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Microelectronic Interconnection Bonding With Ribbon Wire

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MICROELECTRONIC INTERCONNECTION BONDING WITH RIBBON WIRE

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Cover photograph. SEM photomicrograph of bonds made with 3- by 0.5-mil aluminum (1% silicon) wire on 5-mil square aluminum pads. The capability of placing ribbon-wire bonds one on top of another is shown. Four bonds are stacked at the center of the letter "B" (Magnification 60X)

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FOREWORD

This technical note is the final report to the Advanced Research Projects Agency for the period June 1, 1971 to May 31, 1972 on a study designed to show the feasibility of using aluminum ribbon wire for ultrasonic bonding of semiconductor microelectronic device interconnections. The work was carried out under contract number MIPR FY 76167100331 (ARPA Order Number 1889), M. Chernoff ARPA Agent/Project Officer.

MICROELECTRONIC INTERCONNECTION BONDING

WITH RIBBON WIRE

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The feasibility of using aluminum ribbon wire for ultrasonic bonding of semiconductor microelectronic interconnections was studied, and several advantages over the use of round wire of equivalent cross-sectional area were found. Ribbon wire bonds exhibited little deformation or heel damage, and a greater percentage of bonds of a certain quality (as judged by pull strength and appearance) could be made over much greater ranges of the bonding machine parameters, time and tool tip displacement, using ribbon wire than was possible with round wire. The ease of positioning ribbon wire was indicated by making multiple ribbon wire bonds side-by-side on a 5-mil square pad, or by stacking up to four bonds one on top of another. However, bonding with harder than normal wire, previously thought to offer certain advantages with respect to higher bond tensile strength, yielded inconsistent results.

Key Words: Aluminum wire; bonding; fabrication (wire bonds); microelectronics; ribbon wire; round wire; testing (wire bond); ultrasonic bonding; wire bond.

1. INTRODUCTION

At the start of this study, there was no reported industrial use of aluminum ribbon wire for microelectronic ultrasonic bonding nor were ribbon wire bonding machines and suitable aluminum ribbon wire generally available. Prior exploratory work at NBS had indicated that the use of ribbon wire offered significant advantages over the conventionally used round wire [1,2]. The present study was undertaken in order to investigate the use of aluminum ribbon wire for ultrasonic bonding in semiconductor microelectronics, with emphasis on the advantages over round wire and the problems that might be encountered in converting presently used round wire bonding equipment to ribbon wire use.

The criteria used in evaluating bond quality were, primarily, pull strength and, secondarily, appearance. The pull strength was measured using a double bond, destructive pull test. The appearance criterion was based upon a subjective evaluation of the surface finish of the resulting bond and the degree of deformation at the heel as observed under high magnification, usually with a scanning electron microscope (SEM).

1.1. Units

The following units which are in general usage in the bonding field are used rather than the International System (SI) of units in this report: (1) mils (1 mil = 25.4 μm) for dimensions of the wire, bond loop, bond spacing, substrate, and tool, and (2) grams-force (1 gf = 9.8 mN) for the force exerted on the wire or wire bond.

2. FABRICATION AND TESTING OF WIRE BONDS

Except where otherwise noted, wire bonds studied in the present work were fabricated on a commercial ultrasonic wire bonder equipped with a tungsten carbide tool. This bonder, which had been modified to improve its mechanical stability and temperature characteristics [3], was further modified to facilitate the use of ribbon wire. Some exploratory studies were performed using bonds made on a different bonder, one that was intended for ribbon-wire use but later found not to give optimum results. Unless otherwise specified, the nominal value of bond loop height was 10 mils, bond-to-bond spacing was 40 mils, and bonding force was 25 gf.

2.1. Fabrication of Bonding Pads

Bonding pads were fabricated on 10-mil thick, 1-inch diameter silicon wafers coated with a 0.8- to 1.0-μm thick film of steam-grown oxide and a 0.8- to 1.0-μm thick film of evaporated aluminum. The aluminum was etched to leave 5-mil square bonding pads on 10-mil centers by means of standard photolithographic techniques. After etching, the array of square bonding pads was sintered in a helium atmosphere at 550°C for 15 min. Such an array is shown in the cover photograph.

2.2. Procedures Used to Measure Bond Pull and Wire Tensile Strengths

In all of the measurements reported here, the pulling force was applied normal to the plane of the single-level substrates. Pulling was accomplished with an electrolytically-etched wire hook driven by a switch-controlled adjustable speed motor at a pull rate of 1 gf/s. The hook was mounted on a micropositioner so that it could be precisely aligned with respect to the wire. The pulling force was measured by a gram-gage dynamometer.

The wire was prepared for measurement of tensile strength by affixing one end of a 10- to 15-mm length of wire to a base plate with room-temperature curing epoxy and placing a ball of the epoxy on the other end. A small fork placed under the epoxy ball was used to apply the test force. Using the pulling apparatus, each of ten wire specimens was pulled to breaking and the results averaged. Only specimens that exhibited a break in the wire were counted in calculating the average.

3. EXPLORATORY STUDIES

3.1. Ribbon Wire Bonder

Initial efforts to achieve optimum performance and reliability with a bonder manufactured for use with ribbon wire were hampered by a vertical jumping motion of the bonding tool after the first bond had been made. This tended to cause severe cracking in the bond heel. Considerable reduction of the undesired motion was achieved by regrinding the appropriate cam surfaces by hand.

Another problem with the bonder was a considerable variability of bond tail-length that it would produce. This was reduced by a factor of two by improving the wire-feed mechanism. This tail-length variation, which is of only cosmetic concern to bonding on a laboratory basis, must be controlled before the machine can be used in production since long wire tails in actual devices may cause short circuits.

3.2. Bonding Tools

A feature of the bonding tool that was considered desirable but not essential for the initial studies was a rectangular wire-feed hole. At the time these studies were to begin, commercial tools with rectangular feed holes could not be located. However, one company agreed to make such tools if supplied with tungsten wire of rectangular cross section required for the electrical-discharge-machining operation to fabricate such holes. A simple procedure was developed to form the tungsten ribbon wire. Lengths of 1-mil and 2-mil diameter round wire were flattened by placing the tungsten wire in a press between glass plates and applying a load to 45 to 76 MN/m^2 for 1-mil diameter wire, or 103 to 145 MN/m^2 for 2-mil diameter wire. The resulting ribbon was not generally uniform, but pieces could be selected for the desired sizes of rectangular holes. At a later time, a supplier of tools with rectangular feed holes was located. An SEM photomicrograph of the rectangular feed hole in one of the commercially-available tools is shown in figure 1.

