Beam Leads

The vast majority of chips are intended for connection with thermosonic bonds: all other methods require some modification to the wafer. As early as 1972, Jordan described three gang-bonding methods: spider-lead bonding, flip-chip bonding and beam lead bonding. Of these, it is the second which has attracted most continuous development, and is the subject of a separate topic note.

> **'Spider bonding', a precursor of TAB with all-metal tape**
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> The chip used in spider-bonding is of conventional fabrication, but the aluminium interconnecting leads are preformed as a frame stamped out of aluminium foil. Each chip is placed face down at the bonding station over the frame and positioned with the aid of a key on the edge of the chip. All the connections are then ultrasonically welded in one operation.
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> The outer part of the frame is cropped to leave just the leads, and the device then mounted face up on the substrate and the leads bonded to the substrate conductors, again in a single welding operation. The requirements for this technology are a high degree of accuracy, consistency in bonding pads, and a tool able to produce accurate multiple welds.
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> *Jordan 1972*

However, the process with greatest potential was perceived in the 1970s to be beam lead bonding. Here gold 'beams' protruding beyond the chip edges by about 150µm form an integral part of the device, which is mounted face down on the substrate. Welds to the beams provide both electrical and mechanical attachment. Although the processing of beam lead wafers is more expensive than for conventional devices, claimed advantages were:

- Significant improvement in potential reliability from the enhanced wafer passivation process
- Elimination of potential intermetallic problems associated with gold and aluminium, because gold is used instead of aluminium for device metallisation

- Elimination of cracking caused by scribing induced stresses, from separating the chips by back etching rather than scribing
- Improved production efficiency because the devices are gang-bonded, the beams are sufficiently broad to increase the tolerance on substrate-conductor positioning, the bonds are easily inspected, and defective chips can be replaced easily.

As with spider-bonding and TAB, one of the problems with beam lead bonding is the difficulty of generating the correct conditions for bonding each of the leads, so there is much to be said for doing this individually, a practice which negates some of the claimed advantages.

More significantly, the (real) improvements in reliability came not from the construction itself so much as from the need for beam lead processing to include a silicon nitride passivation layer. This approach was later adopted for conventional designs, which had the advantage of needing many fewer processes and a much narrower ‘street’ between dice. In consequence, beam leads are relatively little used, except in special applications such as beam lead microwave diodes.

Unpackaged beam lead diodes have extremely low parasitic capacitance and perform well at frequencies above 10GHz, as well as giving improved performance over their packaged counterparts at lower frequencies. Figure 1 shows a beam lead PIN diode with 15fF capacitance: the device is small, 0.7mm end to end, and mounting or bonding into the circuit requires care. A ‘strong beam’ has a typical pull strength of 10 gm. The diode construction is shown in Figure 2: unlike the usual planar configuration, the cathode is in the same plane as the anode rather than at the base of the chip. This eliminates the die attach process, and the beam lead device is normally bonded upside down.

Figure 1: Beam-lead microwave diode

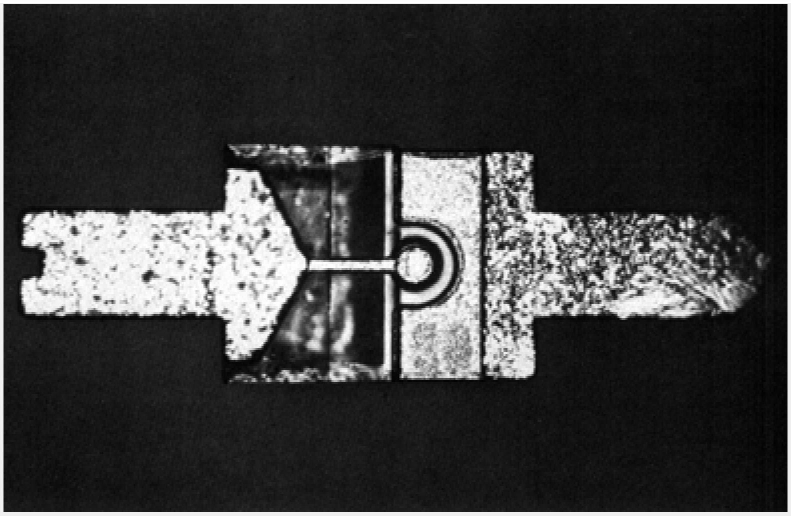
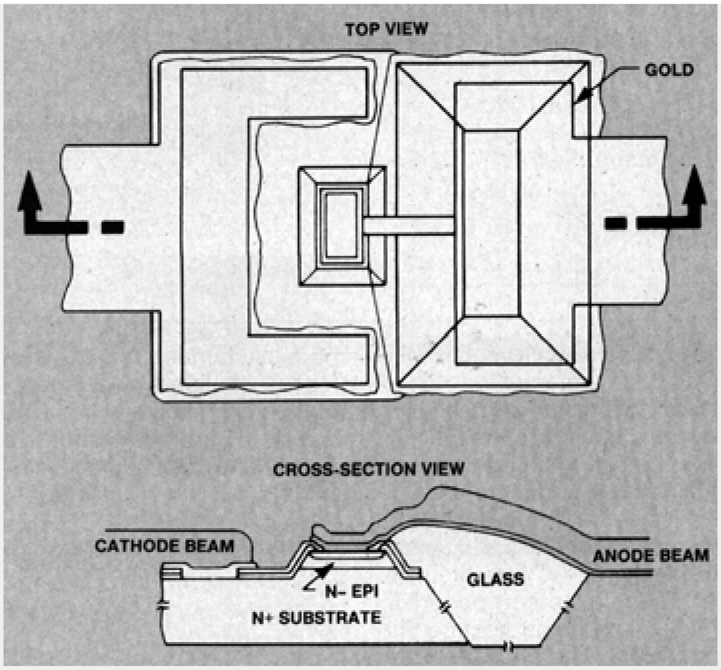


