Bonding in fuse industry

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1 Introduction

Since the sixties 'bonding' is well known in the semiconductor industry. But in the fuse industry it has mainly not been used for the next two decades. One reason for this could have been the fact that in this time there were no advanced requirements neither from the customers nor from the standardization point of view.
The growing of the surface-mount-technology in the electronic industry at the end of the eighties gave 'bonding' a new startup concerning fuses.

2 Bond-technologies in the semiconductor industry

2.1 Definitions

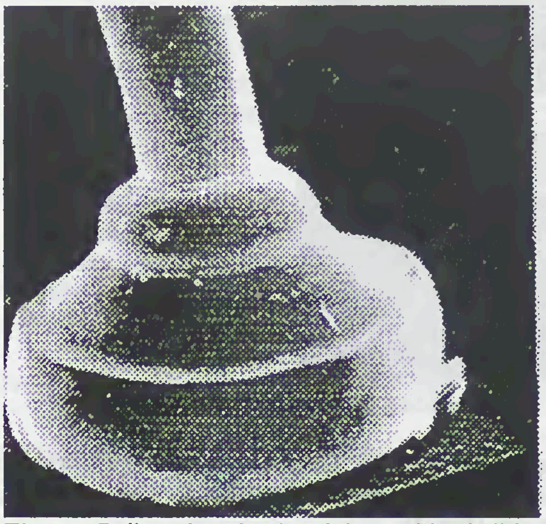
Saying 'bonding' one has to define what is ment using this term. Concerning this article this term is referred to for special intermetallic contacts only. In contrast to this 'bonding' is used as a term for connecting a semiconductor chip to a substrate or carrier ('die-bonding').

2.2 Techniques

2.2.1 Thermocompression ball-wedge bonding

This technique is most commonly used to connect semiconductors to the metal-terminations of the outer housing. The standard metallization of semiconductor chips is aluminum. The wire itself has to consist of precious metal to make it possible to form a perfect ball by melting the end of the wire even when this is done in the presence of oxygen due to the surrounding air. Besides of this materials suitable for bonding have to fulfill a series of other requirements. Pure gold is the standard wire for ball-wedge bonding. Special heat-treatment and dotation of the gold with atoms of different materials are used to achieve best characteristics for the use in the bonding process.

The Au-ball is pressed onto the aluminum metallization and cracks the very thin alumina surface of the metallization. So Au- and Al-metal atoms get into a very close and direct contact. The metal parts are heated up to a temperature around 100°C to support the process.
Ball-bonding makes it possible to reach terminations in every direction from the first bond without turning the bondingtool and is therefore a very fast process. The disadvantage of this kind of bonding is the second bond at the termination. This is a wedge bond which is done by the outer shape of the ball bonding tool and can therefore not easily be optimized **(Fig. 1, Fig. 2)**.



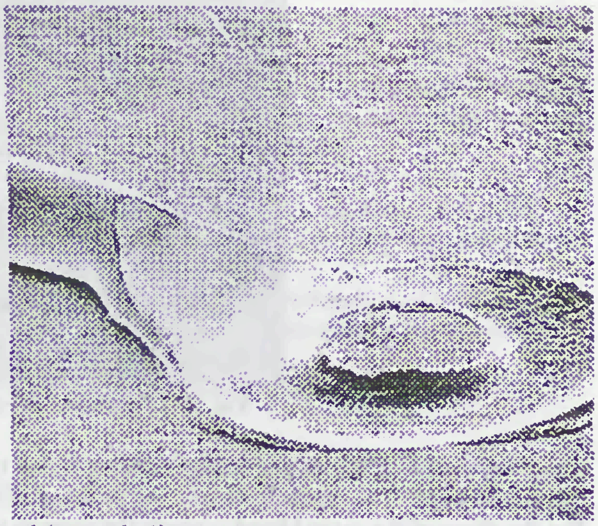


Fig. 1 Ball- and wedge-bond done with a ball-bonding tool (example 1).