3.3. Ribbon Wire

The aluminum ribbon wire used for most of the experimental work was doped with one percent silicon and had cross-sectional dimensions of 1.5 by 0.5 mils. This results in about the same cross-sectional area for the ribbon wire as for 1-mil diameter round wire. Aluminum wire doped with one percent magnesium, silicon-doped aluminum wire of larger dimensions, and undoped gold wire were also studied. Table 1 lists the composition, tensile strength, and nominal cross-sectional dimensions for the various ribbon wire used.

The desired variation of the cross-sectional dimensions was equal to or less than 10 percent. Difficulty was encountered in obtaining wire with this degree of control. Contacts with three manufacturers of ultrasonic bonding wire were required, and nearly half of the period for this study passed, before satisfactory wire was obtained.

The ribbon wire was obtained on 0.5-in. or 2-in. diameter spools. Wire wound on the 2-in. spools showed less twisting and binding and

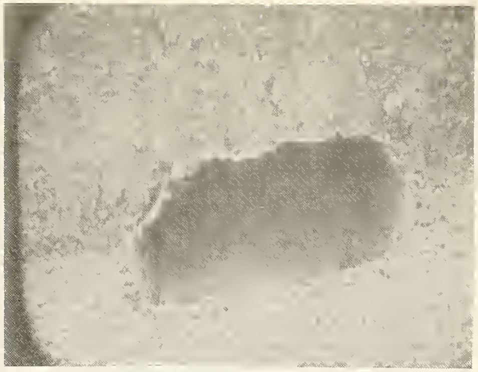

Figure 1: SEM photomicrograph of a rectangular wire-feed hole in an ultrasonic bonding tool. (There is a slight build up of aluminum in the upper left corner of the hole. Magnification: about 750X.)

Table 1: Specifications of Wire Studied

Lot	Composition	Dimensions (mils)	Tensile Strength Range (gf)	Comments
A	Al (1% Si)	1.5 x 0.5	13.0 - 13.5[a]	partially annealed[b]
B	Al (1% Mg)	1.5 x 0.5	∿14	partially annealed[b]
C	Al (1% Mg)	1.5 x 0.5	23.1 - 23.5[a]	hard wire
D	Au	1.5 x 0.8	∿15	partially annealed[b]
E	Al (1% Si)	1.0 (dia.)	12.5 - 13.2[a]	partially annealed[b]

[a] low and high values of breaking strength as measured in the laboratory (see text)

[b] by manufacturer

exhibited better feeding characteristics through the transducer horn, wire clamp, and bonding tool. The tail length and loop height were also more uniform in bonds made from wire wound on the larger spools. Only minor modification of the bonders was needed to accommodate the larger spools.

3.4. Hard-Wire Bonds

It had been speculated [1] that high tensile strength ("hard") ribbon wire could be used to achieve considerably higher bond strengths than with round wire. The expectation was that significant damage to the substrate would not occur with the higher ultrasonic power and bonding force required when using hard wire because less deformation of the ribbon wire occurred. However, in a preliminary test bonding with hard wire (Lot C) proved to be very difficult, and inconsistent results were obtained. The power range in which bonds of high pull strength could be obtained was narrow, and the other bonding parameters were critical in order to accomplish a low variability in mean pull strength. On lifted bonds (those carefully peeled from the substrate), cratering was observed in the substrate due to the increased bonding force required to obtain adherent bonds. Though this experiment was performed using magnesium-doped wire, no significant difference would be expected using silicon-doped wire (see Section 4.3.). Because of the high quality of bonds later found with stress-relieved wire, no further attempts to bond with hard wire were made during subsequent phases of the work.

3.5. Ribbon Wire Bonds - Initial Results

About 2000 bonds were made with Lot A wire on several single-level bonding substrates in order to investigate the pull strength and appearance of bonds made with different bonding power and time. The bond-to-bond spacing was 40 mils, similar to that used in typical devices. A single tool was used to make all the bonds.

A better appearance was obtained with low ultrasonic power and relatively long bonding time (figure 2) than with the higher ultrasonic power and shorter bonding time usually employed in round-wire bonding. In the latter case, the bond surface appearance was rough and irregular, and a significant heel crack appeared in the first bond (figure 3). The bond shown in figure 2, typical of those made with the low-power, long time schedule, had a pull strength approximately 1.5 times that of the bond shown in figure 3, typical of those made with the high-power, short-time schedule.

A test was conducted to establish that the positioning and deformation of the bonded ribbon wire could be controlled sufficiently to permit the use of the same size bonding pad that would be required for round wire of cross-sectional area equivalent to the ribbon wire.

Figure 2: SEM photomicrograph of a ribbon wire first bond made with low power [20-μin. (0.5-μm) peak-to-peak tip amplitude] and long time [155 ms] (Magnification ∿470X).

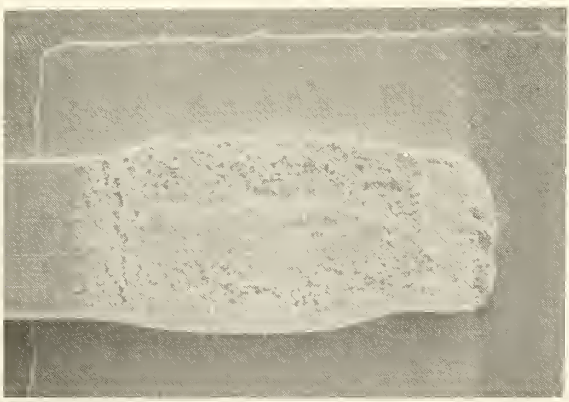

Figure 3: SEM photomicrograph of a ribbon wire first bond made with high power [82-μin. (2.1-μm) peak-to-peak tool tip amplitude] and relatively short time [40 ms] (Magnification ∿500X).

Three bonds were made with 1.5- by 0.5-mil aluminum (1% silicon) ribbon wire side-by-side on a bonding pad 5 mils square. The result, pictured in figure 4, dispelled any concern that larger bonding pads may be required if ribbon wire is used. Figure 5 shows that ribbon wire bonds can be stacked directly one on top of another. This, along with the cover photograph, further illustrates the degree of control in bond placement that the use of ribbon wire offers. This can be an important consideration in device repair or replacement, especially for hybrid devices, and for high frequency devices in which lead inductance must be minimized.

