



AEROSPACE INFORMATION REPORT

Society of Automotive Engineers, Inc.
TWO PENNSYLVANIA PLAZA, NEW YORK, N.Y. 10001

AIR 1141

Issued December 1971
Revised

REPORT ON FLIP CHIP AND BEAM LEAD BONDING FOR ELECTRONIC CIRCUITS

I. INTRODUCTION

Interconnect concepts for semiconductor devices continue to be a focus for development effort in the microelectronic industry. The motivation for this activity is the desire for greater economy and reliability in microelectronic devices. Conventional wire bonded interconnects have inherent limitations in these areas. The time consuming nature of the precise manual operations required in wire bonding is a serious hindrance to cost reduction efforts. Faulty wire interconnects have proven a common failure mode for microelectronic devices. The interconnect concepts evolved from the developmental effort have taken a variety of forms. Two prominent schemes are the Beam Lead and Flip Chip devices. The lion's share of the developmental funds are going into the development of these two concepts. Both have definite weaknesses and the search for other techniques is continuing. Significant of the latter are the "Spider" technique and the "Plastic-Structured Microelectronics".

The purpose of this investigation was to study the evolved interconnect schemes and evaluate them from the economic and reliability aspects.

The study was centered on the Beam Lead and Flip Chip approaches. The basic source of information was a literature survey. Samples of the Beam Lead devices were studied for supporting information. A prior study on the Flip Chip devices (Reference 1) was drawn upon for actual experience in these devices.

II. CONCLUSIONS

Both the Beam Lead and Flip Chip devices have inherent limitations which have prevented the achievement of the dual goals of economy and reliability.

The major restriction of the Beam Lead devices is that its fabrication requires many complex operations beyond that required for basic semiconductor devices. It also has a second limitation in that effective use of these devices requires special handling procedures in all phases of its assembly. The above restrictions are envisioned to nullify much of the economic advantages claimed for these devices.

From a theoretical basis the Beam Lead devices represent real reliability gains. These are represented by its integral passivating silicon nitride coating and its advanced interconnect metallization system. A proven reliability weakness is the handling difficulties encountered due to the low peel strength of the Beam Leads.

The many forms of Flip Chip devices do not generally allow generalizations which fit all types. A common generalization is that, in principle, the approach lends itself to major economic gains. The interconnect system can be fabricated with a small number of simple operations beyond that required for the basic semiconductor devices. The approach has features which make it very attractive to automation. The latter has led to experimental development of automatic machines for sorting and bonding chips. Users of this approach find considerable equipment and process development necessary to achieve the required reliability.

The Beam Lead approach has captured the interest of governmental agencies directing the development of important aerospace systems. This support is hastening the development of the approach into a fully developed interconnect technique for microelectronic devices.

SAE Technical Board rules provide that: "All technical reports, including standards, approved and practices recommended, are advisory only. Their use by anyone engaged in industry or trade is entirely voluntary. There is no agreement to adhere to any SAE standard or recommended practice, and no commitment to conform to or be guided by any technical report. In formulating and approving technical reports, the Board and its Committees will not investigate or consider patents which may apply to the subject matter. Prospective users of the report are responsible for protecting themselves against liability for infringement of patents."

III. PROCEDURE

Material for this study was gathered from three sources: First, a literature search of pertinent articles and reports in scientific journals and government publications was made. Second, manufacturers of face bonding transistor devices were contacted for details of availability, costs and technical information. Third, sample devices were analyzed for construction details, and possible weaknesses.

The material is presented in the following manner. First, a report of the developmental activities by the important elements of the microelectronic industry in new interconnect concepts is presented. Second, a comparison of the Beam Lead and Flip Chip devices is made based on cost, reliability, performance and availability. Finally, description of the known fabrication details for the Beam Lead and Flip Chip devices is presented in an Appendix. Included in the Appendix are the general fabrication concepts for the "Spider" and "Plastic Structured Microelectronic" techniques.