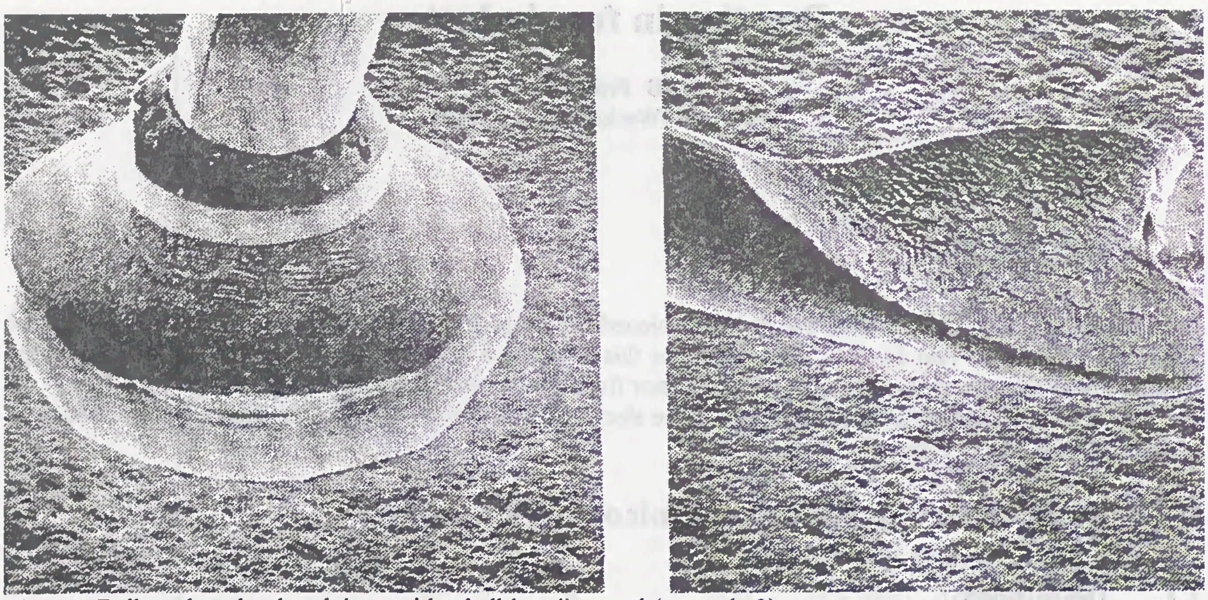


Fig. 2 Ball- and wedge-bond done with a ball-bonding tool (example 2)

But in any case a sufficient conductive contact between the gold wire and the aluminum metallization is accomplished.
The strongly reduced cross-section at the second bond is normally no problem for a standard low-power semiconductor. The diameter of the wire is mainly determined by the maximum reachable handlingspeed so that the wire is somewhat oversized and the current density is quite low even in the shattered area at the second bond.
Another disadvantage is that gold (Au) and aluminum (Al) form intermetallic phases which cause defects in volume. So Au-Al contacts deteriorate by the influence of time and temperature. But if the focus is set on the achievement of very low costs the bondingspeed has to be quite high and the aging of the bond is of minor priority and not so critical especially concerning lowpower semiconductors which are not operating at elevated temperatures. Therefore in the semiconductor industry pure gold is paradoxically used for lowcost applications.

2.2.2 Ultrasonic wedge-wedge bonding

The second technique is preferrably used to perform a high reliable contact to the standard Al-metallization of the semiconductor. To avoid the a.m. intermetallic phases even at higher temperatures Al-wire is used. For highpower semiconductors the cross-section has to be increased as well. Wire diameters around 100 µm are most common for these applications.
The support of the bonding process is done with an ultrasonic-movement of the bonding tool. To avoid oxidization of the aluminum no elevated temperatures are used. The first and second wedge-bond **(Fig. 3 + 4)** are well controlled by the special shaping of the wedge-bonding tool.