Figure 2: Plan and cross-section of beam-lead microwave diode



Three methods can be used for beam lead attachment:

- epoxy attachment
- thermocompression bonding
- resistance welding.

Epoxy bonding does not require high temperature or pressure and is suitable for all substrate types. Also the type of metal and finish of the conductor are not critical, and adequate bond strength can be achieved easily. However, epoxy bonding is less reliable, and temperature cycling over wide temperature extremes can weaken the bond.

Thermocompression bonding is carried out with a bonder similar in style to that used for gold wire ball bonding. Both stage and tool are heated, typical temperatures being stage 225ºC, tool 280ºC. A small (100x50µm) bonding wedge is fitted, with 15g per square .0001 inch applied for 500ms. The optimum parameters have to be established by experimentation, and vary considerably with the bond tool used: a flat bottomed tool is generally better than a concave one.

Because of the relatively high temperature and pressure required, thermocompression bonding is not suitable for soft substrates (such as the PTFE boards much favoured by microwave designers) as deformation may occur, putting excessive strain on the diode. Thermocompression bonding is also sensitive to the type of metals being bonded, and metallisations such copper, or gold less than 2µm thick, are more difficult to bond to than thick gold.

Variations on thermocompression bonding are:

- **Thermosonic bonding** uses ultrasonic energy to provide most of the bond energy, and thus requires less pressure. However, it is not recommended for beam lead devices encapsulated in glass envelopes, as the ultrasonic energy may cause cracking in the glass, affecting the reliability of the device.

- **Wobble bonding** (Figure 3). A process originally developed for beam leaded ICs, this bonds all leads simultaneously, using a tool offset by about 1º, which is wobbled around the device with sufficient force (about 250g) to bond the leads. This method has the advantage of being able to pick, place and bond the device in one operation, although careful adjustment of the bonder is required to ensure that no natural twisting force is applied to the lead.

- Wobble bonding has a number of variables, and Dawes found that wobble angles greater than 1º caused serious damage by cutting through some of the outer leads of the devices. Attempts to reduce the problem by radiusing the tool face were only partially successful.
- **Compliant bonding** (Figure 4) uses a soft tape as an interface between machine and component. Whilst this eliminates any need to make adjustments from batch to batch, it has the additional expense and complexity of handling the compliant member, and exerts considerable pressure on the substrate. For this reason, it has been less popular than wobble bonding. Figure 5 gives further background on this process.