1. EVALUATION

1.1 General:

- 1.1.1 The high interest in the development in new interconnect concepts for microelectronic devices is emphasized by the high frequency of articles describing them in the technical journals. Unfortunately, the articles generally lack objectivity and are slanted to sell the concept to which the author and the manufacturer he represents is committed. Unbiased reports of worth on the new microelectronic interconnect developments are found in three articles (References 2, 3 and 4). These are comprehensive presentations of the developmental activity and its motivation as expressed by an important segment of the microelectronic industry.
- 1.1.2 The situation is very much in a state of flux. This, after 4 to 6 years of developmental effort for the Flip Chip and Beam Lead devices, does not speak well for either concept. Strong proponents for either concept are those committed and have strong economic motivations for their support. For the Beam Lead devices these include Bell Laboratories and their affiliate Western Electric Co., and Raytheon. For the Flip Chip devices, Hughes, Intersil, IBM, and Amelco. Of the above, IBM appears to be the only company successful in advancing the necessary technology to integrate a new interconnect concept into the production of electronic systems.
- 1.1.3 Most of the remaining segment of the semiconductor industry has invested in the Beam Lead and/or Flip Chip technology. Motorola is active in both and, significantly, has invested in a third interconnect concept—"Spider" bonding. Sprague Electric, Semiconductor Division, is reported to have followed a similar course. Texas Instruments has activities in both the Beam Lead and Flip Chip approaches. Sylvania, Nippon Electric Co., RCA, and Signetics have Beam Lead efforts. Fairchild, Union Carbide, General Instruments, Philco, Honeywell and Sperry Rand have invested in Flip Chip studies. Fairchild and Union Carbide have dropped Flip Chip devices from their product lines.
- 1.1.4 Of the potential users of the new interconnect concepts, Autonetics Division of North American Rockwell Co. has invested in extensive studies of both the Flip Chip and Beam Lead devices. These studies seem to have resulted in separate camps at Autonetics, with advocates for each concept. It is reported that Autonetics does not expect to have more than prototype activity in these areas within the near future. Aerojet General has made significant investments in the Flip Chip approach. Included in this investment is an expensive (reported at \$150,000) automatic machine for testing and bonding Flip Chip devices. However, in a current program in which Flip Chips were proposed during the design stages, they have dropped the Flip Chip approach in favor of conventional wire bonding techniques.
- 1.1.5 Much of the impetus for the current developmental effort in the Beam Lead approach is provided by the military, and this investment can be seen to be an important factor in future systems. The Safeguard (Sentinel) program is reported to be funding Beam Lead efforts at Western Electric, Motorola, and Texas Instruments. The commitments represented by the Safeguard program are far reaching. They indicate that the military procurer is strongly sold on the Beam Lead devices and that, unless there is a dramatic lack of performance by the concept, the demand for their application in future systems will be high.

- 1.1.6 Although the developments to date indicate that the concept may have serious shortcomings, the problems are not believed to be insurmountable. It is believed that a capability in applying the Beam Lead concept will be a definite factor in the capture rate of military contracts for future space systems.
- 1.1.7 The search for an economical and reliable interconnect scheme for microelectronic circuits is continuing. Neither the Beam Lead nor the Flip Chip concept has yet satisfactorily performed to these requirements. Motorola has concentrated on economy in its development of the "Spider" bonding concept, which is designed principally for adaptability to automation. The technique is undoubtedly directed toward commercial products and is not expected to be applicable to high reliability devices (See Appendix 4).
- 1.1.8 An interconnect technique developed by General Electric Company Applications and Devices Division, Syracuse, New York, is reported to have been given a security classification by the Commerce Department at the request of the Pentagon. Details of the technique, which were released prior to the reported security clamp, indicate that the technique has great flexibility and a wide range of application. It has economy potentials roughly equivalent to the Flip Chip approach; however, it is difficult to evaluate its potential in performance and reliability.

