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Effect of laser assistance in ultrasonic copper wire bonding

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Abstract

Due to the required low forces and the necessity of short cycle times in industrial production of electronic interconnections, the use of the established ultrasonic wire bonding is limited for hard materials such as copper. To reduce the applied forces and the cycle times, an additional energy source is applied to the process. This is implemented by integrating a near infrared laser source to the wire bonding setup. The laser radiation is focused on the workpiece during or immediately before the bonding process for heating the wire. This approach enables locally applied energy to be increased during the process without affecting surrounding materials. Thick copper wires with 400 µm diameter are used for bonding to rolled copper plates. For evaluation, the mechanical strengths of the bonds are tested afterwards and the bonding interface is microscopically examined. To prevent the hazard of oxidation of the bond partners during the process, the influence of shield gas is considered as well. The results show a direct relation between the applied laser power and the examined bond strength. This approach opens the opportunity to obtain bonds equivalent in strength to standard ultrasonic wire bonds but with reduced forces and/or bonding times. Hence the attempt to combine ultrasonic and laser power shows an advantage over the individual processes in terms of the resulting bond strength and the handling of the materials and tools.

Keywords: laser heating; hybrid process; electronic interconnection; ultrasonic wire bonding;

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1. Introduction

Ultrasonic (US) wire bonding is widely used for generating interconnections in the electronic industry. Chauhan et al., 2014 say that more than 90 % of semiconductor packages in 2013 were interconnected by wire bonding. The principle behind US bonding is the idea to allow interaction between the materials of the bond partners on an atomic level without a change in phase. Therefor additional heat is not necessary and not applied typically in wedge-wedge bonding. The technique has matured over the past decades and produces high quality interconnections with high productivity. This process can be used with a variety of different alloys as well as with valuable metals such as gold and aluminum. Established are different materials like gold, aluminum and different alloys (Harman, 1977). To enhance the understanding of the process different studies look into the mechanics of the bonding interface. Long et al., 2016 for example have investigated the behavior of oxides during the bond process.

Separate from deeper understanding of the bond process itself, a gain in productivity seems limited by now (Liu et al., 2012). Especially the use of copper wires for high current applications requires higher normal bonding forces and/or longer bonding times. A substitution of the ultrasonic bond process with a mere laser process is unfavorable due to the unwanted emissions such as weld splatter or vaporized metal in an otherwise clean environment of microelectronics.

The attempt shown in this paper is to use an additional energy source during bonding to increase temperature at the process area to support the bonding mechanisms. Singh and Haaseb, 2016 showed an influence of thermal energy on copper wire bonding. In contrast to thermosonic bonding and the attempt of Liu and Sun, 2014 who also applied laser radiation to the bond process, heat is only applied near the bonding interface instead of heating the entire part. Trapp, 2002 already showed that the implementation of laser radiation brings several benefits for the bonding of thick aluminum wires. He points out that with the use of laser radiation the bonding strength could be increased by 25 % for the bonding of aluminum wires on silver alloys.

Due to their complexity, laser systems general are generally not the most cost-efficient way to apply heat. However, since the area to be heated in this case is comparably small, the benefit from lasers (contact less, remote, high intensity) compensates the effort.

2. Experimental Setup

Figure 1 shows the basic setup for the implementation of laser radiation to the workpiece. Instead of heating the whole bonding domain consisting of substrate, wire and bond tool, only the wire that is close to the bonding interface is heated. This attempt significantly reduces the influence of heat to the surrounding materials and saves delicate electronics from thermal stresses.