Figure 3: Principle of wobble-bonding for a beam-lead device

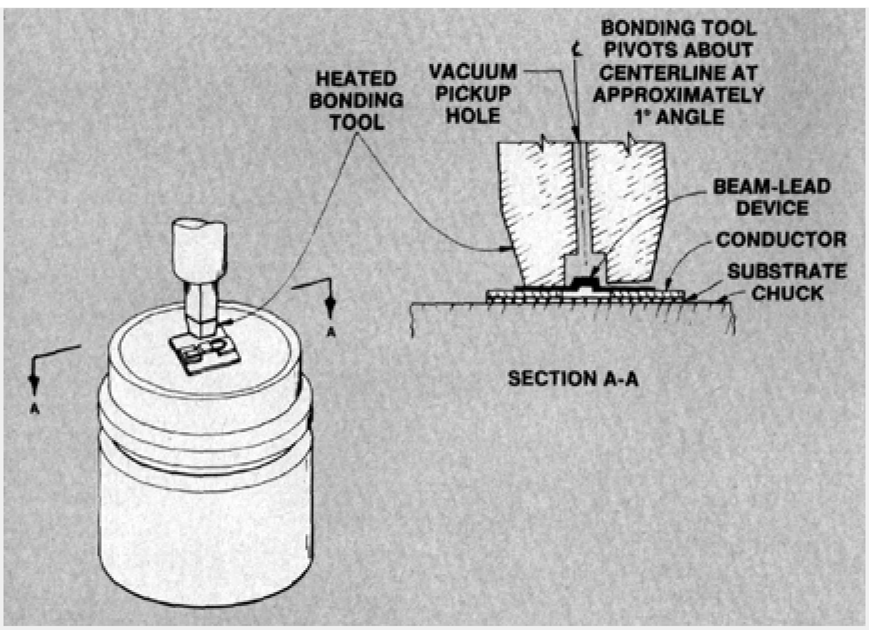
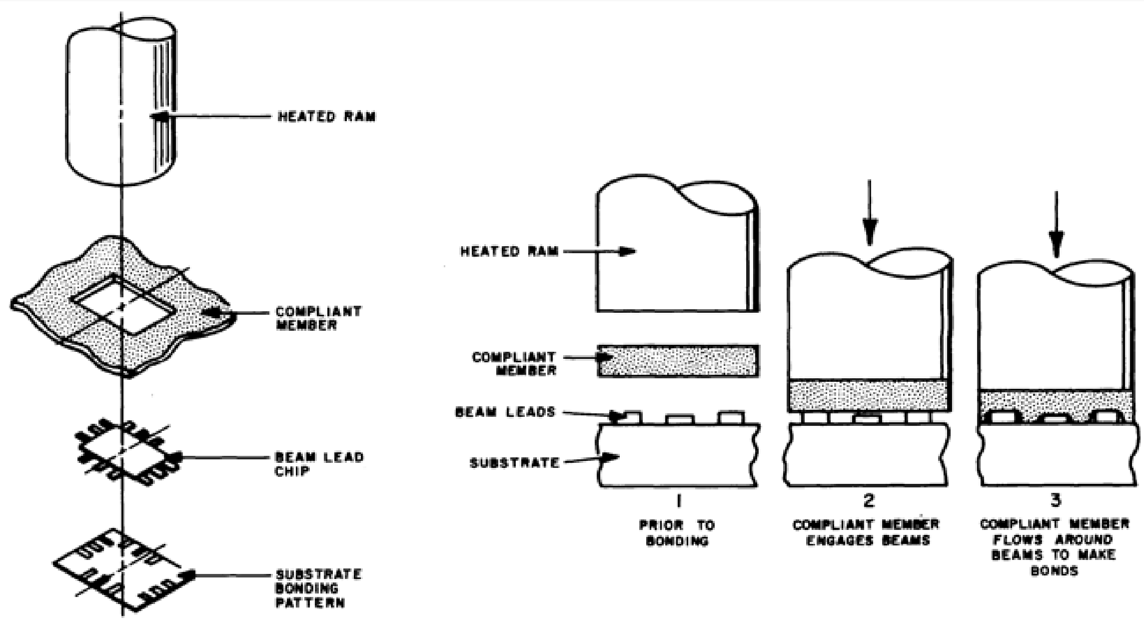


Figure 4: Principle of compliant beam-lead bonding



The compliant beam lead bonding process

Compliant bonding of beam leaded chips uses an intermediate or compliant member, usually of soft aluminium, between the bonding tool and the beams to be bonded. The function of this is to flow around or 'conform' to the beams of the chip in order to achieve a uniform bond with minimal controlled 'squash out' (deformation of the lead).

Since there is no 'neck down' or other major change in cross section of the bond, the compliant bond is inherently stronger than those made by other techniques. Also a flat heated ram can be used instead of a specific tool for each size of the chip to be bonded, since the thickness of the compliance member is greater than the thickness of the chip.

Compliant bonding has the additional advantage of being able to accommodate process variations in chip manufacture, both from metallurgical and dimensional standpoint. It accomplishes this by presenting a fresh tool face with each bond, and it is the flow stress property of the compliant member that becomes the controlling factor in transmitting pressure to the beam lead.

The material used is annealed aluminium foil which has relatively good thermal conductivity and builds up an oxide which will not stick to the gold during the bonding operation. The thickness of the compliant member must be greater than the silicon chip, but also thick enough to prevent lateral flow as it yields around beam leads, since this could cause distortion of the beam leads during bonding as well as some ‘sticking’ due to the rupturing of the oxide surface at the bond interfaces. A typical tape is manufactured from 125µm thick sheet which is slit into reels and punched to create both chip openings and holes for drive pins.