4. RESULTS

Measurements were carried out using aluminum (1% silicon) wire: (1) to compare directly the pull strengths of ribbon and round wire with equivalent cross-sectional areas, (2) to determine the bonding parameters (time, bonding force, and tool tip displacement) necessary to obtain optimum bonds, and (3) to examine the effects of changes in the bonding parameters on bond appearance and deformation. The results of these measurements are given below. Results of bond pull strength measurements using aluminum (1% magnesium) ribbon wire and gold ribbon wire ultrasonically bonded to aluminum pads are also reported.

4.1. Comparison of Ribbon and Round Wire Pull Strengths

Because the exploratory studies showed that high quality bonds could be made with ribbon wire, the investigation was broadened to compare ribbon and round wire bonds over a wide range of power and time settings for a constant bonding force of 25 gf. Using the same bonding machine and tool*, wire bonds of both types (wire Lots A and E) were made with bond-to-bond spacings of 40 mils and loop heights of 10 mils side-by-side on the same metallized silicon substrate in order to minimize any influence of differences in bonding conditions or substrate characteristics.

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* The use of the same tool (with round feed hole) for both round and ribbon wire results in less than optimum conditions for bonding ribbon wire (see Section 5.2.).

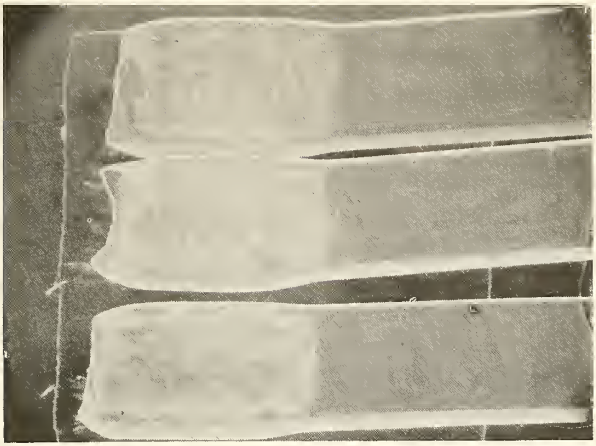

Figure 4: SEM photomicrograph of three bonds made with aluminum ribbon wire with cross-sectional dimensions 1.5 by 0.5 mils on a bonding pad 5-mils square. (The bonding schedule was low power [32-μin. (0.8-μm) peak-to-peak tool tip amplitude] and medium time [80 ms]. Magnification ∿460X).

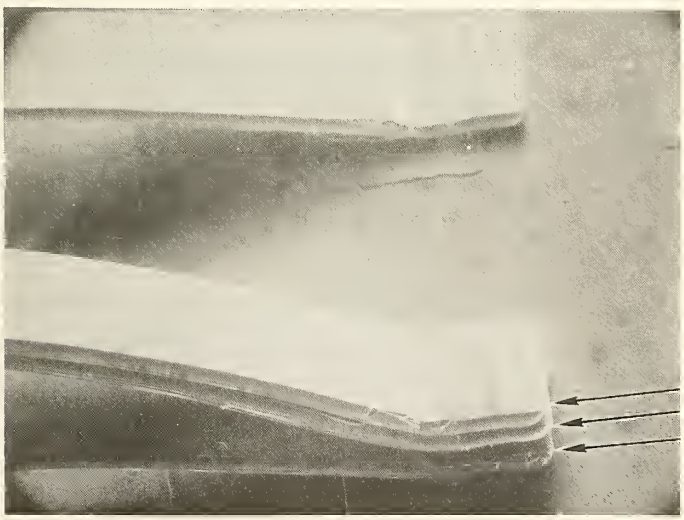

Figure 5: SEM photomicrograph of three stacked bonds (shown by arrows) made with aluminum ribbon wire with cross-sectional dimensions 3 by 0.5 mils on a 5-mil square bonding pad (Magnification ∿200X)

For each combination of displacement and time, 10 bonds were made and their pull strengths determined by pulling vertically at the midpoint of the loop. The average pull strength for each group is plotted against both time and tip displacement in figures 6 and 7 for ribbon and round-wire bonds, respectively. The data points have been connected by straight lines to define planes each of which includes groups of bonds made at a constant time but with a range of power (tool tip displacement). For convenience, different symbols are used for groups with mean pull strength less than 7, 7 to 10, and greater than 10 gf. For clarity the variance is not indicated in the figures. Open points and short dashed lines indicate portions of a plane lying behind another. In general, at the lower displacements, the major mode of the bond failure was bond lift off while at higher power it was breakage at the heel of the bond.

The results of a statistical analysis of the bond data considered as a whole are summarized in table 2. The entries in this table are the averages of the mean pull strength of bond groups with mean pull strength in the specified range and the pooled sample standard deviation for the means. The number of groups included in each category is also given. The mean pull strength of bonds made using ribbon wire was a statistically significant eight percent higher than the mean pull strength of bonds made with round wire in the range of pull strengths greater than 10 gf. About 90 percent of the ribbon-wire bonds showed pull strengths greater than 7 gf while only 42 percent of the round-wire bonds did for the power and time settings studied.

Also shown in table 2 are the results from a comparable series of ribbon-wire bonds using Lot A wire made on a different substrate using a bonding force of 35 gf. Figure 8 shows plots of these data in a form similar to that of figures 6 and 7. In terms of the bond pull strength, the use of higher force appears to result in more of the bonds having pull strengths greater than 10 gf. However, microscopic examination of the substrate used for the series with higher bonding force after removal of the bonds and metallization indicated a slight amount of damage beneath the metallization. Such damage was not observed in the substrate used for the series with the lower force.

