Haverford College
Haverford Scholarship

Faculty Publications Chemistry

1989

Tape automated bonding inner lead bonding with a laser for high performance applications

Phillip J. Spletter

Claire T. Galanakis

Neik Luijtjes

Colin MacKay
Haverford College

Follow this and additional works at: http://scholarship.haverford.edu/chemistry_facpubs

Repository Citation
Spletter, Phillip J., et al. "Tape automated bonding inner lead bonding with a laser for high performance applications." Journal of Vacuum Science & Technology B: Microelectronics and Nanometer Structures 7.6 (1989): 1967-1970.

This Journal Article is brought to you for free and open access by the Chemistry at Haverford Scholarship. It has been accepted for inclusion in Faculty Publications by an authorized administrator of Haverford Scholarship. For more information, please contact nmedeiro@haverford.edu.

JOURNAL OF VACUUM SCIENCE AND TECHNOLOGY B

Tape automated bonding inner lead bonding with a laser for high performance applications

Phillip J. Spletter, Claire T. Galanakis, Neik Luijtjes, Colin MacKay, Yong Jee et al.

Citation: J. Vac. Sci. Technol. B **7**, 1967 (1989); doi: 10.1116/1.584658
View online: http://dx.doi.org/10.1116/1.584658
View Table of Contents: http://avspublications.org/resource/1/JVTBD9/v7/i6
Published by the AVS: Science & Technology of Materials, Interfaces, and Processing

Additional information on J. Vac. Sci. Technol. B

Journal Homepage: http://avspublications.org/jvstb
Journal Information: http://avspublications.org/jvstb/about/about_the_journal
Top downloads: http://avspublications.org/jvstb/top_20_most_downloaded
Information for Authors: http://avspublications.org/jvstb/authors/information_for_contributors

ADVERTISEMENT

Downloaded 29 Apr 2013 to 128.180.77.165. Redistribution subject to AVS license or copyright; see http://avspublications.org/jvstb/about/rights_and_permissions

Tape automated bonding inner lead bonding with a laser for high performance applications

Phillip J. Spletter, Claire T. Galanakis, Neik Luijtjes, Colin MacKay, Yong Jee and Ollie C. Woodard
Microelectronics and Computer Technology Corporation (MCC), Austin, Texas 78727

(Received 31 May 1989; accepted 24 July 1989)

Since 1985, MCC has been developing the use of flashlamp pulsed Nd:YAG (YAG) laser technology to bond tape automated bonding (TAB) leads to I/O pads on integrated circuits (ICs). The I/O pads have 22 micron high gold bumps and the leads are copper plated, in the case described here, with electroless tin. As a result of the work presented here, a methodology has been developed that will result in a high throughput, reliable bonding process that overcomes the limitations of conventional thermocompression (T/C) and thermosonic (T/S) bonding technologies. In addition, because the position of the laser beam is software controlled, the process is very desirable for applications where a broad range of different IC form factors and sizes are to be bonded. Laser bonded devices have been exposed to degrading environments without failure, indicating the long term reliability of the process.

I. BACKGROUND

Laser inner lead bonding was developed because of the recognized need for a benign bonding technology that was fast enough (100 + bonds/s) to be used in a production environment and could bond small leads (< 50 microns) on close pitches (< 100 microns) without damaging the underlying substrate or semiconductor structures. Figure 1 shows a detailed drawing of the structure used for bonding development.

Today, tape automated bonding (TAB) leads are all bonded with either thermocompression (T/C) or thermosonic (T/C) bonding techniques, both of which are mature and reliable methods. T/C bonding uses heat (up to 500 °C) and pressure (up to 15 000 psi).[1] With T/C bonding, either all of the leads are bonded simultaneously (gang) or individually (single point). T/S is another method of single-point bonding that uses heat, pressure and ultrasonic energy. Both of these bonding technologies have limitations. T/C gang bonding is commonly optimized for one specific integrated circuit (IC) type, and to change to different sized parts requires a different set of tooling which is time consuming to replace and reoptimize. This limitation can be overcome on many ICs by using single point bonding which moves a mechanical bond tip to the appropriate location where bonding occurs. However, on many future ICs, the high number of I/O will require that the I/O pads be spaced so close that they will interfere with the bond tip when adjacent leads are bonded.

A laser beam, with a precisely controlled amount of energy that is very small in diameter, and no mechanical components in the bond site, is ideal for bonding leads on close pitches. In addition, since its position and the laser parameters can be controlled by a computer, a broad range of different part types can be bonded without time consuming tooling changeovers.

