International Rectifier

Application Note AN-1061

Bare Die:
Die Attach and Wire Bonding
Guidance for setting up assembly processes

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Note: This document does not claim to cover ALL aspects of the die attach and wire bonding processes. The aim of the document is solely to provide a general overview based on experiences with the supply and use of Bare Die Products.

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INTRODUCTION

The success of a finished product depends on the many key processes achieving their individual quality goals and targets. Of these individual processes, the conversion of a design from drawing and prototype into full production manufacturing is one of the most important. It is in this transition where;

- The practicalities of the design become reality
- The quality of the product is determined
- Product consistency is measured – fit, form and function (yield).
- The product cost is identified.

The time taken (and cost) for this transition, particularly for a new product, could be reduced by establishing the use of 'Best Practice' at each step of the manufacturing process. Many materials and equipment suppliers offer guidance and application notes that identify how to achieve good results and optimise equipment/ material performance.

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Note: that this document does not claim to cover ALL aspects of the die attach and wire bonding processes. The aim of the document is solely to provide a general overview based on experiences with the supply and use of Bare Die Products.

STORAGE & HANDLING.

Before attempting any die assembly, it is recommend that all components are thoroughly inspected. However well controlled the assembly processes may be, the quality of the final assembly is dependent on the condition of the components used, including the environment.

All parts must be scrupulously clean and free of all forms of contamination – oxides, grease, particles, etc - and reasonably smooth and flat. It is also advisable to store all parts in sealed bags (vacuum packed or nitrogen-back-filled), or in dry nitrogen cabinet until ready for use. (See Handling and Storage Application Note, AN1060).

When handling packages and die it is vitally important to use tools specifically designed for the purpose. In particular, the die is very easily damaged. Not only are they easily cracked and chipped, but they also have soft coatings that are very easy to scratch, particularly with metal tweezers. PTFE tipped vacuum pencils are recommended. Where metal and ceramic tipped tools are needed, for high temperature operations, these should be designed to contact only the edges, rather than top or bottom surfaces of the components.

Under no circumstances should parts be handled with bare hands. Even when wearing gloves or finger cots, it is still possible to transfer contaminants from other surfaces. Any area of skin, or any surface which may have come in contact with unprotected skin, will have a coating of natural oils in saline, which will both act as a barrier to the bonding process and produce a highly corrosive alkaline at high temperature.

Talc, which is widely used as a lubricant for gloves etc, is also a common contaminant. As are skin flakes, hair and fibres, silicon and aluminium dust particles.
It is therefore highly recommended that all die assembly operations be performed under lamellar flow or in an environment maintained at Class 1000, or better.

When using PCBs, the wrapping materials may contain an anti-oxidant coating, which will inhibit both the die attach and wire bonding. As will the flux used in the soldering operation, if not completely removed before further processing.

Poor handling of bare die, if undetected by visual inspections, may result in catastrophic failure such as shorts, opens or leakage, or may have latent effects, such as localised leakage or hot spots, which may only be revealed when the ambient temperature approaches datasheet maximum, resulting in the local hot spot being taken outside safe operating and into avalanche.

Note on ESD

Accidental electrostatic discharge can permanently damage any semiconductor. Some structures, such as FETs, are especially susceptible. The human body can carry in excess of 25,000 volts. We are not normally aware of this, apart from the occasional mild shock, when getting out of a car, or inserting a key in a lock on a frosty morning. In clean dry areas, with plastic seats, nylon coats, neoprene gloves and Perspex widows, this charge can build up in a few milliseconds. The biggest risk to the die is when it is resting on a large metal, or electrically earthed, surface and the simple way to avoid damage is to ensure that all operators, equipment, trays and other items of tooling are well earthed, before contact with the die is made. Half measures can often be worse than no measures at all. Possibly the two easiest ways to induce ESD damage are; someone, who is earthed, handing a finished part to some one who isn't; or an unearthed operator inserting a package into an earthed test socket.

SOLDERS & EUTECTICS.

