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AUTOMATED INTERCONNECT ON GaAs INTEGRATED CIRCUITS

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TEXAS INSTRUMENTS

Abstract

Although GaAs integrated circuits provide significant advantage over silicon in both digital and microwave applications, automated assembly of this brittle material presents a considerable technical challenge. As volume and cost effective demands increase, automated interconnect becomes a key requirement. This paper discusses how automation can be achieved with consistent reliability in ball bonding on GaAs.

Introduction

Previous investigators have reported inability to consistently automatically bond to GaAs due to material and design characteristics which cause fracturing, cratering and pattern recognition failure resulting in an automated nightmare. This paper discusses how automatic ball bond interconnect can be achieved on GaAs material. It describes those parameters which are vital to implement as well as those which are critical to avoid.

Typically, GaAs devices and monolithics are bonded utilizing a manual approach with thermocompression wedge/wedge bonding, a technique which can be unreliable as well as inconsistent in performance. Variability in tool position, tail length, clamping mechanism, and foot deformation can all contribute to questionable reliability. In addition, due to the large footprint inherent in this type of bonding, placement accuracy can become a serious issue particularly on small pad sizes with one mil wire.[1] At Texas Instruments the use of a manual thermocompression chisel bonder has alleviated some of these problems with a much smaller footprint and more sensitive methods of bonding control. In order to achieve a more reliable bond connection, multiple stitches are often made in each bond location (see Figure 1). With both manual wedge or chisel bonding, loop configuration, as well as bond strength, remain under the control of an operator, contributing to wire inductance variability particularly in high frequency microwave applications. Thus, circuit performance becomes directly related to bonding skill level.

Although manual wedge/wedge bonding is the acceptable approach industry-wide in small prototype fabrication, it quickly becomes intolerable in a high volume production environment both from a throughput and cost point of view and also from a performance repeatability requirement. Implementation of some level of automatic bonding is a necessity.

Unfortunately, when automated thermosonic ball interconnect is attempted in assembly of GaAs devices and monolithics, a host of new problems quickly become apparent. Cratering, chipping, cracks and fractures are the worst of the problems; pattern recognition failures are those which become evident immediately when the bonder refuses to bond.

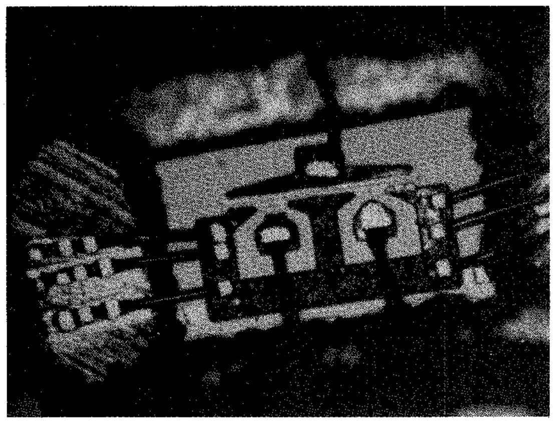

FIGURE 1. MULTIPLE STITCHES IN MANUAL CHISEL BONDING

Identification of Variables

Since the history of automation in GaAs device assembly is relatively limited, variables which affect problem areas have not yet been clearly defined. Identification of these variables became the primary task before a test design could be developed to isolate and control the variables.

The initial mode of operation then was to bond a variety of devices while utilizing an array of bonding parameters which eventually began to converge toward a set of optimized bonder settings for GaAs. When the variables of device fabrication and bonding parameters were clearly defined, a test design could then be constructed to analyze the respective contributions of each.

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The automated bonder utilized in this study was the Hughes 2460 thermosonic ball bonder. It possesses programmable bond and loop control as well as two modes of touchdown technique, optical or ultrasonic touchdown.

Pattern recognition is the preferred referencing technique for automation, although manual referencing can also be used with this machine. During initial set-up, process development was done on thin film networks with gold metallization. Reliable settings could then be established after environmental cycling, bond pulls and the graphing of mean pull strength and standard deviations. These were the settings utilized for initial bonding to GaAs.