II. LASER SELECTION

Several laser technologies including CO_2, CW YAG, Q-switched YAG, and pulsed YAG were chosen for initial experiments because they are mature technologies that are proven in production environments.

CO_2 was quickly excluded because radiation at that wavelength (10.6 microns) is reflected by the metals of interest such as copper, gold, and tin. This reflectivity is traditionally overcome by coating the metals to be joined with an organic material such as flux to absorb the energy and transfer the heat via thermal conduction.[2] The use of additional coatings that must be removed after bonding is very undesirable, particularly on devices that have close pitches which make thor-

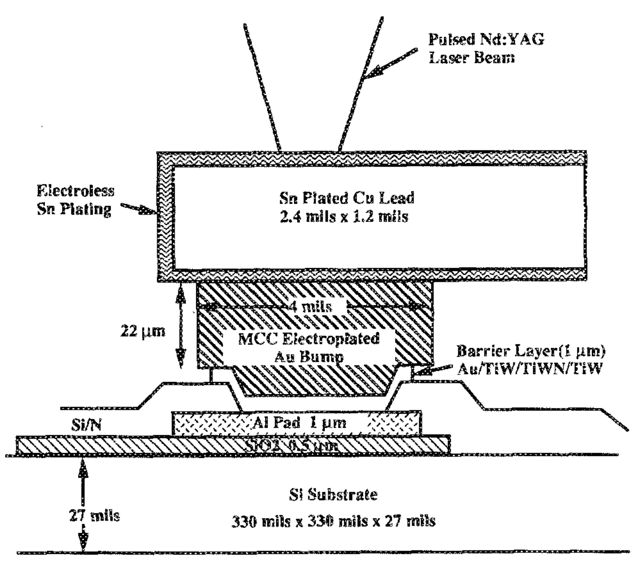

FIG. 1. Cross section of bond structure used for laser bonding development.

 © 1989 American Vacuum Society

Downloaded 29 Apr 2013 to 128.180.77.165. Redistribution subject to AVS license or copyright; see http://avspublications.org/jvstb/about/rights_and_permissions

ough cleaning extremely difficult. Failure to clean residual organics can degrade the reliability of the circuit.

Nd:YAG lasers emit radiation with a fundamental wavelength of 1.06 microns. Copper and gold do not absorb much energy at that wavelength (1.4% and 1.5%, respectively),[3] whereas tin absorbs 53.6%.[4] Thus, for this application, YAG lasers seemed the most appropriate.

Q-switched YAG lasers have high peak power for short periods of time (kilowatts for nanoseconds). As such, they can easily ablate material so they are often used for cutting and drilling and are not satisfactory for bonding.

CW YAG lasers have constant power output for the duration of the pulse. However, experiments showed the energy could not be controlled well enough to prevent damage to the IC surrounding the bond site. When enough power was applied to initiate melting, the pulse could not be terminated fast enough so that heat was continuously applied to the bond site. Sufficient heat was conducted to the structures adjacent to the bond site to damage the chip.

Flashlamp pulsed YAG proved to be the most satisfactory laser technology for this application. With this technology, the pulse width can be short enough to allow melting without damaging the surrounding IC. In addition, with the exponential rise and fall of the pulse that is characteristic to flashlamp pulsed lasers, the power is distributed in a fashion that is most suitable for bonding.

YAG lasers can also be frequency doubled to get a wavelength that is more readily absorbed by the metals of interest, especially gold and copper. However, the conversion efficencies of the doubling crystals are so low that the laser must be Q-switched to get enough power, but as is the case at the fundamental wavelength, the pulse width is too short to be useful for bonding. With frequency doubled CW lasers, the output power is too low to be useful and the pulse width is too long. Frequency doubling of flashlamp pulsed YAG lasers has not been reduced to practice as of yet so the technology was not considered for this application.

As a result, because of their availability and/or absorption and metallurgical characteristics, the optimal combination of materials and laser technology for this application is bonding tin plated copper leads to gold bumps with a flashlamp pulsed Nd:YAG laser. This combination produces consistent reliable bonds by taking advantage of the localized, concentrated energy of the laser beam and the absorption and bonding properties of tin in conjunction with copper and gold. Photographs of typical bonds and a typical cross section are shown in Figs. 2 and 3, respectively.