Whilst laboratory scale compliant bonding can be carried out using aluminium preforms, production equipment uses a continuous reel of aluminium, which is advanced so as to present a clean face for each operation, with the tape held flat against the tool face.

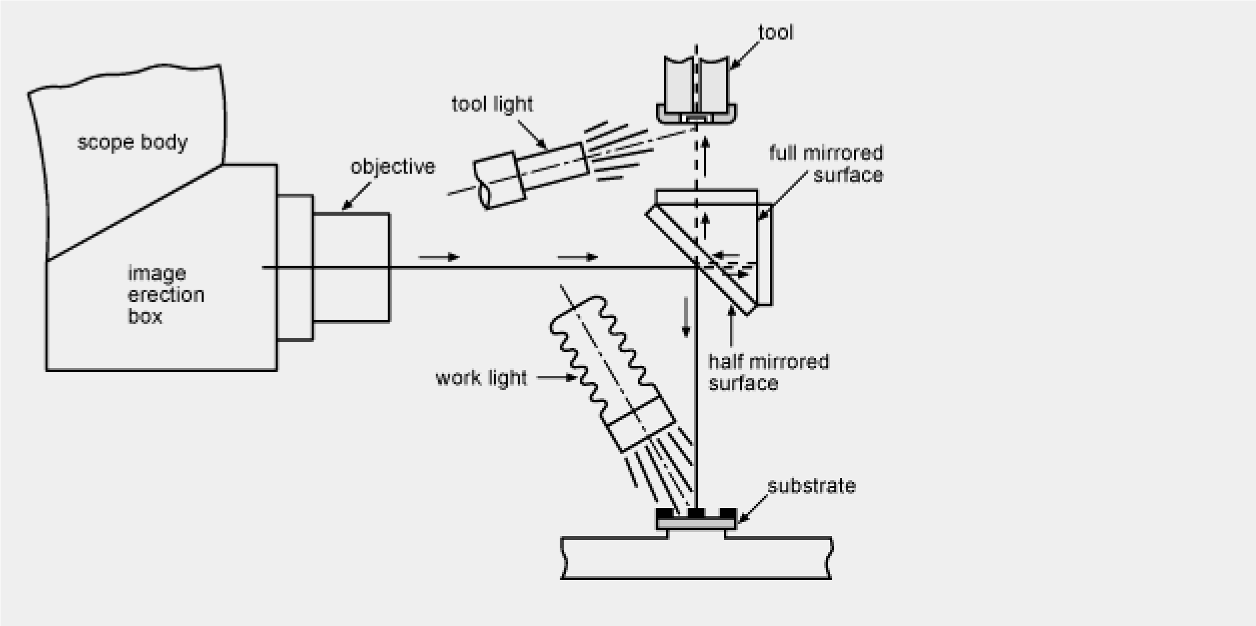
The yield stress for the aluminium compliant member at around 300ºC is approximately 5000psi. To allow for friction and lateral distortion on the load, a pressure of 15,000psi is applied through the compliant member to bond the leads, and a typical force setting is 20-30lbs for a device with up to 50 beam leads.

With compliant bonding, there is minimal deformation of the beam, and reduced squash out means that bugging or vertical movement of the chip due to inward extrusion of the beam material is never excessive.

With these high bonding forces, the work station has to be designed so that the devices are held down against the fixed ground work surface. Referencing on the base of the package may cause slight variations in the height of the bonding plane, and a vertical viewing optical system is therefore required.

Bycer 1970

Figure 5: Schematic cross-section of beam-lead bonder showing principle of 45º mirror for alignment (compliant bonder version)



All these processes are restricted to hard substrates, as the pressure required is sufficient to deform soft ones.

Resistance welding applies controlled heat and force, with the temperature generated by resistive heating. The term ‘welding’ is actually somewhat misleading, as the mechanism involved is really a thermocompression bond, formed by the diffusion of surface atoms from one metal to another. This provides a bond which is stronger than the beam leaded device itself, and the lower input energy results in lower stress than straight thermocompression.

There are three methods of resistance welding:

- In the **fixed gap** welding system shown in Figure 7, two electrodes are bonded together with an insulator between them. Current is passed through the beam lead from one electrode to the other.
- **Parallel step gap** welding is a modified form of fixed gap welding in which the electrodes can move vertically and independently, with one electrode placed on the beam lead and the other on the adjacent conductor. This allows current flow through the interface of the metals being bonded and reduces the restrictions on electrode size. The problem is the unequal distribution of force caused by the

difference in heights, and accurate preparation and levelling of the electrodes before bonding is essential.

