



Self-cleaning mechanisms in ultrasonic bonding of Al wire

Yangyang Long^{a,*}, Folke Dencker^b, Andreas Isaak^b, Jörg Hermsdorf^c, Marc Wurz^b, Jens Twiefel^a

^a Institute of Dynamics and Vibration Research, Leibniz Universität Hannover, Appelstr. 11, 30167 Hannover, Germany

^b Institute of Micro Production Technology, Leibniz Universität Hannover, An der Universität 2, 30823 Garbsen, Germany

^c Laser Zentrum Hannover e.V., Hollerithallee 8, 30419 Hannover, Germany



ARTICLE INFO

Keywords:

Self-cleaning mechanisms
Ultrasonic wire bonding
Oxide removal process
Transportation mechanisms

ABSTRACT

Real-time observations of the artificially increased oxide layer during the ultrasonic (US) bonding process were carried out to reveal the self-cleaning mechanisms. After the normal force loading, cracks occurred in the Al_2O_3 layer at the peripheral region of the wire/substrate interface and were perpendicular to the wire direction. As the US vibration started, the oxides started to detach from the pure metal surface and moved towards the middle of the contact area. With further vibration cycles, these detached oxides were milled from flakes into small particles. Due to three mechanisms including penetration, oxide flow and pushing, the small oxide particles were transported to the peripheral contact region or the outside of the contact area. When a metal splash existed, the flowing out of large amounts of oxides was facilitated. Pre-deformation originates cracks; vibration plays a significant role in detachment, milling, penetration and oxide flow; while the plastic deformation induced material flow is more critical on removing the oxides from the substrate by pushing. The shear tests showed that a 50 nm oxide coating could significantly enhance the Al-glass bonding strength by 2–3 times.

1. Introduction

As with other welding technologies, the contaminants at the wire/substrate interface must first be removed before direct metal-metal contact for ultrasonic (US) wire bonding. Among the contaminants including dusts, water vapor and other carbon contaminants, metal oxides play an essential role for preventing microwelds formation. Unlike Au wire, Al wire is always covered by a natural oxide layer whose average thickness is around 5 nm. This oxide layer is dense enough to inhibit the invasion of oxygen and prevent the growing of the oxide layer. Other contaminants exist on the top of the oxide layer. Similar to the wire, different kinds of contaminants remain on the substrate surface and constitute an obstacle between the wire and the substrate from direct metal-metal contact, as stated by Long et al. (2017a). Since oxides are the main contaminant that prevents bonding, the oxide removal is the focus of this work.

The US wire bonding technology applies normal force and US vibration to break and remove the oxides at the wire/substrate interface. According to Long et al. (2017a), the US bonding process can be divided into four phases: Pre-deformation and activation of US vibration, Friction, Softening and Interdiffusion. The first three phases have significant impacts on the oxide removal. During Pre-deformation, the normal force induced plastic deformation can cause cracks on brittle oxide scales (Al_2O_3) at the tips of asperities and the peripheral region of

the wire/substrate contact, as pointed out by Harman and Albers (1977). The oxides are then detached from the pure metal surface. Based on the classic wear law, Seppänen et al. (2007) calculated that the friction during a 120 ms bonding process can only remove 0.6 nm of Al_2O_3 . As a result, the discretized oxides shall be detached with a whole 5.0 nm thickness by tall asperities during the friction phase. During the softening phase, the continuous plastic deformation induced material flow also facilitates the oxide removal. However, the specific roles of friction and softening are still unclear. It was suggested by Gaul et al. (2006) that the US vibration induced relative motion detached the discretized oxides from the metal surface and the continuous plastic deformation induced material flow carried the detached oxides to the periphery of the contact. This hypothesis will be verified in this work. As observed by Maeda et al. (2013a) and Long et al. (2016a), the oxides roll like snowballs and accumulate in the peripheral region. The current knowledge of the oxide removal process and the related phases is summarized in Fig. 1. The font size of the phases qualitatively indicates their significance on the corresponding removal step. The wire bonding process, especially the wedge-wedge bonding, has a very high self-cleaning efficiency. As proved by Krzanowski and Murdeshwar (1990) and Long et al. (2016b), a 40 nm carbon layer and a 200 Al_2O_3 coating did not hurt the quality of thin wire and thick wire bonding, respectively. Despite this, not all oxides can be removed. Geißler (2008) and Xu et al. (2010) observed that some oxides remain within the wire/

* Corresponding author.

