function that will define specific process variables for the user.

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