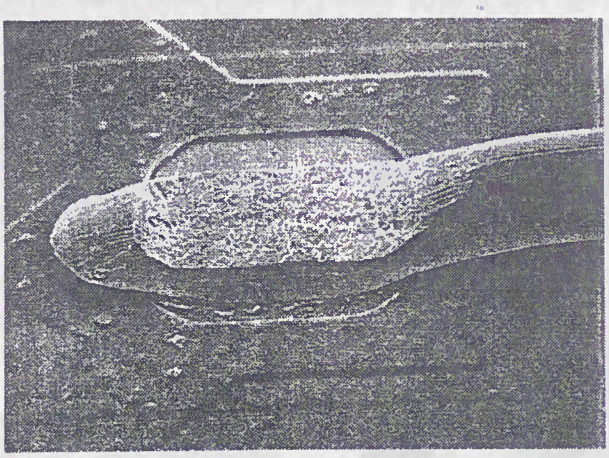


Fig. 3 First bond done by a wedge-bonding tool

The disadvantage of the wedge-wedge bonding is that the orientation of the first bond determines the direction to the second bond. The necessity to turn the tool makes this technique somewhat slower than ball-wedge bonding. But the shape of the second bond is nearly the same as the first one **(Fig. 4)**.

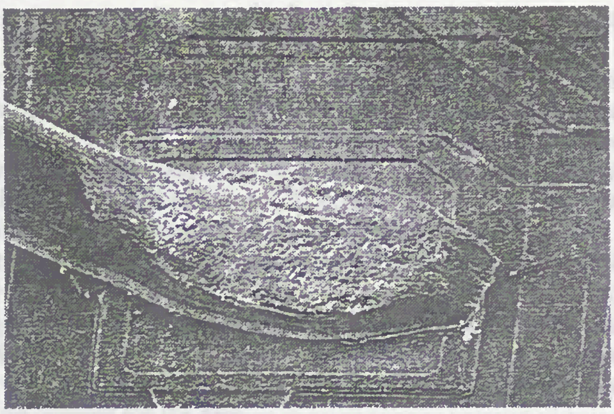


Fig. 4 Second bond done by a wedge-bonding tool

3 Surface-mount-fuses

3.1 Probable surface-mount-fuse application problems

Surface-mounted-devices became more and more common concerning all types of electronic components at the end of the eighties. At that time the fuse industry was mainly not involved in this development. Most of the fuse-manufacturers wondered if there is a real need for sm-fuses. This discussion was focussed on two points:

- most customers may worry about the exchange of soldered-in sm-fuses
- the I-t-characteristics of such a small fuselink might be influenced too much by the heat interchange with the surrounding circuitry

3.2 Surface-mount-fuse requirements

Some fuse-manufacturers had overcome the above mentioned questions and decided to start conversations with the customers concerning probable applications for sm-fuses. The main requirements for such a component are:

- small
- available for low and high voltage applications (up to 250 Vac for line-crossing)
- not mainly influenced from the local environment
- heat resistant for any kind of soldering
- no aging (long lifetime)
- cheap, but
- fully approved according to the relevant standards (IEC, UL etc.)

Most of the possible applications were not so critical with regard to inrush-currents because at that time switching power-supplies had already replaced ancient linear regulated ones with high charging-currents flowing into huge capacitors at power-on. So the ´classic´ time delay was not longer a ´must´ for a sm-fuse.

The question of easy replacement was discussed at the beginning of the eighties. If it is considered that a fuse will only operate if there is a defect in the circuit a repair has to be done anyhow to replace the defective device which caused the fuse to blow.
Therefore the easy exchange of a blown fuse is only a minor requirement. From the economical point of view it is more important to design fuses appropriate for automatic pick-and-place machines than suitable for fuse-holders.

From the manufacturers point of view there have been some other options which should be realized:

- reliable and well-known technique
- good automation available for the manufacturing process

3.3 Specific problems concerning sm-fusedesign

A fusedesign using a standard soldering technique does not perfectly meet the requirements given in 3.2 because of the diffusion problems between the solder and the meltingwire. If materials like nickel or platinum are used for the wire the diffusion can be reduced but the contact may be poor. To achieve a sufficient heat resistance of the sm-fuse to the soldering process which is applied later by the user a high-temperature soldermaterial for the internal connections of the fuse has to be chosen. If this is done by increasing the lead content the tendency to get a ´dry joint´ is increased as well. Agressive flux is no solution as it causes other well known problems.
To avoid all these difficulties a direct connection between the meltingwire and the terminals such like welding or bonding is beneficial.
If welding is used the terminals and the meltingwire have to be melted by applying high temperatures directly, in form of electric power (resistance welding) or any other means (e.g. laser). All these techniques have their own difficulties if applied to very thin wires on massive substrates.

