# Connecting Copper Wire to Thin Metal Layers

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***Abstract* – The process or a system of creating connection between two electrical conductive materials is referred to as heat bonding. In this case it is correct to call it micro bonding. Essential characteristics of this process are pressing two materials together and applying heat. Similar processes are used to create connections to LCDs (Liquid crystal displays) or PCB. This paper discusses copper wire bonding technology to a thin metal layer made on dielectric sheet for micro coils.**

***Keywords* – electrical bond, connecting, thin metal layers, weld, pressure.**

## 1. Introduction

How is the connection created?

Dielectrically coated (enameled) copper wire is placed over the spot in which a weld should be created. A thin layer of metal, in this case gold + nickel, creates a base for the weld.

Connection creation process is executed in three steps:

- Applying pressure to the copper wire, which forces the wire onto the metal film.
- Applying heat to the place of weld. Thanks to the applied pressure, the heat melts the coating off the copper wire, which allows creating electrical connection between the wire and the base. Actual welding process occurs by applying enough heat in order to melt the copper.
- In case that particles of the copper wire and metal base are bonded correctly, the weld should be mechanically strong enough to hold together after cooling down, and it should be electrically conductive.

Considering that there is only one material interface for the current to flow through, it is expected to reach very low resistance. [1]

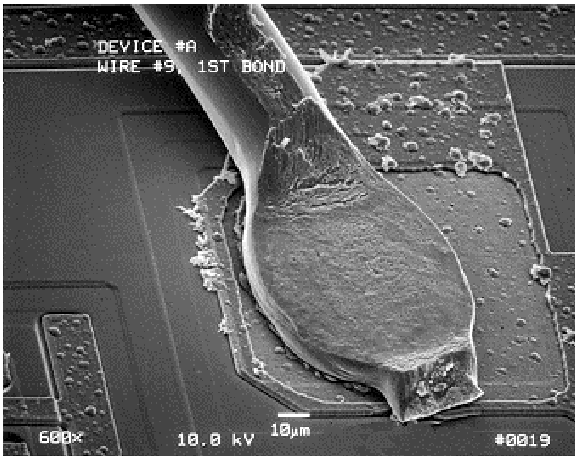


*Figure 1. Bonded wire.*

## 2. Micro Bonding Process

Micro bonding process uses pulse-heated hot bar technology. Two-pole electrode is used as a pushing element, putting force onto the place of the weld, and heating up the area by striking a short current impulse through it. The length of the impulse, amperage and pushing force differs according to the types of bonded materials and size [9].

Main parts of bonding systems are:

- power supply
- bonding head
- electrode
- fixture (tooling)

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The role of power supply is not only designed to be an impulse generator, therefore it generate controlled electrical current for the electrode, but it also regulates flow of current in time, timing, amperage, voltage and in many cases provides an interface with output data for higher level PLC.

Bonding head provides force control and holds the electrode. Furthermore the bonding head provides repeatable force application, and it usually needs precise mechanics to be able to position the electrode repeatedly within tight tolerances.

Electrode, sometimes referred to as a thermode, which is made out of electrically resistive material. This is the reason why it generates heat when current flows through it. The effort is to make the cross sectional area of the electrode in place of contact point as small as possible, in order to achieve a fast heat up and allow quick cooling. In some cases a bonding system with a thermocouple is used, in which the power supply is regulated via temperature feedback loop. In this case, spaces around the process are too tight to use temperature feedback. Regulation and system setup is therefore done by calculations. Thanks to the precise manufacturing and material purity, it is possible to regulate bonding temperature of the electrode within a few degrees Celsius. [2]

*Figure 2. Pulse generator for heat bonding.*

The electrode as a key component of bonding system is usually shaped as the letter V. Current flows through the electrode only, which is why no discernable voltage drop between close conductors .

Thanks to the fast heating up of the electrode and quick cooling down, pressure is maintained during a whole solidifying of the weld. This aspect guarantees good mechanical and electrical parameters of the weld. [3]

The importance of precise fixture is essential for the repeatability of the bonding process. This need of precision strongly relies on product character. In our case there isn't a possibility to hold part within necessary tolerance. Optical vision guidance system is used for changing position of the weld bed. In addition, in order to hold the parts in position, the fixture provides a support to counterbalance of the force, acting from the bonding head pressing on the wire.

## 3. Bonding methodic

Once positions of the wire and the electrode have been aligned, it is possible to start the bonding process.

Firstly, there must be a pressure applied. A bonding head creates enough pressure to force the copper wire onto the metal film without damaging either of them. Mechanical precision of the force application and shock reducing capabilities of the system are crucial when dealing with micro dimensions.