2. COMPARISON - FLIP CHIP TO BEAM LEAD

2.1 Cost:

- 2.1.1 The cost comparison, Flip Chip to Beam Lead, is definitely in favor of the Flip Chip device. In general, the Flip Chip circuit has a potential for substantial cost reductions over conventional wire bonded circuits. The Beam Lead technique entails higher costs in almost all phases of fabrication.
- 2.1.2 The additional processing necessary to convert conventional semiconductor devices into "bumped" Flip Chip devices are, in general, minimal in number and simple in execution. The cost for such additional processing is estimated to cause cost increases of 10 to 15% for the Flip Chip devices. To convert conventional semiconductor devices into Beam Lead devices on the other hand will roughly double the number of necessary major processing operations. Many of these additional operations are critical and will require precise controls as well as new technology. Cost increases for such processing will strongly be dependent on yields. A rough estimate on cost increases is 100 to 1000% that of conventional chips. Raytheon presently claims their Beam Lead prices are 50% greater than its conventional counterpart and that their aim is to reduce this to 20%. The cost for Beam Lead devices offered by different manufacturers varies considerably depending upon the unit quantity purchased and the packaging, among other factors.
- 2.1.3 The Flip Chip concept possesses greater potential for economy in testing, sorting and assembly. The design concept for the Flip Chip approach is directed toward automation. The devices are of sufficient ruggedness to give them good resistance to mechanical damage and are readily adaptable to handling by mechanical equipment. The raised electrical interconnect bumps facilitate automatic electrical testing of the semiconductor device at the chip level where they can be effectively sorted according to their electrical characteristics. The raised interconnect contacts also permits simultaneous bonding of the necessary interconnects for a device.
- 2.1.4 The initial goal for the Beam Lead concept was to automate as much as possible. However, the fragile nature of the beamed interconnects has presented serious obstruction to these attempts. In fact the need to protect the interconnects from mechanical damage has necessitated the incorporation of rather elaborate protective handling procedures in the processing of these devices. It is anticipated that significant cost additions will incur as a result of the increased handling time and from breakage losses due to the susceptibility of the beamed leads to damage. A major selling point for the beamed lead concept is the incorporation of an integral protective seal for environmental protection. This feature eliminates the necessity for providing hermetic packages for the devices and allows substantial cost savings. However, the advantageous application of these devices is visualized to be in hybrid microcircuits with other microelectronic components. In such applications the integral protective seal of the Beam Lead device loses some of its advantage because the other components generally will require the environmental protection of a hermetic package.

2.2 Reliability:

- 2.2.1 Evaluation of the factors affecting reliability favor the Beam Lead device. The interest of the military in Beam Lead devices can be directly attributed to this fact. The innovation of the more stable metal system for the interconnect network in Beam Lead devices is widely accepted as a step towards greater reliability. Improved environmental protection is expected from the addition of the silicon nitride layer to the passivation scheme in Beam Lead devices. The above are real reliability factors affecting the performance of semiconductor devices. The weaknesses of the less stable aluminum metallization used to provide interconnects in conventional devices are known; intermetallic formation resulting in "purple plague" and diffusion resulting in "disappearing metallization" are common symptoms.
- 2.2.2 It is not expected that the platinum silicide—titanium—platinum—gold metallization system of the Beam Lead device to be completely free of metallurgical instabilities affecting the performance of the semiconductor devices. To the contrary, it can be expected that the new system will have its own set of failure modes; however, their frequency will hopefully and very likely be much less frequent. A reported failure mode for the above system is the diffusion of gold into the active area of the transistor due to breaks in the platinum diffusion barrier due to improper processing.
- 2.2.3 The silicon nitride provides a more effective barrier to trace impurities of ubiquitous alkali metal ions than conventional silicon oxide passivation layers. The reduced migration of alkali ions to the semiconductor surface effectively reduces performance degradation resulting from the accumulation of electrical potentials at the silicon dioxide-silicon interface.
- 2.2.4 The ready direct access of the gold beam leads to the agent affecting the bond allows greater bonding efficiency when compared to the indirect techniques which are required for Flip Chip devices. The interconnect bonding is further facilitated by the use of gold to gold interconnects. The exceptional bondability of gold to the low temperature bonding processes required in microelectronic circuits make it an ideal interconnect material. Another advantage of the accessibility aspect of the beamed lead device is that the bonds can be visually inspected. A great deal of comment is made of the latter; however, it is very difficult to judge the quality of a bond from visual criteria and the value of this advantage is overestimated.
- 2.2.5 On the negative side, the characteristic of the beamed structure causes an inherent weakness in these devices. It is the belief of the writer that the dominant failure mode for these devices will be the peeling of the gold beams from the surface of the semiconductor. The reasons for this are:
- a) The nature of the beamed structure maximized stresses imposed on it at its point of attachment.
 - b) Loads tending to peel the lead will further be concentrated by the natural stress riser at the metallization to silicon dioxide interface at the edge of the chip.
 - c) Regardless of processing, the adhesive strength of a metal system to a silicon dioxide surface is an estimated order of magnitude less than the cohesive strength of a metal system.