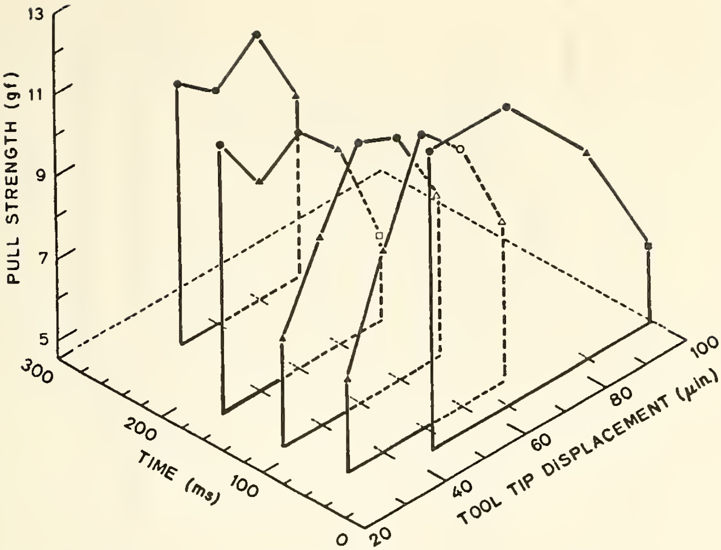

Figure 6: Pull strength of ribbon wire bonds as a function of time and tool tip displacement. (Bond pull strength range is shown by symbols: ●,○ > 10 gf; ▲, △ 7-10 gf; and ■, □ <7 gf.)

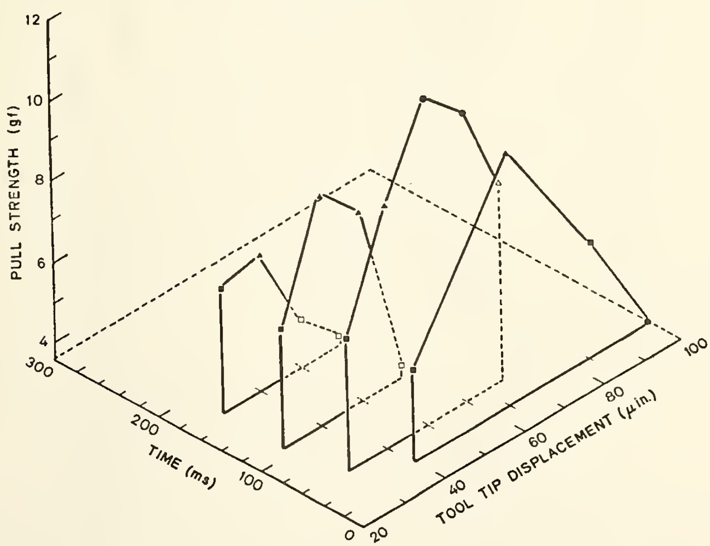

Figure 7: Pull strength of round wire bonds as a function of time and tool tip displacement. (Bond pull strength range is shown as in figure 6.)

Table 2 - Comparison of Pull Strengths of Ribbon and Round Wire Bonds

Range (gf)	Ribbon[a] Strength (gf)	Ribbon[a] No. of bond groups	Round[a] Strength (gf)	Round[a] No. of bond groups	Ribbon[b] Strength (gf)	Ribbon[b] No. of bond groups
> 10	11.3±0.7	8	10.5±0.2	2	11.0±0.4	14
7 - 10	8.7±0.4	9	8.7±0.7	6	8.8±0.4	5
< 7	6.7±0.4	2	5.3±0.7	11	3.9±0.7	2

[a] Bonds represented in these two columns were made on the same substrate with a bonding force of 25 gf.

[b] Bonds represented in this column were made on a different substrate with a bonding force of 35 gf.

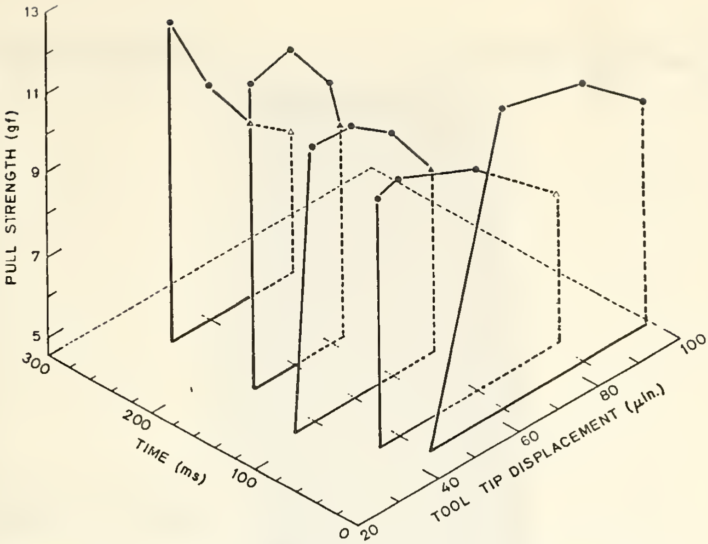

Figure 8: Pull strength of ribbon wire bonds as a function of time and tool tip displacement; bonding force of 35 gf. (Bond pull strength range is shown as in figure 6.)

The experiments reported above show that a major advantage of using ribbon over round wire is that with ribbon wire less precise control of bonding machine parameters is required to yield bonds of a certain quality than is required with round wire. This is illustrated graphically in figures 9 and 10 which delineate the regions of time and tool tip displacement where bonds of pull strength greater than 7 gf and 10 gf, respectively, were obtained. In both cases, these regions are much smaller for the round wire bonds than for the ribbon wire bonds. Although ribbon wire bonds with high pull strength were obtained over a much wider range of power and time than was indicated in the initial experiments, observations confirmed that, as previously reported, the best appearance was obtained at low power and long time.

4.2. Pull Strength as a Function of Loop Height

Measurements of ribbon wire bond pull strengths as a function of bond loop height were made. As shown in figure 11, up to a loop height of about 10 mils, the variation of pull strength as a function of loop height is in good agreement with the mechanical resolution of forces analysis (solid curve) [4]. Above 10 mils, the measured pull strength