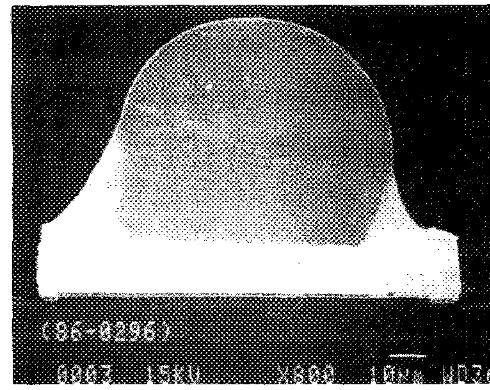

FIG. 3. Cross section of tin plated copper lead bonded to a gold bump with pulsed Nd:YAG laser.

The laser that was used for bonding development was a 50 W avg. power pulsed YAG from Carl Haas GmbH & Co in Schramberg, West Germany. It was fitted to a model 44 laser trimmer with linear motor beam positioning from Electro Scientific Industries in Portland, Oregon.

III. BONDING PHENOMENA

A cross section of a bond that shows the localized heating unique to laser bonding is shown in Fig. 4. This sample, which has been preferentially etched to highlight the grain structure of the copper, shows three distinct regions of temperature distribution in the bond. It should be noted that the copper lead was formed by electrodepositing (ED) copper. In the as-deposited state, ED copper has a very distinct grain structure. The top region, marked "A", contains copper that has been completely melted as evidenced by the lack of any grain structure. The middle region, marked "B", was heated

FIG. 2. SEM photograph of typical laser bonds (note localized bond zone and lack of melting on gold bump away from the bond interface).

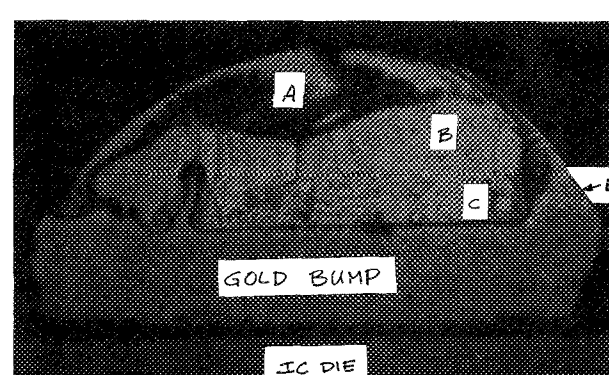

FIG. 4. Cross section of tin-plated copper lead bonded to a gold bump. Copper has been preferentially etched to show difference in grain structure indicated high temperature gradient in bonding process. Region A has been completely melted, region B has recrystalized and region C has not been altered. The compounds containing tin have been displaced to region D.

Downloaded 29 Apr 2013 to 128.180.77.165. Redistribution subject to AVS license or copyright; see http://avspublications.org/jvstb/about/rights_and_permissions

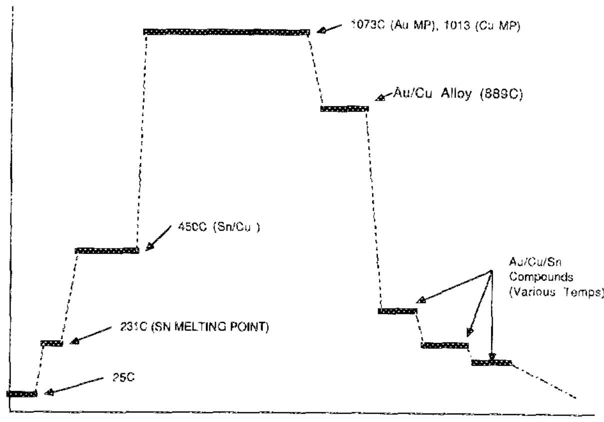

FIG. 5. Notational time–temperature relationship of reactions during bond formation (not to scale).