In any case the handling and positioning of the wire, tool and substrate is critical and has to be attended. Especially the latter problem is solved in a nearly perfect way when the bonding technique is applied.

3.4 Realization

To realize a defined heat capacity together with a sufficient current carrying capacity, highly conductive terminations should be used as a base for the connection of the melting wire.
The result of the ongoing investigations at Wickmann´s was a melting wire bonded to a massive copper substrate. These copper terminals have to be equipped with a sufficient surface cladding for the bonding of the wire.

The good conductivity and the substantial cross-section of the copper prevent additional heat generation due to the current flow even when higher rated currents are realized. The heat-conductivity and heat-capacity ensure a temperature that is always near room temperature. The solderability is easily achieved by cladding the outer part of the terminals with a standard tin-lead layer.

From chapter 2 it can be derived that the main advantage of the ball-wedge technology has to be paid by a loss of control at the second bond. If high current densities are applied on such a wire this heel-region (passage between the distorted and the untouched part of the wire) will be very critical. In this region thermocycles could cause additional mechanical stress owing to the thermal elongation of the wire material.

So wedge-wedge bonding **(Fig. 5)** is a much better choice particularly because the disadvantage (direction of the second bond is determined by the first one) is unimportant for an application in fuses as well. The realization of different amperages can be achieved by parallel bonded wires but there´s no need to place the second bond somewhere else.

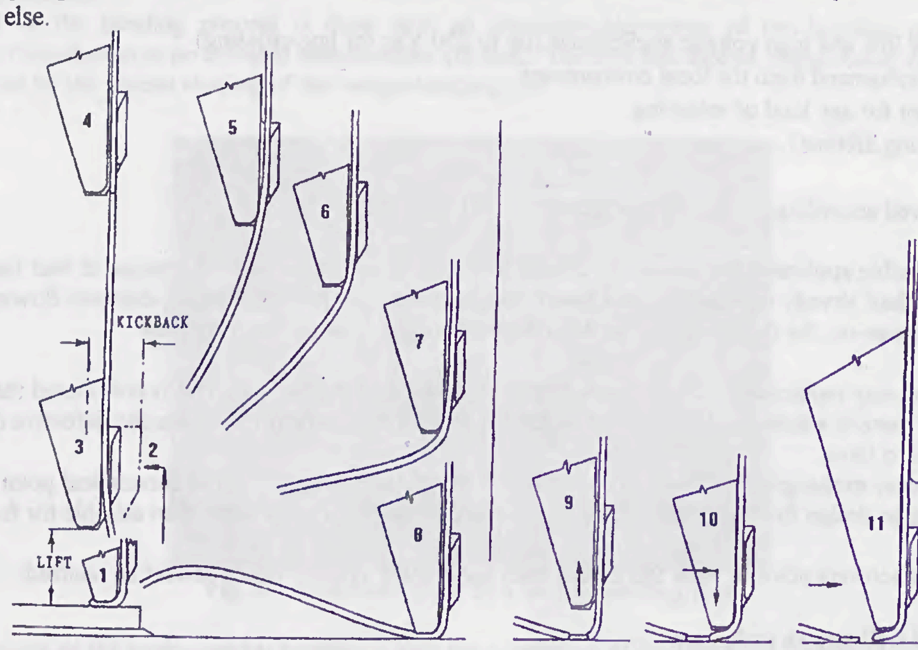


Fig. 5 Standard wedge-wedge-bonding process

But even in the wedge-wedge bonding technique attention has to be paid to the cracks in the heel-region.