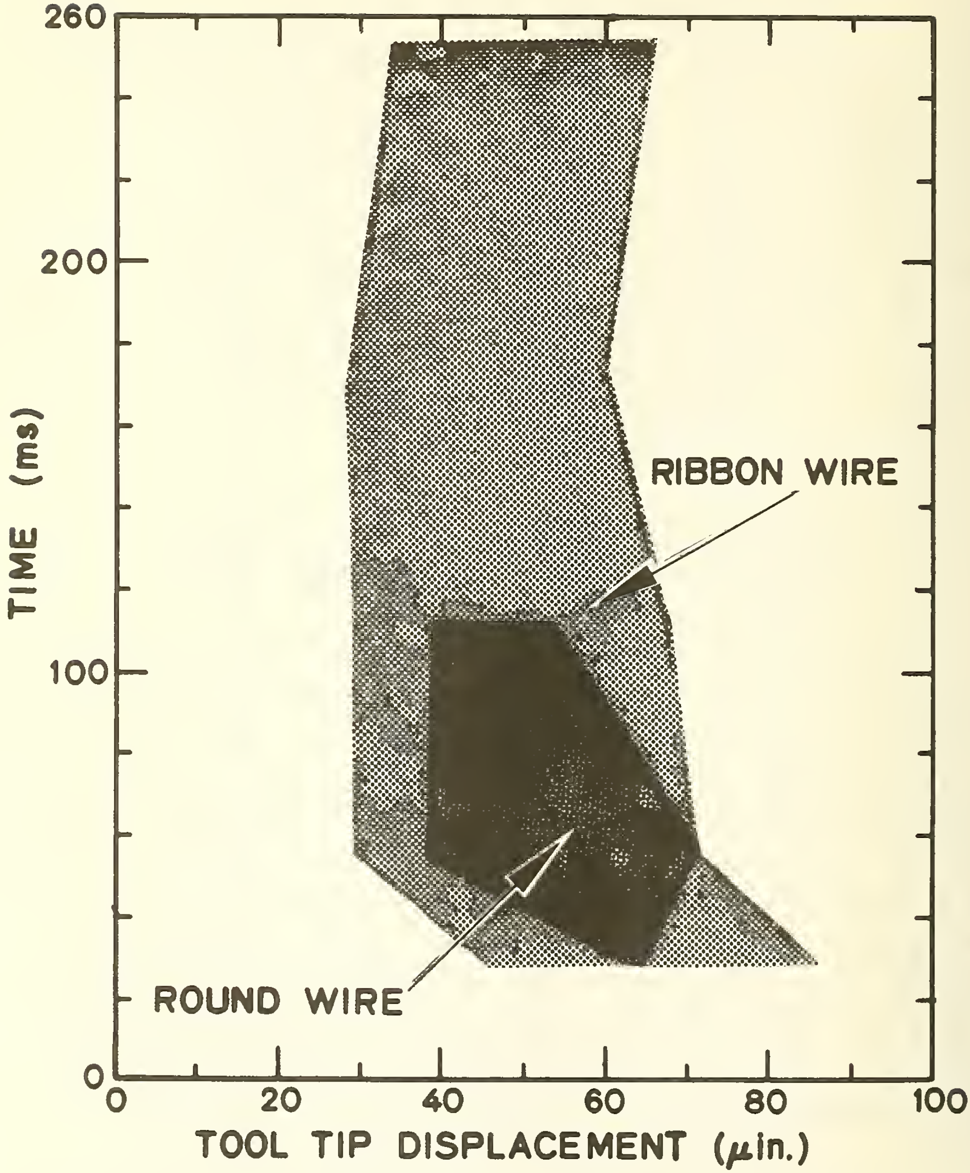

Figure 9: Time and tool tip displacement settings used in this work that yield bonds with a pull strength of 7 gf or greater.

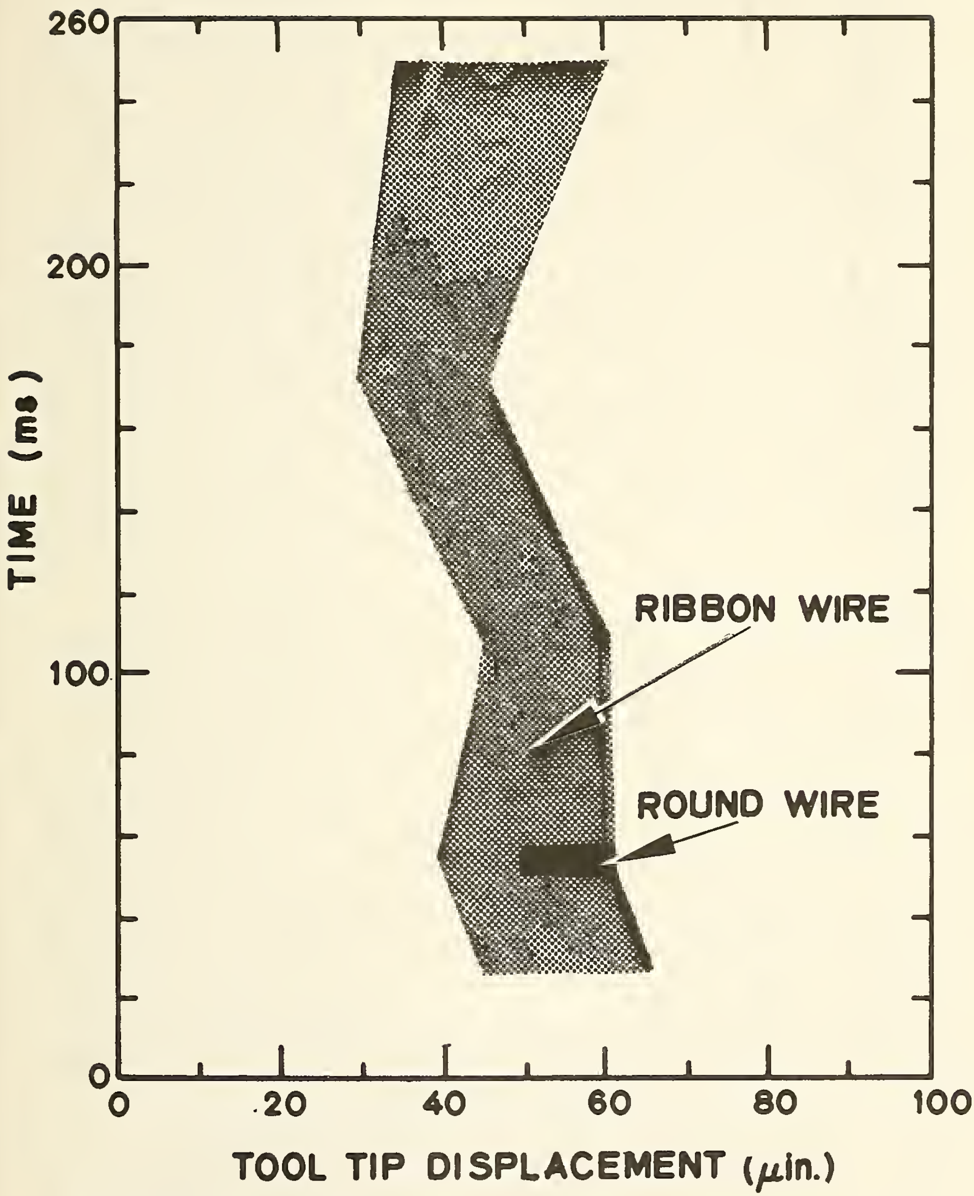

Figure 10: Time and tool tip displacement settings used in this work that yield bonds with a pull strength of 10 gf or greater.