A "solder" is a term generally applied to an alloy that is used to join together metals of higher melting point. The solder bond is in some ways analogous to an adhesive bond, in that the bond is formed by the intimate contact between the solder and the metal and not by fusion of materials (welding).

One commonly used solder being 60 Tin /40 Lead. Although Lead has a melting point of 327°C and Tin 232°C, the melting point of the mixed alloy is much lower than either of its constituents. In simple binary alloy systems, such as Lead/ Tin, one particular combination will form a unique structure, which will have a single melting point. The metallurgical term for such an alloy is "the eutectic", which for the Lead/ Tin system is 63 Tin/ 37 Lead.

In electronics packaging, the term "Eutectic die attach" originally referred to 97 Gold/ 3 Silicon, which forms naturally when pure Silicon is heated in contact with a clean Gold plated surface, i.e. the two elements mix together to form an alloy. This alloy has a eutectic melting point of 363°C and the resulting joint is very reliable, but not very flexible. So, its use tends to be limited to smaller die in ceramic packages.

For larger die, particularly those attached to Copper headers, other alloys can be used, provided that the die themselves that are suitably coated on the rear surface. Tri-metal backed devices (adhesion layer, plus Silver-coated Nickel), used by International Rectifier, can be attached with a wide range of alloys.

Some frequently used solders, along with their melting points are shown below. Where only one number is shown, this indicates a true eutectic.

Alloy	Melting Point (°C)
95 Lead/ 5 Tin	310 to 314
80 Gold/ 20 Tin	280
90 Lead/ 10 Tin	278 to 305
65Tin/ 25Silver/ 10 Antimony	228 to 395
96.5 Tin/ 3.5 Silver	221
60 Tin/ 40 Lead	183 to 188
63 Tin/ 37 Lead	183
80 Indium/ 15 Lead/5Silver	149
52 Indium/ 48 Tin	118

SOLDER DIE ATTACH

The first consideration, in selecting an appropriate alloy, is the melting point. Many silicon based die can be heated to about 400°C, for very short periods, without suffering any permanent ill effects. However, if the maximum storage temperature, as specified in the data-sheet is exceeded for any duration, the manufacturer will not be able to underwrite the performance, or reliability, of the die. International Rectifier datasheets for bare die products usually identify a maximum die attach temperature for optimum electrical results as 300°C.

The second consideration is the effects of thermal stress. All materials expand and contract when heated and cooled, the rate of expansion with respect to temperature being referred to as the CTE. Silicon has a comparatively low CTE (2 to 4 ppm/°C); Alumina ceramic has a CTE of 5 to 7 ppm/°C and Copper PCB around 17 ppm/°C.

A large silicon die will crack, if directly attached to a copper header, using gold-silicon eutectic. For this reason power transistors have a “Trimetal” backing, so that it can be soldered directly.

The safest approach is always to use the same processes and materials as used by the die supplier, International Rectifier, in the assembly of its die into discrete packaged parts. These processes and materials will have achieved acceptable reliability standards prior to release to production. Generally, most bare die products offered by International Rectifier have achieved six months maturity in packaged part format prior to release in bare die form.

When mounted in packages, the melting point, of the die attach material, has to be significantly higher than the reflow soldering temperature, of the final assembly. However, when using bare die directly onto the circuit board, particularly when using organic boards like FR4, FR5 and BT-Resin, the high temperature will damage the board itself. So lower temperature solders or adhesives are required.

It may be considered advantageous to mount the die at the same time as, or even after, the remaining components. Under no circumstances should die be mounted directly using solder paste, or flux be used to hold the die in place, during reflow. Even “no-clean” and “water-washable” fluxes can cause irreparable damage to the surface of the die. Also, trapped flux and solvent will produce voids under the die, which will impact both on contact resistance and the ability of the die to dissipate heat.

One of the most favoured approaches is to print paste on the die attach pads, reflow and thoroughly clean the board. Then mount the die in a clean inert atmosphere, such as nitrogen or forming gas (95 Nitrogen/ 5 Hydrogen).