It is necessary to keep an electrode contact surface coplanar to the surface of the base to ensure correct contact. Electrical resistance of the material interface is important for component functionality over the whole life span of the product. [6]

After the force has been applied, heating up of the electrode begins. Parameters need to be set accordingly to the wire diameter, metal film thickness and electrode specification. When dealing with micro thin parts, many physical material aspects must be settled upfront on a theoretical level, in order to achieve the required bond. Thermal conductivity stands as an important role in the process. Heat dissipation through materials needs to be precisely calculated, to overcome cold joining or overheating.

By the time, the cooling down of the electrode and the solidifying of welded materials begin, the bonding head keeps the pressure controlled and applied. After the weld is cured, it is possible to remove the electrode from the contact with the weld bed [12].

*Figure 3. Bonding heads for hot bar technology.*

## 4. Design guidelines

It is theoretically possible to bond wires of any diameter. Bonding is usually used in a small electronics manufacturing, thanks to its parameters and production capabilities. Bonding to the micro thin layers is considered a specialty because of the need of precise heat dissipation control. Basic rules for designing such connection types are:

- The use of enameled wires with thin coating. It is easier to dispose small amount of coating from between the raw wire and the contact area of the metal layer, which is supposed to weld to. It is necessary to consider the time needed to melt and dispose the coating from the weld bed. This process usually takes place in the beginning phase of the electrical impulse. Melting point of the coating is significantly lower than the melting point of the wire material.
- Maximize the layer thickness as much as possible. Enlarging thermal capacity of the metal layer is reached via increasing its volume and choosing the correct material. Ideal setup is when there is a base layer with slightly higher thermal capacity than the thermal capacity of the wire bonded to it. This is important for the process, because the bonding priority should be given to melt the wire into the base metal layer. If circumstances do not allow to reach this setup, it is far more difficult to find the correct bonding parameters.
- Calculate the weld bed area (electrode contact surface) considering material interface resistance [10],[11].

## 5. Process Limitations

Every technology has its field of use and its limitations. Micro bonding is suitable for connecting materials with close melting temperatures. In some rare cases and under special circumstances, it is possible to create a connection between materials with melting points far apart. There is usually a third substance used, or surface of the material with significantly higher melting temperature that undergoes preparation in order to enable creating the bond. This micro bonding technology is designed to weld copper (Melting temperature t = 1080°C) and gold (Melting temperature t = 1060°C). [4] This technology is especially suitable for connecting wires to metal bases.

Miniaturization represents the second most limiting factor. Copper and gold are materials, conductors, widely used to manufacture wires for microelectronics. The principle of this limitation lies on a mechanical factor: the size of the particles. Copper and gold are easily formable into wires, and thanks to the low recrystallization temperatures they are easy to make in small diameters. It is common to find D = 20 µm copper wire in micro coils, and even thinner golden wire is used inside microchips, usually D = 5 µm. Various materials are used to manufacture bonding electrodes. Most common material is tungsten, thanks to its high melting temperature and natural electrical resistance. A stock of tungsten is made by pressing particles of wolfram and binder together. It creates a hard stock of material, but it has remarkably larger structure than a raw material, such as recrystallized gold or copper. It is not possible to recrystallize tungsten. Because of this material structure, there is a limitation in a dimension of the contact point of the electrode. [5]

The distance between bonded wires needs to be larger than the electrode contact point when using single point bonding.

## 6. Bonding head design

The key feature of the bonding head is its positioning system. Micro bonding heads require accurate positioning. Majority of positioning systems use ball screw drives and precise linear bearings. Servo drives are the usual choice of motors for such applications. Thanks to the special zero backlash gearboxes, accuracy of 1 micron is manageable.

Some types of bonding head positioning systems are preferred with linear motors. This technical solution is used in time demanding operating conditions.

Force generating systems are almost exclusively made in two variants only:

- Pneumatic: Pneumatic cylinder is used to move the electrode to the position and press on the wire. This solution is very cost effective and brings some positive characteristics. For example, it is easy to set up an approaching speed and it provides constant force in any position of the valve. It is usually more suitable for larger wire diameters.
- Electric: In this variant, linear motors are most commonly used types of force generators. This solution finds its use in high speed production, because it can save the production time. To run linear motors, more demanding motor management is required. It’s necessary to keep the system under power all the time, it uses more electricity and needs high level control units (motor drives). It is beneficial to use when precise control of speed is needed. This is usually the solution when dealing with small wires

Materials with high melting temperatures, good mechanical (hardness at high temperatures) and chemical (resistance to oxidation at high temperatures) properties are used to manufacture thermodes. Most common materials are tungsten, tungsten carbide, molybdenum etc. It depends on welding parameters and the materials of the wire and the base. The shape of the electrode for micro bonding is similar to the letter V, in which two contact surfaces on sides are used to connect it to the power supply, and the thin bottom is formed into a welding tip [7],[8].