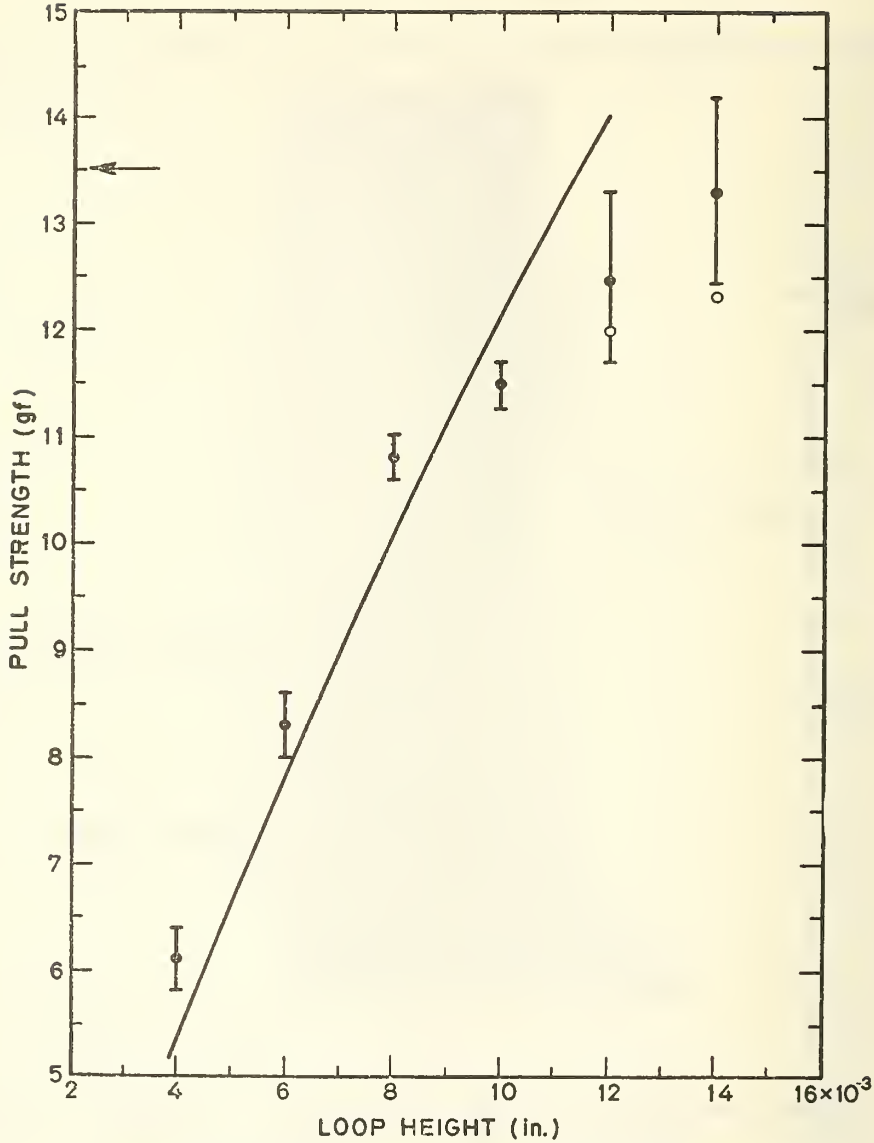

Figure 11: Pull strength of ribbon wire bonds as a function of loop height. (The data points represent the mean for up to 10 bonds. Solid circles include only bonds which ruptured at the heel; open circles include both bonds which ruptured at the heel and which failed by lift off. Error bars represent one sample standard deviation. The solid curve is calculated from resolution-of-forces using the wire tensile strength indicated by the arrow.)

is lower than the predicted value. The solid data points are average pull strengths for groups of nominally 10 bonds each, excluding those bonds that failed due to lift off of one of the bond pairs. The error bars represent one sample standard deviation above and below the mean. To obtain the two open data points at the two highest loop heights used, pull strengths of bonds which failed by lift off were included in the average pull strength calculation. As the loop height becomes increasingly higher, more vertical pulling force is exerted on the bonds. The experimental data, where bond failure known to be due to complete lift off is included, suggest some peeling of the bond before breakage at the heel caused by the increased vertical pulling force might account for the measured pull strength being less than predicted. This conclusion is in agreement with the results of measurements of pull strength of round wire bonds as a function of loop height [5].

4.3. Magnesium-Doped Wire

The pull strength and appearance of bonds made with Lot B aluminum (1% magnesium) ribbon wire were investigated using single-level bonding substrates. A single tool with a round feed hole was used for all bonds.

Measurements of pull strength of bonds made with various values of ultrasonic power (tool tip displacement) and time showed that, in agreement with the results obtained on aluminum (1% silicon) ribbon wire, the use of a low-power, long-time bonding schedule resulted in higher pull strengths and better appearance than a high-power, short-time bonding schedule. The highest average pull strengths and smallest variations are obtained at tool tip vibration amplitudes of 25 to 35 μin. (0.6 to 0.9 μm) and times of 110 to 285 ms. These groups of bonds made at low power and long time show mean pull strengths of from 11.0 to 12.2 gf with an average standard deviation of ±4 percent about the mean. Thus, there appears to be no significant differences between aluminum (1% magnesium) and aluminum (1% silicon) ribbon wire of comparable tensile strength.

4.4. Gold Wire

A series of experiments was undertaken to determine the feasibility of ultrasonically bonding gold ribbon wire (Lot D) to aluminum pads. It was found that bonds with mean pull strengths of 11.0 gf could be obtained by using high power, about 95-μin. (2.4-μm) peak-to-peak tool tip displacement, long time, from 150 and 275 ms, and a bonding force of 35 gf. The largest standard deviation was 10.7 percent for a group of ten bonds.

5. BONDING EQUIPMENT

The results of the previous section showed that ribbon-wire bonds with high pull strengths and a good appearance could be obtained. These were made on an existing round-wire bonding machine with only slight modifications which are discussed in this section.