During the first phase, nine different types of GaAs devices were evaluated for a total of 600 chisp automatically bonded. Depending upon the bond pad size, either 0.7 mil or 1.0 mil wire was used. No evidence of bonding problems was observed on seven of the nine device types, and pattern recognition performed well on all devices. However on two devices, one a FET (A), one a monolithic (VI), pad cratering was apparent. Results of this initial bond study are summarized in Table 1.

TABLE 1. Automatic Bonding Results to TI Manufactured GaAs Devices

TI Mfg GaAs Devices	Pattern Recognition	Wire Diameter	Metal Pullup/ Cratering
FET A	Yes	1.0 mil	Yes
FET B	Yes	0.7 mil	No
Monolithic I	Yes	1.0 mil	No
Monolithic II	Yes	0.7 mil	No
III	Yes	0.7 mil	No
IV	Yes	0.7 mil	No
V	Yes	0.7 mil	No
Monolithic VI (4 mil pad)	Yes	1.0 mil	No
VII (2 mil pad)	Yes	0.7 mil	Yes

Additional tests were run evaluating the possibility of bonding to only evaporated gold without the additional step of plating gold over the evaporated gold. The results are shown in Table 2. Twenty-eight of 248 wires peeled metal/or cratered when bonding to only the evaporated gold surface. When a layer of gold was electroplated over the evaporated gold, the metal peel/cratering problem was not observed on any of 29 devices (232 wires). In addition, the pattern recognition system of the Hughes 2460 automatic wire bonder performed accurately on the plated gold, while it has limited success on evaporated gold. Evaporated gold appeared dull in the television monitor inhibiting the pattern recognition from obtaining a distinguishable surface.

TABLE 2. Bonding Data for Evaporated Au Versus Plated Au

Metallization Type	IC Qty.	# Wires	#Bonds Which Pull Metal/ Cratered	% Yield (per wire)	Pattern Recognition % Yield
Evaporated Au	31	248	28	89	19
Plated Au	29	232	0	100	100

From these tests it was determined that two factors examined thus far were critical in the investigation of cratering on GaAs: small pad size, with a width of 2 mils or less, and no plating on the bond pad. Bond pads without plating eliminate the use of pattern recognition.

The evaluation was then focused on the elimination of cratering on small pad sizes which are often encountered on discrete FET structures. Bonder machine variables tested included optical versus ultrasonic touchdown, ultrasonic rise time, force, time and ultrasonic power, and reduction of ball diameter width. Additionally, device fabrication variables were analyzed to achieve craterless bonding. Tests involving further fabrication variables included bonding to those structures often encountered on GaAs devices: bonding to pads with and without an alloy under the pad, and bonding to pads with a trough structure under the pad (Figure 2).

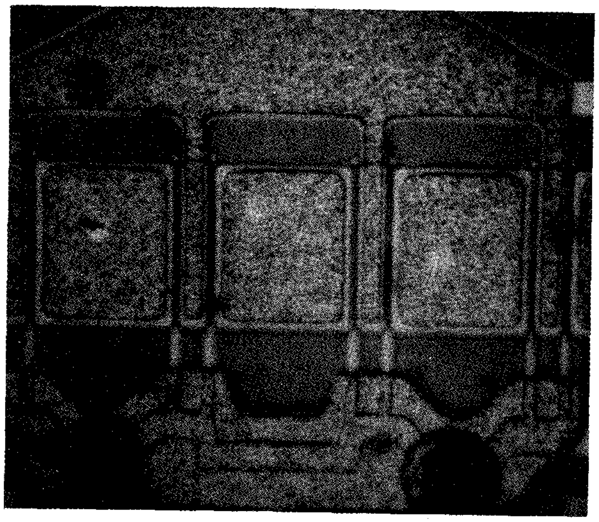

FIGURE 2. TROUGH UNDER THE BOND PAD ON A GaAs DEVICE

At the conclusion of these studies, several factors were noted as important in contributing to fracturing and cratering in GaAs: pad size in relation to ball diameter, absence of alloy under the bond pad, position of the ball in relation to device structures such as the gate recess, touchdown technique, and open clamp position in formation of the bond loop.