In addition to the metal system for the bond connection two possible solutions were found concerning this topic:

1. re-enforcing the heel-area with a metal-compound
2. modification of the bonding parameters to optimize the heel-region without enforcement

Version 1 resulted in a two-compound wire (e.g. Ag-core with Al-cover) bonded on an Al-plated copper-substrate. During the production process of the wire special measures have to be taken to ensure that the contact between the meltingwire and the covermetal is achieved and stabilized.
After bonding (wedge-wedge) the heel-region is covered by a removable epoxy and in the next production step selectively etched with NaOH. If a sufficient ratio of the corewire to the covermetal is chosen, the conductive cross-section at the heel-region will be greater than the cross-section of the remaining core-wire **(Fig. 6)**. Heel cracks - when occuring in this mechanical and electrical reinforced area - will normally stop when reaching the different core material structure. So silver, one of the best-conductive rigid materials, is made available also to bonding-technique as a melting element for the fuse.

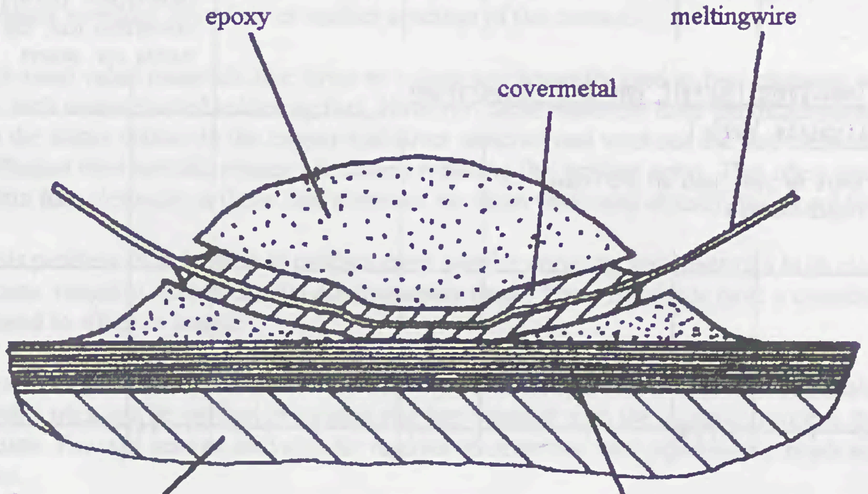


Fig. 6 Meltingwire after etching process

Version 2 realized a special doted Au-wire bonded to an Au-surface therefore being highly resistant to any kind of treatment like heat, humidity or even chemicals.
To keep the thin Au-cladding on the surface a nickel layer is implemented underneath. Aging of the wire itself is of cause not a problem. Gold being less conductive than silver makes it possible to realize lower rated-currents than silver at the same wire diameter.

Another advantage of gold is the smaller heat-conductance. So the hot spot in the center of the wire which is operating at a few hundred degrees Celsius under steady state conditions is thermally slightly isolated from the terminations. Consequently it is possible to realize real small sm-fuses without thermal problems for the outer temperature of the housing or terminations.

To check if an optimized set of bond-parameters is capable to address the problem of heel-cracks in a sufficient way some pulse load tests are carried out **(Fig. 7)**.
The pulse load is shaped rectangularly and applied with currents of approximately ten times the rated current. After a pulse 30 seconds pause will allow the wire to cool down to room temperature.
If more than 83% of the I^2t-value are loaded to the wire the melting temperature is reached and the material melts partially. Some deterioration of the outer shape results in the reduction of cross-section of the wire at some spots. Hence within one of the next pulses this reduced area will cause the fuse to operate.
But if the the I^2t-value is kept low enough not to heat up to the melting temperature, the mechanical stress does in no way influence the device. This can be seen in comparison with a soldered wire which suffers from the diffusion more and more with every pulse. If more than 1000 pulses are required in an application the load has to be kept below 60% of the I^2t-value.