This is reflected in the mechanical strength properties of Beam Leads listed in Table I. It is for the above reasons that special handling procedures are required for the Beam Lead devices during the assembly and related operations. It is easily conceivable that much of this type of damage will go undetected due to their microscopic nature. Such defects can be an important reliability factor in installation where hermetic packages are not employed.

- 2.2.6 A reported failure mode related to the above is that the Beam Lead device is subject to shorting between the beam leads and the body of the chip. This shorting apparently occurs where the beam extends over the edge of the chip. Since the leads are separated from the silicon only by the thicknesses of the silicon oxide and silicon nitride passivation layers at this point, an order of 10,000 to 20,000Å thick, the failure mode could easily be either by deformations in the beam lead which bridge this gap and/or by cracks occurring in the passivation layers.

TABLE I

Mechanical Strength Characteristic of Typical Beam Leads*

Test Mode	Average Strength Grams
Peel Strength	2 to 3
Buckling Strength at Room Temperature	7 to 9
Buckling Strength at 350 C	1 to 2
Shear Strength	32 to 38
Tensile Strength	10 to 12

* Reference 5

- 2.2.6.1 The danger of electrical shorts resulting from deformation of the relatively thick, soft, plated gold metallization of the interconnect pattern is very real in these devices. The effect of inadvertent scratches and damaging of the metallization of these devices will be accentuated. The thicker metallizations of these devices can also be expected to present cavities which will trap foreign particles and make cleaning difficult. These problems have been masked in conventional devices by the very thin nature of the thin film interconnect metallization.
- 2.2.7 The intimate nature of the active face of the bonded Beam Lead device to the surface of the substrate is expected to create surface contamination problems. The narrowness of this gap will cause it to act as a capillary, and entrapped foreign particles and chemical residues will be difficult to remove. Although it is difficult to conceive of any significant chemical attack on the stable metallization system of the Beam Lead devices, the entrapped particles and chemical residues could create paths for stray currents and degrade the performance of the semiconductor devices.
- 2.2.8 The Flip Chip approach has not yet achieved widespread application because many users have not been able to control ultrasonic bonding techniques for these devices to an acceptable level of reliability. The cost saving potential of the Flip Chip approach is intimately linked to the ultrasonic bonding technique, for many applications where the other bonding methods available for bonding these devices - thermocompression bonding and solder reflow techniques - are not feasible. The success of IBM in developing a usable solder reflow process has not gained converts in significant numbers because the technique does not appear to have broad economic advantages.
- 2.2.8.1 The ultrasonic bonding of Flip Chip devices has proven to require considerable attention. Reproducibility of bond strength is difficult to achieve even under laboratory conditions. It is believed that the main fault lies in the bonding equipment. The problem is complicated by the fact that, although there are at least a half dozen manufacturers of ultrasonic flip chip bonders, most use a common source for the ultrasonic power supply, the electromechanical transducer and bonding head. Design of these components may not yet be refined enough to achieve the consistency required for production flip chip bonding.