5.1. Wire Clamps

The major difference between round and ribbon wire ultrasonic bonders is in the wire-feed and wire-clamp mechanisms. Round wire clamps usually open and close in the horizontal plane while ribbon wire clamps usually open and close in the vertical plane in order to grip the wire across its largest dimension. During the course of the program, three companies developed ribbon wire clamps for evaluation. In general, two types of relatively simple modifications were found necessary in order to obtain optimum performance from these clamps. They involved the clamping surfaces and the clamping force on the wire.

The clamping surfaces were lapped plane-parallel and polished to prevent damage to the wire. It was also found advisable to mill away a portion of the clamp that comes closest to the substrate so that bonds could be made in areas on the substrate such as those, for example, near the edge of a package not readily accessible otherwise. These modifications can be performed during manufacture of the clamp.

It was found that ribbon wire clamps should have adjustable clamp pressures so that the pressure can be set at a point where the bonding surfaces of the wire are not work hardened by excessive pressure. One of the clamps examined did not have provision for easily adjusting the clamping pressure. Another had a pneumatic control that proved satisfactory for this purpose. In one case, the clamp linkage had to be modified so that the clamping surfaces were far enough apart when open that the wire could move freely between, otherwise unwanted variation in bond loop height was found to result.

5.2. Tools

In addition to the experiment previously described where a single tool was used, ultrasonic bonding tools made from different materials and from different vendors were used for making aluminum and gold ribbon wire bonds. Bonding tools from four vendors were used with round and rectangular feed holes in tungsten carbide, titanium carbide, and alloy-tip tools. Rectangular feed holes proved better than round feed holes in feeding the ribbon wire through the bonding tool, and yielded more uniform tail lengths, loop heights, and less twisting of the wire under the tool. In addition, with a rectangular feed hole, positioning the wire on a small bonding pad is easier to accomplish (see figures 4 and 5).

The surfaces of the bonding tools supplied by a given company as well as on tools obtained from different sources appeared to vary significantly. Some tungsten carbide tools were not homogeneous and had a rough surface finish as shown in figure 12. Another tungsten carbide tool from the same source had a much smoother surface finish as shown in figure 13. Both tools were used for bonding both aluminum and gold ribbon and round wire. Some gold build-up is apparent on the tool shown in figure 12. None appears on the tool shown in figure 13. Some titanium carbide tools that were obtained had pin holes on the bonding surface, and the surface finish was poor (figure 14). The titanium carbide material appeared to be softer and to exhibit more wear than other materials. Alloy-tip bonding tools showed gold build-up on the bonding surface, and some gold particles at the exit of the wire feed-hole due to the roughness of the machined hole as shown in figure 15. During the bonding operation, in many cases, some wire shavings were observed to come off the round or ribbon wire and were found as little curls on the bonding substrate. In addition, the tail length of the ribbon wire varied considerably when using any tool with a roughly-machined feed-hole. For one tool, after polishing the feed-

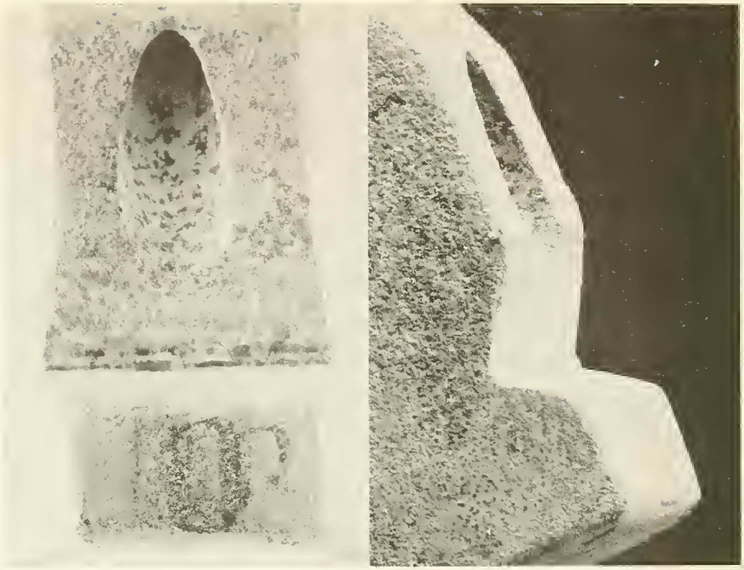

Figure 12: SEM photomicrograph (magnification $\sim$240X) of two views of a bonding tool showing rough surface finish.

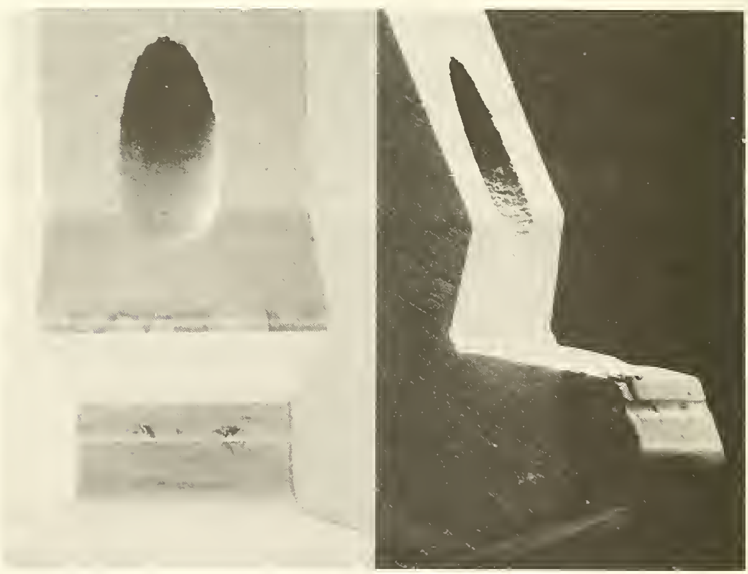

Figure 13: SEM photomicrograph (magnification $\sim$200X) of two views of a bonding tool with a relatively smooth surface finish.