Test Design

In order to comprehensively examine the most significant variables contributing to the problem, and to establish the relative importance of each variable, a GaAs test structure was designed. A matrix of five slices with varying bond pad plating thicknesses were evaluated. Slice plating levels were: 0.0 microns of gold plating, 1.6 microns, 2.6 microns, 3.4 microns and 4.5 microns. The test structure was composed of a range of pad sizes as follows: 1.5, 2.0, 3.0, 4.0, 6.0 and 8.0 mils square, 2 mils x 8 mils, 5 mils x 10 mils, and 6 mils x 4 mils. Half of the pads were constructed with an alloy under the pad and half without the alloy. A photograph of one of the evaluation devices is shown in Figure 3.

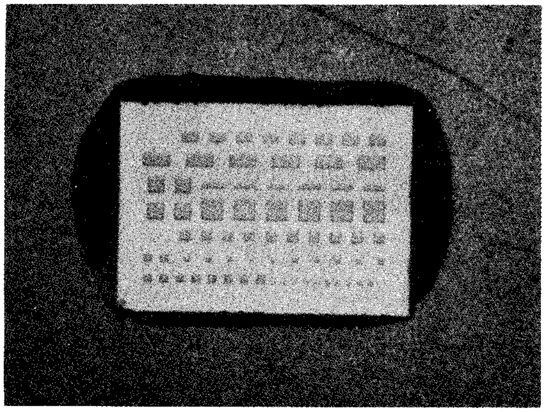

FIGURE 3. PAD SIZE EVALUATION TEST DEVICE

Automatic bonding was accomplished using optimized settings of force, time and ultrasonics derived from the first phase of the program. What still remained ambiguous were effects of touchdown sensing technique and clamp position in formation of the loop. These effects were tested before more extensive evaluation on the plating thickness could take place. Results of 0.7 mil bonding are recorded in Table 3. These results compare optical versus ultrasonic touchdown technique and open versus closed clamp condition. Bonding was performed on a plating thicknesses of 4.5 microns.

With 0.7 mil wire, both closed clamp and ultrasonic touchdown sensing resulted in a greater incidence of cratering. As the pad size increased, however, the importance of these variables continued to decrease. Further testing was completed using one mil wire on the smallest pad sizes and the open clamp condition when forming the loop. Touchdown sensing was also varied. Results obtained for 1.0 mil wire bonding are shown in Table 4.

As observed with 0.7 mil wire, pad size is the most important variable associated with cratering. With the 1.0 mil wire, touchdown sensing technique is not a significant factor. Plating thickness on the bonding pads was at 4.5 microns. The 1.5 mil square

TABLE 3. Cratering Results Using 0.7 Mil Wire Varying Touchdown and Clamp Conditions

PAD SIZE (mils)	OPTICAL OPEN		OPTICAL CLOSED		ULTRASONIC OPEN		ULTRASONIC CLOSED	
	#	%	#	%	#	%	#	%
1.5 x 1.5	7/21	33	5/6	83	19/20	95	5/6	83
2.0 x 2.0	0/15	0	0/8	0	11/30	37	7/10	70
3.0 x 3.0	0/38	0	2/10	20	0/18	0	0/10	0
4.0 x 4.0	0/30	0	2/10	20	0/29	0	1/10	10
6.0 x 6.0	0/14	0	0/3	0	0/10	0	0/4	0
8.0 x 8.0	0/24	0	0/6	0	0/8	0	0/1	0
2.0 x 8.0	0/24	0	0/6	0	0/6	0	0/6	0
5.0 x 10.0	-	-	0/4	0	1/13	8	0/4	0
6.0 x 4.0	0/25	0	0/6	0	0/24	0	0/8	0