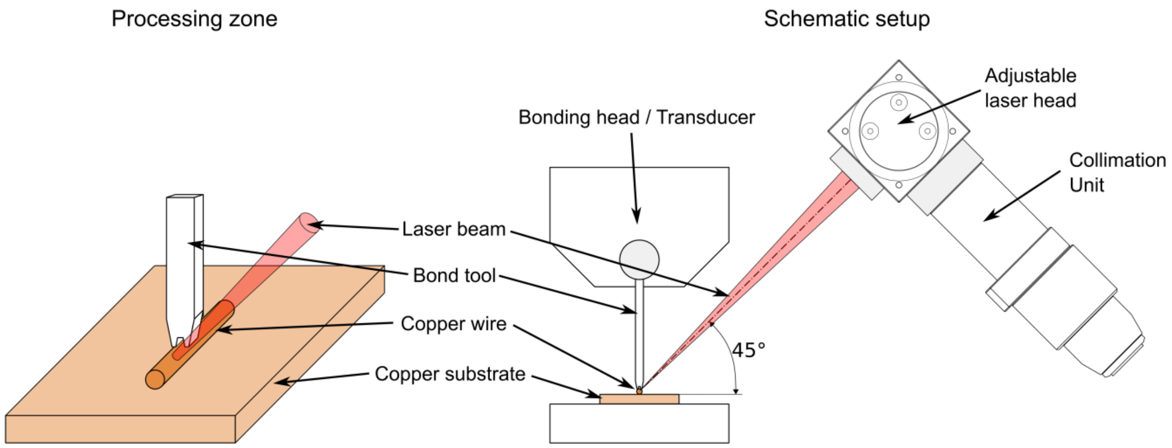

Fig. 1. Processing zone and schematic setup of the laser assisted bond process

2.1. Specimen

Thick copper wires with a diameter of 400 µm from Heraeus were used. It has a specified breaking load of 2000 – 3100 cN and an elongation of more than 15%. K09 copper plates from Wieland with a thickness of 1 mm were used as the substrate.

2.2. Ultrasonic Bonding

The ultrasonic energy was applied via a bonding head HBK 07 from Hesse GmbH. A phase-locked-loop control device was used to generate the stimulation frequency of 60 kHz for the bond tool. The direction of the vibration of the tool tip is in parallel with wire direction.

2.3. Laser assistance

Laser assistance was implemented by using a nLight alta fiber laser. The source is capable of 3 kW continuous emissions at a wavelength of 1080 ±10 nm. The laser radiation is fed to the working head via a fiber with a core diameter of 50 µm. The head contains a mirror mounted on an adjustable platform for exact positioning of the spot onto the wire.

The optical elements for collimation and focusing allow a minimal spot size of 150 µm. To decrease intensity, experiments were conducted out of focus with a spot size of about 300 µm.

2.4. Parameters

Table 1 shows the parameters used for the examination. Variations were carried out for laser power, bonding time and laser-bond-delay. The latter one defines the time between the start of laser radiation and ultrasonic power. The parameters for exposure time, normal force and ultrasonic power have been identified in preliminary studies to be the most promising to show the influence of laser radiation.

Table 1. Parameters for laser assisted wire bonding

Parameter	Unit	Value
Laser power	W	0, 120, 180
Bond time	ms	300, 450
Laser-bond-delay	ms	0, 100, 200, 300, 400, 500
Exposure time	ms	300
Normal force	N	30
Ultrasonic power	W	3

2.5. Evaluation methods

The bonds were evaluated with destructive methods to quantify the mechanical properties and by metallographic imaging to assess the grain structure qualitatively. To obtain the mechanical properties shear tests were conducted with a Condor 70 from XYZTEC. To obtain a statistical value, a set of six specimens were prepared and shear tested with the same parameters.

For metallographic imaging an additional specimen was cut, ground, polished and etched with ammonium persulfate solution to reveal the grain structure. The images were taken with an AxioCam from Zeiss attached to a microscope.

3. Results and Discussion

The strength of the generated bonds is dependent on the tensile strength of the used copper wire and substrate. However there is no linear correlation between input parameters and bond strength and the latter value reaches saturation over bond time. This is where the additional energy in form of laser radiation comes into account to reduce the bond time. As mentioned above, the laser beam was targeted on the part of the wire that was close to the bond tool. Figure 2 Left shows a macro image of a bonded wire. A mark from the applied laser beam is clearly visible close to the bond interface.

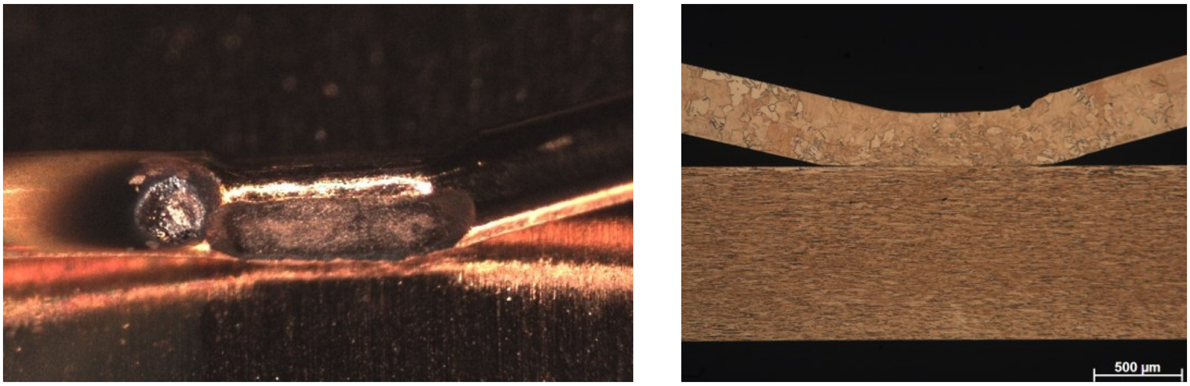

Fig. 2. Left: Bonded wire with laser marking from 120 W radiation; Right: cross section of bond

Figure 2 right illustrates a generic cross section of a bonded wire. Besides its deformation due to the applied energies there is no abnormality and a consistent connection is visible. The grain structure of the material shows no sign of change because of thermal impact.