EPOXY DIE ATTACH

The terms “epoxy” and “resin” are also used to describe other forms of adhesives, such as “Thermo-plastics”, “Polyimides” and “Ester-Cyanates”.

All of these materials contain a similar mix of substances;

- A filler material - such as
  - o silver or gold, for electrically conductive adhesives,
  - o or copper oxide or alumina, for non-conductive adhesives;
- A bonding agent, which attaches the die to the substrate;
- Various organic resins that keep the viscosity of the material constant then burn off at elevated temperature;
- A volatile solvent, which allows the material to be dispensed, or printed.

The main benefits of these materials are firstly, that the die can be directly placed in wet paste, since they do not contain potentially corrosive flux and secondly, that they do not need an inert atmosphere. Tri-metal backing is not needed for a mechanically reliable interface.

All adhesives have a limited shelf life and may require refrigerated storage. Some are also hygroscopic and will absorb moisture from the atmosphere, especially when cold. Other potential reliability problems can arise from resins bleeding out of the materials and migrating onto the wire bond pads on the substrate and die. These materials are not recommended for diodes, transistors and other devices that require reliable back face connections.

As with solders, selecting the right material and maintaining the correct thickness is the key to optimising reliability. Most epoxy materials are relatively hard, so far less tolerant to CTE-mismatch, than most solders. They generally require a thicker deposit than solder and the wet thickness may be twice that of the cured material. Film adhesives guarantee a controlled thickness, but need to be mechanically clamped, during curing.

Great care must be taken, when placing the die into wet paste. The die needs to be flat and level, with respect to the substrate.

Excessive downwards pressure may cause the die attach material to be forced out from under the die, reducing the spacing between die and substrate, or up the sides and onto the top surface of the die.

When drying and curing epoxies, a well ventilated oven is essential, since volatile materials can build and redeposit themselves on the surface of the components. Over heating is also a problem, since some materials can break down and release potentially harmful substances. These are particularly important considerations where the die may be soldered but other components on the board are attached with epoxy materials. Choosing the best build order for circuit board assembly becomes of prime importance where such a mixture of materials exists.

There is also a real risk of allergic reactions and irritation, to uncovered skin and eyes. So always observe the precautions, as stated in the manufacturers data-sheets and health and safety information.

DIE ATTACH INSPECTION

Generally the visual appearance of the die attach should conform to the requirements of MIL-STD-883, method 2010b, paragraph 3.2.3, except that, for solder attached devices, there will be no fillet.

Visual inspection alone cannot guarantee a reliable back face connection. So, some additional methods need to be employed, for process optimisation, equipment certification and incoming material acceptance.

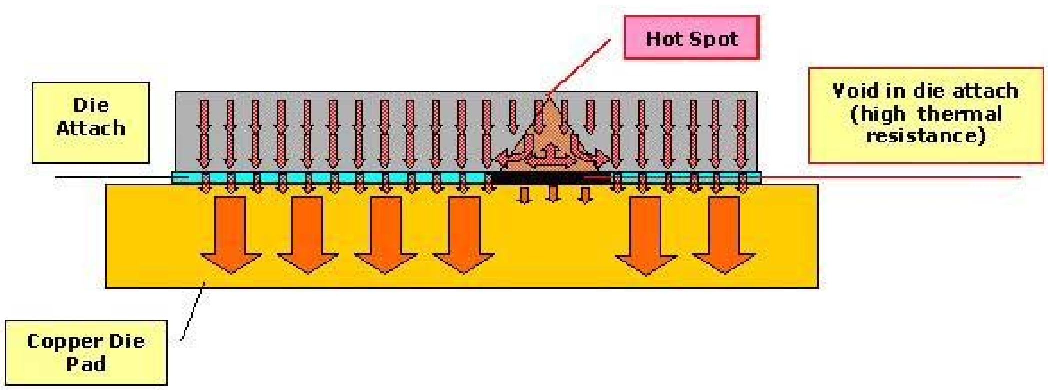
The most common is die shear testing (MIL-STD-883, method 2019). A flat tool, attached to a force gauge, is driven against the side of the die and the value required to detach the die recorded. A variation on this is the pull test, where a rod is glued onto the surface of the die and pulled upwards. Again the force required to induce failure is recorded. Both tests are destructive and hence are only used for initial evaluation of materials, SPC and final sampling. Where 100% non-destructive screening is required, constant acceleration, X-ray, ultra-sound scanning and thermal transient testing can be employed.
During constant acceleration testing (method 2001), the parts are placed in a centrifuge, with the reverse side of the die facing towards the centre. By spinning at high speed, the effective force on the die can be increased, to over 30,000 times greater than normally produced by gravity.