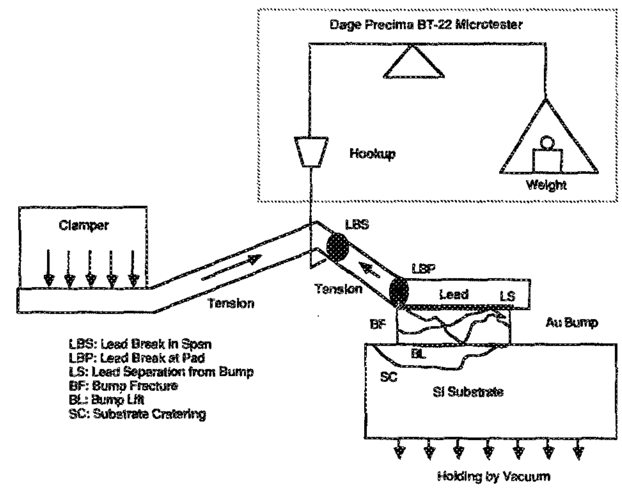

FIG. 6. Method and equipment for determining bond quality and locations of possible failures in the chip/bump/bond/lead structure.

enough to recrystallize the grain structure but not melt it completely. Region "C" of the lead is virgin ED copper, indicating that the region stayed below any recrystallization temperatures. The bond is at the interface between region "C" and the bump.

It is postulated that the bond is formed as follows: The tin absorbs a high percentage of the incident laser energy but, due to its low vapor pressure, does not evaporate. Rather, the molten tin enhances thermal coupling and produces intermetallic compounds with gold and copper. The compounds, once formed, melt at temperatures below the melting points of the elements in independent states. See, e.g., a copper–tin phase diagram. The molten copper and tin flows around the outside of the lead and initiates melting of the gold on top of the bump. The molten material also decreases the thermal contact resistance in the interface between the copper lead and the gold bump so that conductive heat transfer is maximized. In this way, atomic copper and gold are introduced into liquid phases early in the laser pulse/temperature cycle so that full alloying is accelerated and enhanced while being contained in a small region.

With molten material in the bond interface, the laser energy is fully coupled to the lead and the bump so that a complete metallurgical bond is formed. Finally, solidification occurs from the inside out by conduction of the heat to the outside where convection carries the heat away. Thus, the gold and copper alloy solidifies first. Any ternary compounds at this stage are still molten and are displaced to the joint exterior by the advancing solidification front because the solubility of tin in copper and gold is low. The net result is that any copper/gold/tin intermetallic compounds solidify on the exterior of the copper/gold alloy bond. In this location they do not have any effect on bond strength or reliability. This area, which is very tin rich, is marked "D" in Fig. 4. A notional time vs. temperature profile, shown in Fig. 5, illustrates the various stages of reaction taking place during the bond formation process.

A simple experiment gave further indication of the localized nature of laser bonding. A 10 micron high bump was located over a seven micron thick layer of silicon dioxide. Under the silicon dioxide was a diode with a constant current applied. The voltage change in the diode, a function of temperature, was monitored and recorded with a storage oscilloscope during a bonding cycle. The measured voltage change in the diode corresponded to approximately a 100 °C temperature rise.

IV. BOND QUALITY AND RELIABILITY

After bonding, the leads are mechanically stressed to determine the quality of the bond. Figure 6 schematically shows the set-up. The IC is held to the stage with vacuum and the TAB lead frame is clamped to the fixture with a portion of the lead exposed so that a small hook is used to lift the lead until some portion of the structure fails. The location of the failure and the amount of force that was required to induce the failure are both recorded. Figure 6 also lists the six possible failure mechanisms and the location in the structure where they occur.

The most desirable failure is when the lead breaks in span indicating that the bond and the rest of the structure is at least as strong as the copper lead. However, when there are failures elsewhere in the structure they are deemed acceptable if their pull strengths are at least 25 grams.

Figure 7(a) shows the cumulative probability of failure vs pull strength while Fig. 7(b) shows the failure frequency vs pull strength for the possible failure modes. The units for failure frequency are an arbitrary scale from zero to 100 and not percentage.

In order to prove the long term reliability of the process that has been discussed in this paper, a series of devices were bonded and subjected to environmental testing. In all, 60 CMOS ICs with 48 leads on each one were bonded, then divided into six sets of ten. Each set of ICs was then subjected to one of a number of tests (see Table I).

Most tests were performed in accordance with the provisions of MIL-STD-883.