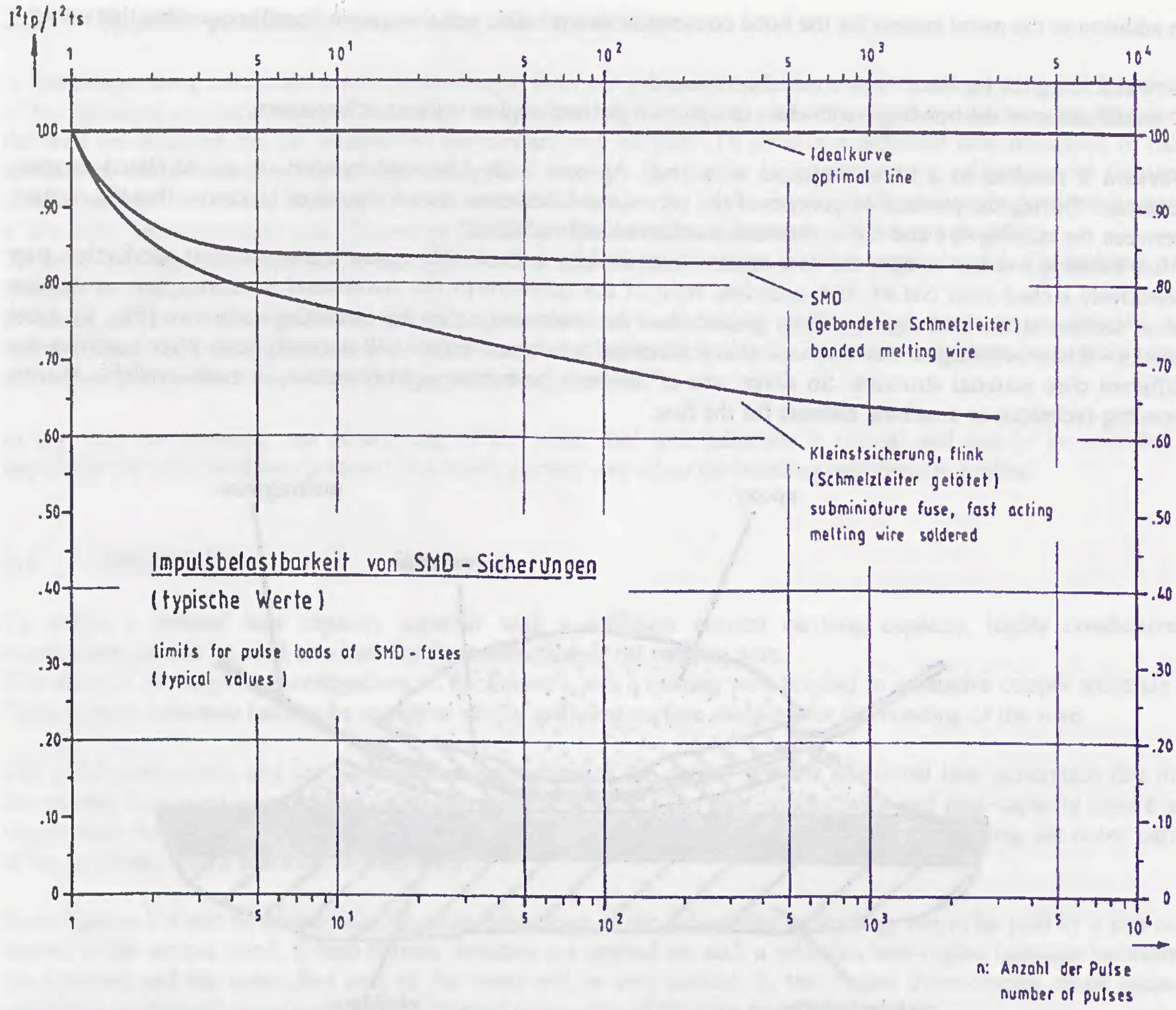


Fig. 7 Pulseload on different fusetypes

Both versions avoid all problems at the bond itself by using a monometal-system (Al-Al or Au-Au). The diffusion between the wire and the cladding of the substrate will not result in the deterioration but in the reinforcement of the connection.
High melting temperatures of the wire itself (approx. 1000° C) guarantee a really small influence of the ambient temperature on the switch-off-current.