X-Ray (method 2012) and Ultrasound (method 2030) testing are both enhanced visual techniques, which enable the die attach material to be viewed through the die and substrate. These tests are particularly useful for identifying the presence of voids or delaminations in the die attach material.

Voids in the die attach can cause several problems during the normal operation of the device, such as:

- Disruption of heat flow from the operating junction leading to hot spots and thermally induced avalanche failure.

- Differential expansion and contraction during normal operation leading to mechanical damage such as micro-cracking in dielectrics or cracking of the bulk silicon.



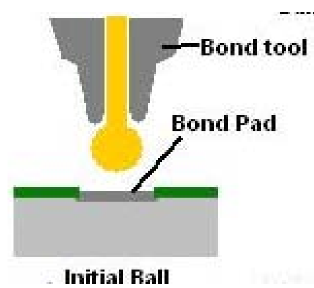
For single die, particularly transistors and diodes, the most useful non-destructive screening method is thermal transient testing, which can simultaneously test electrical, thermal and mechanical integrity. In this test, the device itself is used as both the means of applying a force and the means of monitoring its effect. The die first needs to be wire bonded to the package or substrate, so it can be connected to a power supply and meter or oscilloscope. Then, the forward resistance of a diode, or other suitable temperature sensitive parameter (TSP) is recorded over a range of temperatures. Finally, the device is powered up, in still air, at room temperature, and the TSP monitored during operation, which can then be directly related to the temperature on top of the device.
The best die attach process is characterised by the lowest stable values of electrical and thermal resistance.

The test can also be extended to include monitored power cycling, thermal shock, thermal cycling, high temperature storage and mechanical shock and vibration.

GOLD WIRE BONDING

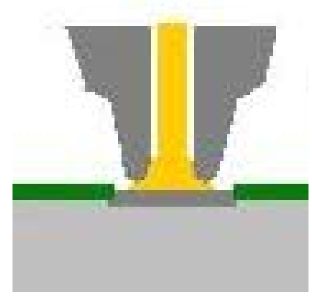
In applications where the current carrying requirement and hence heat generation is relatively low, gold wire may be used for connection to the aluminium bond pads.
The most common gold wire bonding method used in the assembly of die is 'thermo-sonic ball bonding', which uses an optimum balance of temperature, force and ultrasonic energy to produce reliable bonds.

The process starts with a fine wire being threaded through a hole, in the centre of a specially shaped capillary. The protruding wire is then heated with an electric spark (or a hydrogen flame), so that it rolls back to form a ball, which is larger than the bore of the capillary.



The ball, on the tip of the capillary, is then brought down onto the surface to be bonded, which has been preheated to the required temperature. Typically for thermo-sonic bonding this is between 100°C and 175°C.

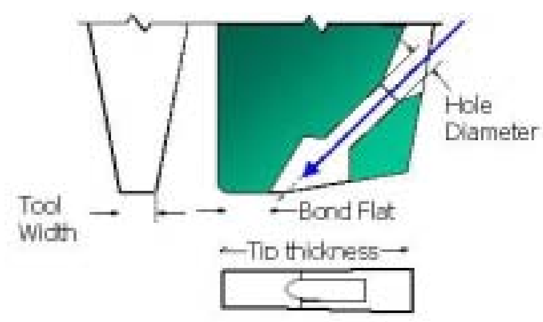
In the thermo-sonic bonding process, the capillary is agitated with ultrasonic energy as the bond is made. This is achieved by mounting the capillary in a transducer, which converts an alternating sinusoidal electrical signal into transverse motion. The frequency of the applied signal is adjusted such that it is close to the resonant frequency of the transducer, when in the unloaded condition.