Downloaded 29 Apr 2013 to 128.180.77.165. Redistribution subject to AVS license or copyright; see http://avspublications.org/jvstb/about/rights_and_permissions

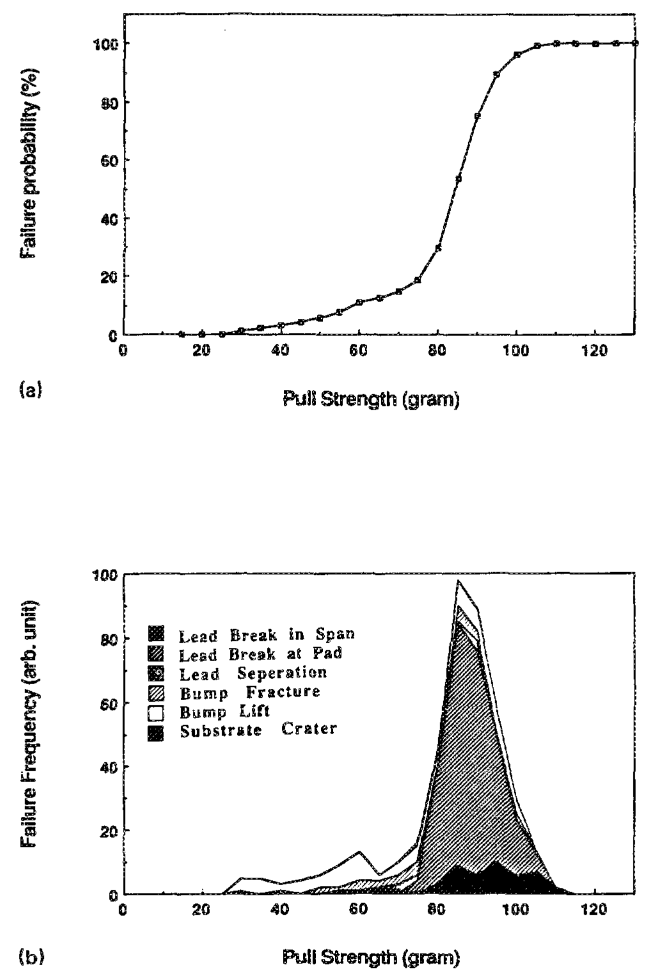

FIG. 7. (a) Cumulative probability of failure vs pull strength. (b) Pull strength vs failure frequency for various failure modes.

TABLE I. Environmental tests performed on laser bonded devices.

Test	Environment	Duration
Autoclave	121 °C, 100% R.H. and 15 psig	96 h
High temp storage	150 °C	1000 h
85/85	85 °C and 85% R. H.	1000 h
Moisture resistance	− 10 °C@2.7% R. H. to 65 °C@95% R. H.	50 cycles
Liq-to-liq temp shock	− 55 °C to 125 °C	1000 cycles
Air-to-air temp cycle	− 55 °C to 125 °C	1000 cycles

TABLE II. Failure modes and failure forces for laser bonded devices after environmental testing.

Failure mode	Avg force	% of failure
Lead break in span	55.66 gms	10.81
Lead break @ bond	39.91 gms	66.38
Lead lift from bump	26.81 gms	16.49
Bump lift from die	34.24 gms	06.32
TOTAL	39.10 gms	100.00

The devices were removed from the environments at periodic intervals and electrically tested. The entire 100% of the bonds passed the tests. After the environmental testing was complete, the leads were then pull tested. The results are summarized in Table II.

As can be seen from Table II, the bonds, and in fact the entire structure, remained very strong during and after exposure to the severe environments.

V. CONCLUSIONS

The process described takes advantage of the unique properties of the localized, concentrated energy in a focused pulsed YAG laser beam to reliably bond tin plated copper leads to gold bumps on ICs. The process relies on the rapid alloying of copper and gold with tin as an enhancer of coupling the laser energy to the bond site. The tin also causes the copper and gold to melt at lower temperatures than in their elemental state, and promotes conductive heat transfer in the bond without forming the brittle intermetallic compounds often found in gold tin alloys formed with conventional methods such as soldering.

Because of the extreme flexibility of a computer controlled laser and laser beam positioning system, the process has very important implications for manufacturing, especially in those environments with a broad product mix. While much work remains before this process is used in high volume manufacturing, the potential and the feasibility of the process have been established here.

[1]A. Keizer and D. Brown, Solid State Technol. **30**(3), 59 (1987).
[2]F. Burns and C. Zyetz, *Electron. Packaging and Prod.*, Vol. 21, no. 5, 109 (1981).
[3]D. E. Gray, *American Institute of Physics Handbook*, 3rd edition, (McGraw-Hill, New York, 1972).
[4]R. E. Lindquist and A. W. Ewald, Phys. Rev. **135**, A191 (1964).

Downloaded 29 Apr 2013 to 128.180.77.165. Redistribution subject to AVS license or copyright; see http://avspublications.org/jvstb/about/rights_and_permissions