TABLE 4. Cratering Results Using 1.0 Mil Wire Varying Touchdown Technique

PAD SIZE (mils)	OPTICAL OPEN		ULTRASONIC OPEN	
	#	%	#	%
2.0 x 2.0	18/18	100	20/20	100
3.0 x 3.0	7/20	35	8/20	40
4.0 x 4.0	0/20	0	3/20	15
2.0 x 8.0	8/12	67	6/12	50

pad could not be bonded with 1.0 mil wire due to insufficient surface contact since ball diameter size is approximately 3.0 mils.

Additional testing analyzing effects of plating thickness and of presence of the alloy was then completed with both 0.7 mil and 1.0 mil wire bonding. Since the closed clamp seems to create an upward force instigating fracture during formation of the loop, the open clamp was used for this bonding. With 0.7 mil wire, touchdown technique was a significant variable, therefore optical touchdown was used. Touchdown technique was not seen to be critical with 1.0 mil wire bonding, therefore ultrasonic touchdown sensing was utilized with 1.0 mil wire. A summary of cratering frequency of 1.0 mil bonding and of 0.7 mil bonding on GaAs are seen in Figure 4.

All tests have indicated that the most important factor contributing to cratering on GaAs devices is ball diameter in relation to pad size. With a ball diameter of approximately 3.0 mils using 1.0 mil wire, a pad size of 4.0 mils square is the smallest pad size which can be reliably bonded with automated equipment. With 0.7

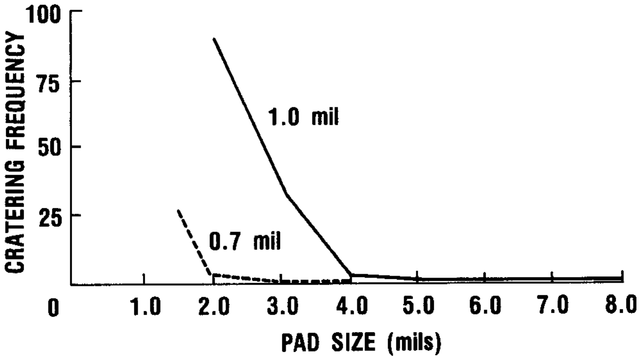

FIGURE 4. CRATERING FREQUENCY AS A FUNCTION OF PAD SIZE

mil wire and a ball diameter in the range of 2.0 mils, the smallest pad size for reliable bonding is 3.0 mils square.

Presence of alloy, touchdown technique and open or closed clamp are all lower level effects while plating thickness is apparently not a critical variable in the cratering equation.

Summary and Conclusions

In summary, implementation of automated interconnect on GaAs monolithic and component devices is a necessity if high volume demands and consistent circuit performance needs are to be met. Since very little published history exists on automated bonding to GaAs, a bonding evaluation of a wide array of devices was first conducted to define problem areas and to identify primary variables. From the preliminary testing the primary areas of concern were fracturing of the GaAs and pattern recognition failure. Pattern recognition failure was easily eliminated by the utilization of pads which were plated rather than evaporated. Preliminary testing identified major variables in the complex cratering matrix.

A test design was then structured to test those variables of major concern. It consisted of GaAs devices with varying pad size, plating thickness, pad shape and alloy under the bond pads. Cratering results were tabulated and bonder parameters varied to evaluate changes.

Finally, compilation of results demonstrated that the most important factor in the elimination of cratering is the bonding pad size in relation to the ball diameter. Second order effects are touchdown technique, open or closed clamp condition during loop formation and presence of alloy under the bonding pad.

Automated ball bonding can be achieved on GaAs with reliability and with repeatable performance. For 1.0 mil bonding, 4.0 mil square is the smallest pad size which can be automatically bonded, resulting in no cratering effects. This can be reduced to 3.0 mils square for 0.7 mil wire bonding.

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