- 2.2.9 The major objection generally voiced of the Flip Chip approach is that the interconnect bonds are not visually inspectable. The writer agrees with the proponents of the Flip Chip device that this is a minor disadvantage. Although it is emotionally reassuring to be able to see the bond, from the practical point of view it is very difficult to make an accurate evaluation of the quality of a bond without conducting a physical or mechanical test.
- 2.2.10 A general comment applicable to all types of Flip Chip devices is that their interconnect metallization systems are less stable than that used in the Beam Lead devices. The performance limits of flip chips with aluminum bumps are readily predictable; however, the performance limits of the silver-tin metallization used in the Hughes Flip Chip and the solder system used by IBM are not known. It is possible that these devices have failure modes attributable to the metallization system used, and that such modes will be induced by conditions significantly milder than that required to cause failures, resulting from metallization system instabilities, in Beam Lead devices.
- 2.2.10.1 There are a number of possible failure modes in the Flip Chip devices related to the ultrasonic bonding operation. It is not uncommon to see chipping occur along the edges of the chips during bonding if a collet type bonding tool is used. Although cracking of the chips themselves have not been observed, the indirect transmission of the ultrasonic energy through the chip to the interconnect bonds is considered by some to be a rather harsh treatment for the semiconductor device. The ultrasonic bonding operation can also cause extensive deformation of the interconnect bumps if not properly controlled. In some instances the degree of deformation was such that the danger of shorts in the interconnects was evident. In the Hughes device, the application of high ultrasonic energy tended to delaminate the tin coating from the silver bumps thus presenting the possibility for loose conductive particles in a critical area.
- 2.2.11 Flip Chip devices do not, however, present a handling problem. They are of comparable ruggedness with conventional devices and have no special failure mode attributable to handling. However, care should be exercised in probing such devices. Deformation in the interconnects can be extensive from careless electrical probing. Such deformation can cause difficulties in subsequent bonding operations.
- 2.2.12 The face bonded design presents a cleaning problem in flip chips similar to that predicted for the Beam Lead device. The magnitude of the problem is less with the Flip Chip device since they stand off the substrate by a finite height; however, the small gap between the active face of the device and the substrate may present a contamination control problem unless a suitable chip passivation or a hermetic package is used.
- 2.2.13 Although the problem of heat dissipation is not stressed in the literature, both the Beam Lead and the Flip Chip devices appear to have significant limitations in this area. Table II is a tabulation of the direct paths available to thermal conduction in typical face bonded devices. It shows that the cross-sectional area of direct paths for thermal conduction in these devices are greatly reduced from that available in conventionally die bonded devices. In the Flip Chip device the decrease is roughly an order of magnitude, in the Beam Lead device the decrease may approach two orders of magnitude. It is apparent that effective alternate means for heat dissipation are required for these devices to maintain operating temperatures within a safe range.

2.3 Performance:

- 2.3.1 There is much discussion in the literature of the benefits of the two approaches on the electrical performances of microelectronics circuits. The short lead lengths made possible by these techniques are seen to significantly reduce lead impedances and improve high frequency performance. Test data generally do not accompany these claims and it is difficult to make an evaluation of this aspect. The Flip Chip approach appears to have a slight advantage in this respect in that they allow shorter lead lengths. However, since impedances result from the combined effects of resistance, inductance, and capacitance a simple evaluation based on lead lengths is not valid. Both the Flip Chip and Beam Lead concepts are attractive in high frequency applications where short and controlled lead lengths are important features.

TABLE II
Data Pertinent to Heat Dissipation Aspect of Face Bonded Devices

Device Type	Vendor	Dice Size, Inches	Interconnect Size, Inches	No. of Interconnects	Interconnect Material	Interconnect Length Inches	Dice Area Square Inches	Interconnect Cross Sectional Area Square Inches
Flip Chip	Hughes	0.032X0.032X0.008	0.007 Diameter	4	Silver with Tin Coating	0.0025 ⁽¹⁾	0.0010	0.00015 ⁽²⁾
Flip Chip	Amelco	0.028X0.028X0.006	0.005 Diameter	4	Aluminum	0.00075 ⁽¹⁾	0.00078	0.000078 ⁽²⁾
Beam Lead	NEC	0.018X0.022X.003 ⁽³⁾	0.007X.0005 ⁽⁴⁾	4	Gold	.005 ⁽⁵⁾	0.00040	0.000014
Beam Lead	Raytheon	0.015X0.020X0.006 ⁽³⁾	0.0035X0.0005 ⁽⁴⁾	3	Gold	.005 ⁽⁵⁾	0.00030	0.0000052

- (1) Average height prior to bonding.
 (2) Based on prebonded interconnect diameter.
 (3) Dimensions were made by indirect means.
 (4) Beam thickness is an arbitrary value.
 (5) Estimated value.