If correctly "tuned", the system looses energy ("lugs down") when the bond adheres to the surface, due to the change in the effective length of the transducer, thus self limiting the bonding operation. If not correctly tuned the bonder may become super-sensitive to surface condition, on one hand, or continue to apply additional energy, which may then disrupt the bond or cause damage to the structures beneath the bonding pad.

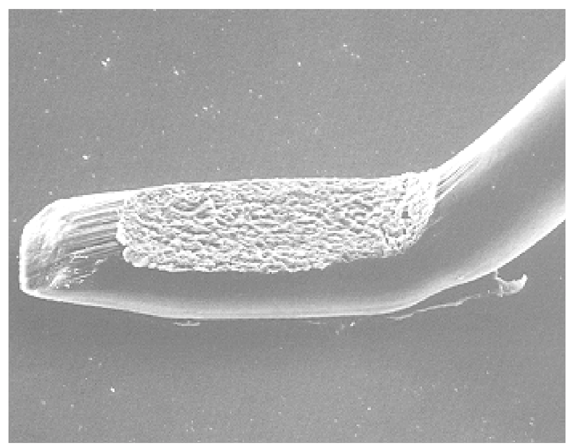
ALUMINIUM WIRE BONDING

For high power and high temperature operations, it is advisable to use aluminium wire. The most common method of wire bonding using aluminium wire is to use ultrasonic wedge bonding.



A tungsten "wedge" is fitted into an ultrasonic transducer. The wire is fed through a channel and under the front "foot", as shown by the arrow in the figure opposite. The ultrasonic energy then simultaneously bonds and flattens the front end of the wire. The wedge then rises and moves back along the length of wire to just above the second bond position. Clamps positioned further back along the wire then close, so the wire is bent as the wedge descends. After the second bond is formed, the wedge "steps back", breaking the wire and leaving a short length protruding from the front of the foot, so the whole process can be repeated.

A typical wedge bond is shown below. Aluminium wire bonds are usually made at room temperature, so the wire is still quite hard. There is also no lug down of the transducer, making the 1st bond time much more critical.



Excessive power, force or time will cause damage to the bond pad and under lying structures, particularly brittle barrier layers such as dielectrics, gate oxide and doped silicon.

SET-UP FOR ALUMINIUM WIRE BONDING

When setting up for aluminium bonding all three major variables may need to be simultaneously optimised. It is also advisable to perform functional testing, once the optimum conditions have been determined, to confirm that no structural damage has occurred.

Note on why IR cannot 'recommend' bonding parameters.

Room temperature aluminium wedge bonds are formed by the ultrasonic joining (welding) of the aluminium wire to the aluminium top surface of the die. For this to be a successful bond the three main parameters of the process need to be carefully optimised and balanced for each specific combination of equipment, materials, die and environment. Too much bond force may restrict the ultrasonic action to the point of mechanically damaging the die or even stall the generator, too little may limit the amount of intimate contact during the ultrasonic bonding cycle. Similarly, too little ultrasonic energy will limit bond formation.

Example of a set-up procedure:

1) Ensure that the ultrasonic generator is correctly tuned, as per manufacturers' instructions.
2) Initially the 1st bond force should be set to between 1.5 and 2.0cN for each micron of wire diameter, 1st bond time set to 50ms and the optimum power determined as follows:
   - i. Firmly clamp a clean aluminium plated surface onto the heat column
   - ii. Gradually increase the 1st Power until the bond just sticks
   - iii. Continue to increase the 1st Power until excessive deformation occurs
   - iv. Set the 1st Power half way between the two extremes
   - v. Replace the aluminium plated surface with a typical die
   - vi. Gradually decrease 1st power until bond no longer sticks
   - vii. Divide the range between iii and vi into 10 equal steps
   - viii. Make 10 bonds at each setting
   - ix. Pull test 5 bonds at each setting (Initial)
   - x. Bake for at 300°C for 4hrs (or 200°C for 24hrs).
   - xi. Repeat Pull Test (Aged)
   - xii. Set the 1st Power in the centre of the range defined by acceptable results
   - xiii. Reduce the 1st bond Time to 20ms and make 10 more bonds
   - xiv. Repeat Pull test.
3) With the 1st Power to the optimum value, determine the minimum (first- stick) and maximum (over deformation) values for 1st bond force.
4) With the 1st bond force set mid range, determine the minimum and maximum values for 1st bond time and then set the 1st bond time mid range.