- **Series welding** positions a single electrode on the beam lead and provides the current return path through a welding frame or probe positioned near the point of the weld, as shown in Figure 8. Care must be taken to ensure that the welding current does not flow through the diode junction.

Figure 7: Fixed gap welding of beam lead

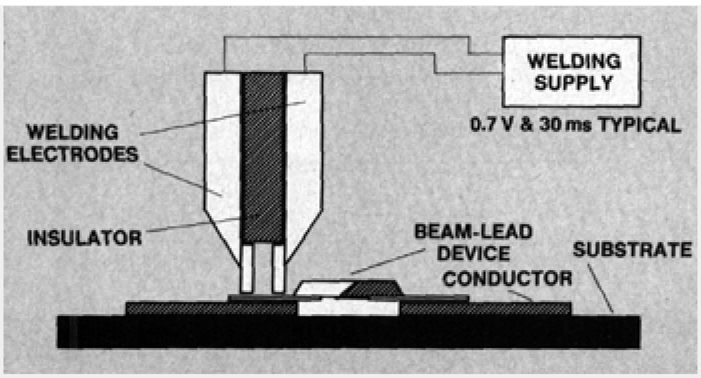
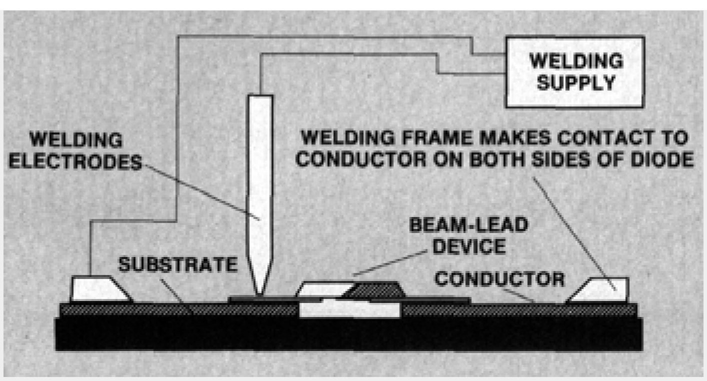


Figure 8: Single electrode series welding of beam lead

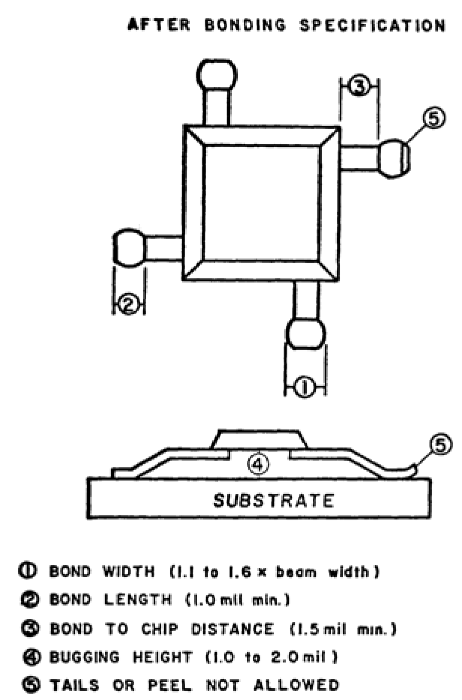


Of these three methods, the parallel gap method is the easiest to implement and the least sensitive to electrode size. Electrodes for fixed and parallel gap welding have a rectangular cross-section and should be high in conductivity and hardness and low in contact resistance. For beam lead diodes, tungsten, copper-tungsten or molybdenum electrodes are suggested, although for parallel step gap welding, the lower contact resistance of copper-tungsten helps compensate for the unequal force distribution on the electrodes.

For beam lead diodes, the optimum weld energy is 0.1–0.15J, and best results are obtained with pulse duration below 15ms, as this reduces energy loss due to thermal conduction. This is more serious on ceramic substrates or copper conductors because of the higher thermal conductivity of these materials.

In the process of bonding of beam lead devices, a certain amount of '**bugging**' occurs (Figure 9). This term refers to the chip lifting away from the substrate during the bonding process due to the deformation of the beam by the bonding tool. This effect is beneficial as it provides stress relief for the device during thermal cycling of the substrate. The coefficient of expansion of some substrate materials, especially softer polymeric boards, is such that some bugging is essential if the circuit is to operate over a wide temperature range.

Figure 9: Specification for beam lead bonding: shows width, length and bugging for bonds



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