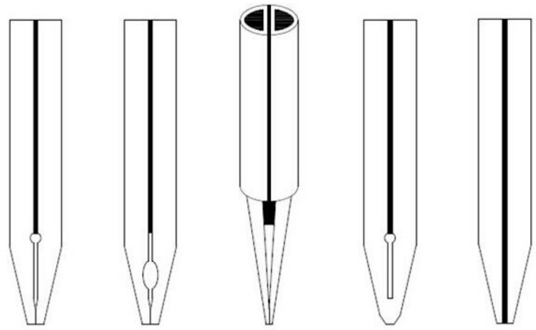

*Figure 4. Illustration of electrodes.*

## 7. Achievement

Our technology uses some of the above mentioned technical means.

The electrode design has proven to be critical in making a reliable bond. After unsuccessful testing of standard electrode shapes, we proceeded to design a new special shape that suits this application.

The most striking problem was the mechanical reliability of the bond. Standard electrodes were unable to maintain repeatable process quality or, in some cases, to create bond at all.

The second most common defect was breaking the wire at the boundary of the bond. Standard electrodes formed a relatively significant notch on the edge of the bond. For this reason, we have experimented with the leading edge of the electrode and the shape of the contact surface.

*Figure 5. Final shape of the electrode tip.*

The above figure shows the shape of the electrode that gave us the acceptable and repeatable results. Bonds were mechanically strong. Thin gold layer was not damaged. Thanks to the rounded and angled edge of the electrode, the notch did not appear on the wire.

Functional area of the electrode is slightly angled. This modification helped with the evacuation of the wire coating material.

Third most common defect was insufficient support of the thin metal layer from the bottom. Pressure from the bonding head caused the collapse of the metal layer, and the result of this defect is shown in the figure 6 bellow.

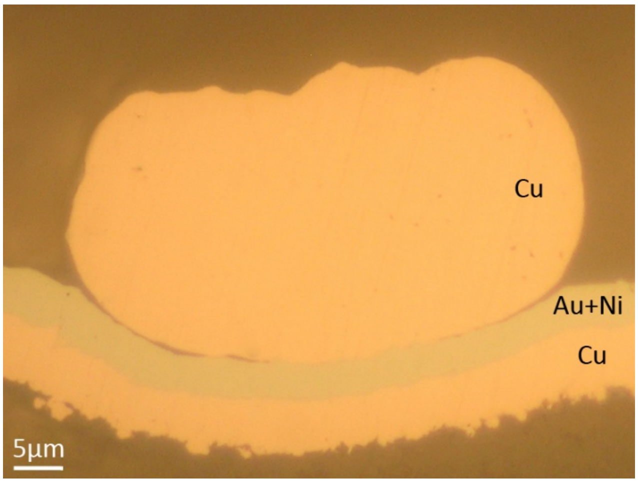


*Figure 6. Insufficient support from the bottom.*

Repeatable and reliable bonding process was achieved with correct shape of the electrode, accurate settings of the power supply (pre-heat and main impulse), precise positioning of bonding head and securing good flatness and cleanliness of the bottom support for metal film. Top layer of the gold applied to the nickel base bonded correctly with the copper wire as shown in the figure 7 bellow. Each connection is tested in the process electrically to ensure functionality.

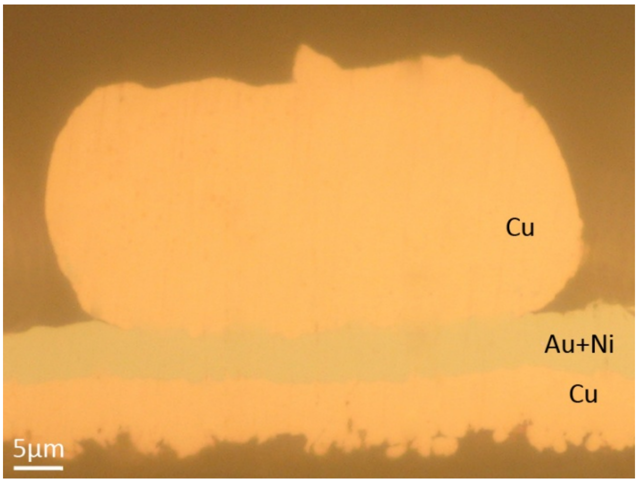


*Figure 7: Correct bond.*

## 8. Conclusion

Micro bonding (pulse-heated bonding) is a well-controlled and stable welding process. Smart product design and understanding all physical aspects of this technology may produce reliable electrical connection method for production. Thanks to the manageability of the whole process such as timing, current flow, temperature control etc. plus its cost effectiveness, make this bonding technology suitable for a wide range of electronics manufacturing.

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