Even with the machine set up correctly it may be necessary to fine-tune the 1st bond power, force or time, within the predetermined range, for certain device types. This can be 1)achieved using carefully designed experiments. Refer to 'DOE Guidance Note'.

Wire pull tests, as specified in Mil-Std-883, method 2011, test condition D is normally used to assess bond quality.

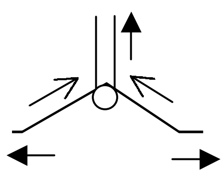
After bonding, a hook is inserted under the approximate centre of the wire and pulled in a direction normal to the die surface. When a failure occurs, both the force and failure mode are recorded. But, only the minimum force is used as criteria for acceptance.

Great care must be exercised in positioning the hook, during pull testing, to avoid misleading results. This test works best when both ends of the wire are at the same level. However, even then the length of the wire can significantly affect the readings. So, it has tended to become common practice to only accept wire break as an acceptable failure mode and only reject parts where bond failure occurs, irrespective of the recorded value.

INTERPRETING PULL TEST RESULTS

Consider the cases shown below. In all cases, assume that the breaking strength of the wire is 10cN.

Case 1.Wedge bond - same level –1mm wire - 30° wire angle.



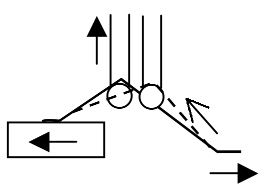
The vertical load is opposed by the wires, which are anchored at the substrate. The 30° forces in the wire resolve into vertical and horizontal components. But, only the vertical component is measured.

Maximum Force recorded will be;

F = 2 x 10Sin30° = 10cN

Note that as the loop height increases the reading will increase proportional to the Sin of the angle. So a flat wire of infinite length would give a reading close to zero and if both bonds were at the same location the reading could be as high as 20cN. The key element is that if the wire breaks, 10cN must have been applied between the hook and the bond on the side where the break took place.

Case 2.Wedge bond – 0.5mm step - 1mm length – 30° wire angle.



Only when the hook is located at the highest point of the loop will the reading be 10cN

Maximum Force recorded if hook is at centre is

F = 10Sin20° + 10Sin45° = 3.42 + 7.07 = 10.49

If the hook is placed in the centre of the wire, there is a much smaller angle at the die than at the substrate. Although there is no change in the wire or bonds the maximum reading will be 0.5cN greater. But, what is of greater concern is that, the forces are concentrated at the substrate, effectively reducing the force applied to the bond onto the die and making wire break on the substrate side more likely. Also both bonds may be weakened due to fatigue, at the heel of the bond.

In summary, the values recorded by the pull test, generally bear no relation to the quality of the bonding and are totally dependent on the position of the hook, the loop height and the length of the wire. The only relevant information is the failure mode, which, though recorded, is not used as acceptance criteria in the Mil standard test.

REFERENCES

- Mil Std 883E – a number of methods have been cross-referenced in this document. Mil Std 883E manual can be found on the web, for example at; www.dscc.dla.mil. This document remains one of the most widely recognised international standards for microelectronic and semiconductor product quality.
- JEDEC Document JESD 49 – Procurement Standard for Known Good Die (KGD). Available at the JEDEC website; www.jedec.org.
- International Electro-technical Standards, IEC 62258 – Semiconductor Die Products:
    - Part 1 - Requirements for Procurement and Use
    - Part 3 – Recommendations for Good Practice in Handling, Packing and Storage.

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