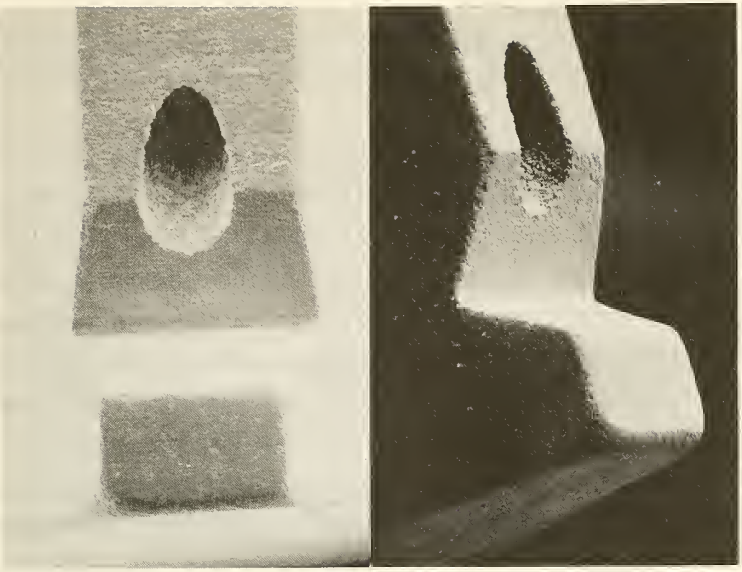

Figure 14: SEM photomicrograph (magnification ∿190X) of two views of a bonding tool showing pin holes in the surface finish.

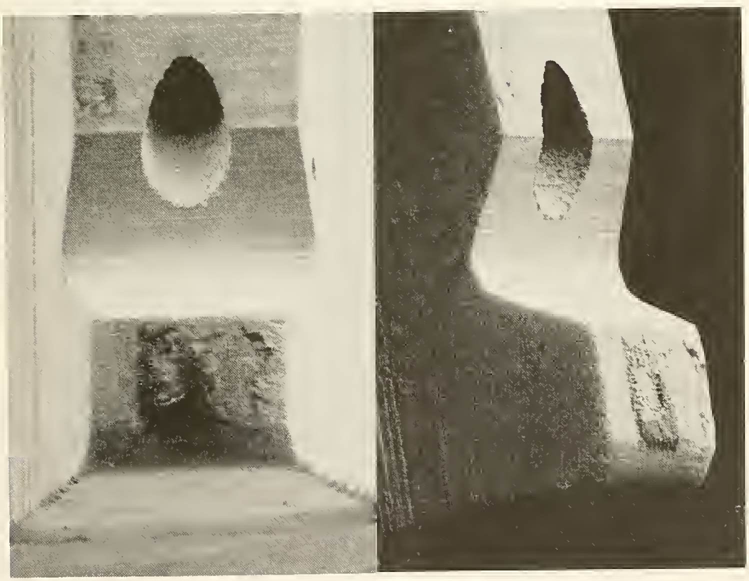

Figure 15: SEM photomicrograph (magnification ∿200X) of two views of a tungsten carbide bonding tool showing build-up of gold at the wire feed hole.

hole with a nylon filament and 3-μm diamond polishing compound, the tail length variation decreased, and the shaving of the wire was virtually eliminated.

Tools with different footlengths, and front and back radii were examined for use with ribbon wire. In order to achieve optimum reproducible pull strength from ribbon wire bonds it is important to make those bonds with a tool having the correct foot length. In round wire bonding, the tool sinks into the wire as it deforms and increases the length (and area) of contact to include much of the front radius of the tool which is typically 1.5 mils. This increases the actual weld length (and area). However, ribbon wire bonds show less deformation than round wire bonds, and the extra length provided by the front radius over the foot length does not contribute to the bond length. A tool with a specified foot length of no less than 4.5 mils has been found to give a satisfactory weld length of approximately 3 mils. Tools with shorter foot lengths tend to produce weaker bonds and bond loops which typically fail in bond pull tests on the second bond. Studies also revealed that the tool heel radius should be no longer than approximately 0.2 mils, otherwise the wire cutoff operation may be impaired.

6. CONCLUSIONS

The advantages that are obtained from the use of ribbon wire rather than round wire can be summarized as follows:

1. Bonds of a desired pull strength can be made with ribbon wire over a much greater range of bonding time and power (tool tip displacement) than can comparable round-wire bonds.

2. Ribbon wire bonds can be made one on top of another. This implies that device repair or replacement, as in hybrid devices, can be simply achieved using ribbon wire bonds.

3. Location of ribbon wire bonds can be readily controlled and such bonds can easily be placed side-by-side on a small bonding pad because there is less tendency for ribbon wire to twist or roll out from under the tool tip during bonding than for round wire.

The results presented in this report have demonstrated the basic feasibility and principal advantages of using aluminum ribbon wire for semiconductor microelectronic ultrasonic bonds.

7. ACKNOWLEDGEMENTS

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8. REFERENCES

References 1, 2, 3, and 5 are contained in quarterly reports of the NBS Semiconductor Technology Program issued in the NBS Technical Note series under the title, Methods of Measurement for Semiconductor Materials, Process Control, and Devices, W. M. Bullis, editor.

1. G. G. Harman, H. K. Kessler, and K. O. Leedy, NBS Technical Note 488, pp. 24-25 (July 1969).

2. K. O. Leedy, NBS Technical Note 495, pp. 24-25 (September 1969).

3. G. G. Harman and H. K. Kessler, NBS Technical Note 527, p. 39 (May 1970).

4. H. A. Schafft, Testing and Fabrication of Wire-Bond Electrical Connections - A Comprehensive Survey, NBS Technical Note 726, pp. 60-68 (September 1972).

5. K. O. Leedy, A. H. Sher, and C. A. Main, NBS Technical Note 743, pp. 27-28 (December 1972).

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16. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)

The feasibility of using aluminum ribbon wire for ultrasonic bonding of semiconductor microelectronic interconnections was studied, and several advantages over the use of round wire of equivalent cross-sectional area were found. Ribbon wire bonds exhibited little deformation or heel damage, and a greater percentage of bonds of a certain quality (as judged by pull strength and appearance) could be made over much greater ranges of the bonding machine parameters, time and tool tip displacement, using ribbon wire than was possible with round wire. The ease of positioning ribbon wire was indicated by making multiple ribbon wire bonds side-by-side on a 5-mil square pad, or by stacking up to four bonds one on top of another. However, bonding with harder than normal wire, previously thought to offer certain advantages with respect to higher bond tensile strength, yielded inconsistent results.

17. KEY WORDS (Alphabetical order, separated by semicolons)

Aluminum wire; bonding; fabrication (wire bonds); microelectronics; ribbon wire; round wire; testing (wire bond); ultrasonic bonding; wire bond.

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