3.1. Variation in laser power and bond time

Figure 3 shows the average shear force and the corresponding standard deviation (except 180 W and 450 ms) over applied laser power for 300 and 450 ms bond time. The shear force amounts to 22.6 N without laser assistance, 32.4 N for 120 W and 36.1 N for 180 W applied laser radiation. The standard deviation is around 6 N for all three sets of 300 ms bond time. With 450 ms bond time the bond strength increases to 25.7 without laser, 41.7 N for 120 W and 49.2 for 180 W laser radiation.

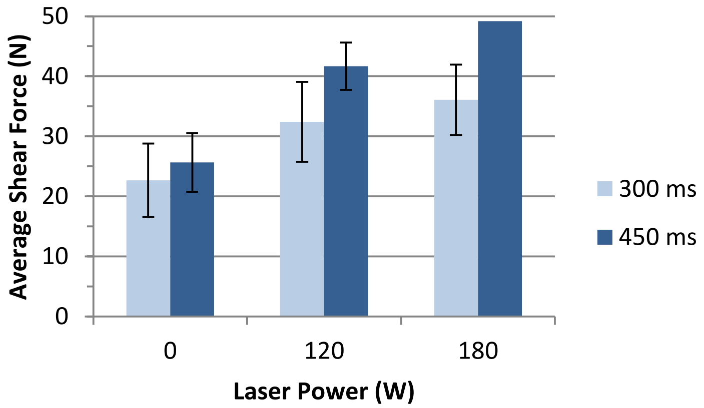

Fig. 3. Shear force over laser power for different bonding times

3.2. Variation in delay time

Figure 4 shows the average shear force over the applied delay time between applied laser and ultrasonic power. Both were applied for 300 ms each, the laser power was 120 W. For reference the graph also contains the value of the set without laser assistance. A growth in bond strength is visible over increasing delay time. This confirms the conception of heat conduction from the laser spot to the bond interface. The values otherwise reach saturation or probably even a maximum when the applied laser energy is absorbed fully and only distributes over the material.

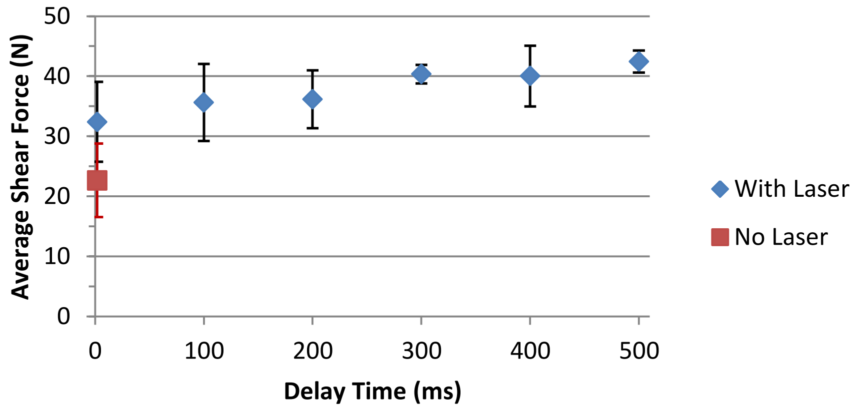

Fig. 4. Shear force over delay time

3.3. Influence of shield gas

Single tests with shield gas were conducted as well for different parameters. Argon was carried to the bonding interface to prevent the influence of oxygen. The results show no significant difference between the bond with and without shield gas. The bond strengths measured for the same sets of parameter differ less than the above determined standard deviation of around 6 N. Without laser assistance the bond strength amounts to 25.2 N with argon and 25.7 N without argon (450 ms bond time). With 180 W laser power and 200 ms delay the difference between shield gas (47.8 N) and no shield gas (52.6 N) is less than 5 N. These numbers imply that a thermally induced effect on the oxidation of the bond partners probably occurs. The mechanism behind this is yet uncertain.

4. Conclusions

The results show a significant benefit for laser assisted ultrasonic wire bonding against conventional US in terms of bonding strength. It is shown that the application of laser induced heat significantly increases bonding strength. In this case by over 60 % with even moderate powers without visibly affecting the grain structure.

Given the low absorptivity of copper for the used wavelength of 1080 nm and the remote spot on the wire heated, the results are promising. Further investigations with higher ultra-sonic power will be done to verify the results on a more practical level for industrial application. As Kaierle et al., 2016 showed, the use of 532 nm wavelength laser radiation could increase absorption and would therefore reduce the required laser power. Also the use of process monitoring tools will be used in the future to control the applied temperature.

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