E-mail address: long@ids.uni-hannover.de (Y. Long).

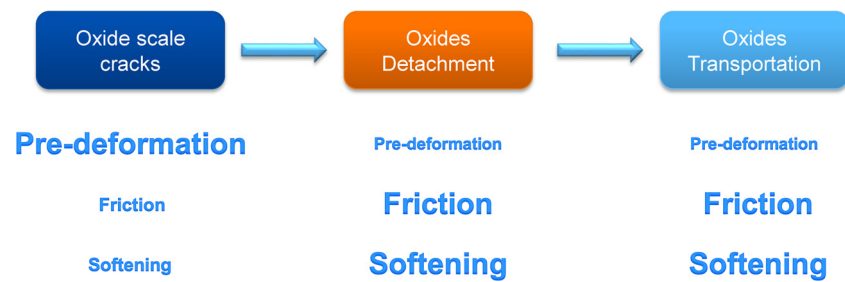


Fig. 1. The literature described oxide removal process with the significance of corresponding phases.

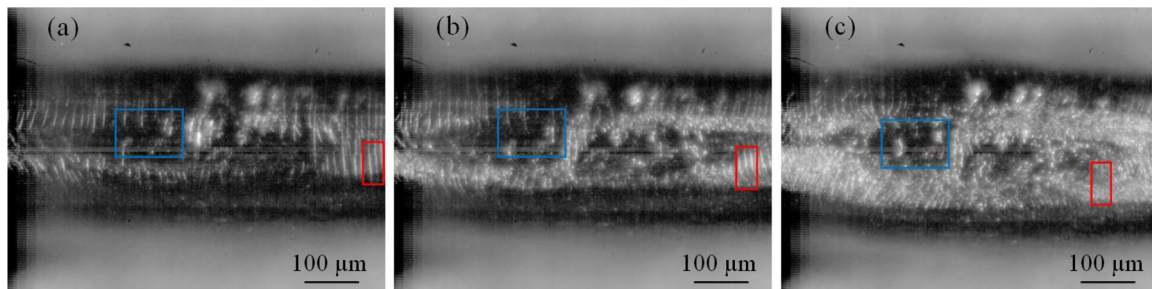


Fig. 2. Cracks, detachment and milling of Al_2O_3 coated layer at the wire/substrate interface under 5 N, 1.4 W at the processing time of (a) 0.00 ms (b) 1.20 ms (c) 3.50 ms (For interpretation of the references to colour in text, the reader is referred to the web version of this article).

substrate contact region and no microwelds can form at those locations. Nevertheless, the steps are not completely understood and the mechanisms for oxides transportation are unknown. These issues are the subject of this work and analyzed by visualization of these steps.

To realize the visualization of the oxide removal process at the wire/substrate interface, transparent SiO_2 glass was used to substitute the normally used metal substrate. Since the natural oxide layer on Al wire is too thin to be observed, different kinds of oxides were artificially coated on the surface of either the wire or the substrate in order to facilitate the visualization of the oxide removal mechanisms. In the following sections, the coating process and the real-time observation system are first described. The results on the oxide removal mechanisms as well as their validations are then provided and discussed. This work can be considered as a preliminary effort to understand the oxide removal mechanisms in metal-metal bonding.

2. Experimental setup

The aluminum wire used in this work is Al-H11 purchased from Heraeus GmbH. The thick wire has a diameter of 400 μm and a breaking load of 500–700 cN with more than 5% elongation. The transparent silica glass with a dimension of 40 \times 40 \times 3 mm and a surface roughness of less than 1.2 nm was used as the substrate. Some of the wires and glasses were coated with Al_2O_3 or ZrO_2 within a Kenotec RF (13.56 MHz) 6.5" target magnetron sputter device. Al_2O_3 and ZrO_2 were deposited at a rate of 6 nm/min and 2 nm/min, respectively. When a thick oxide layer was required, the deposition process was interrupted every 10 min to prevent high chamber temperatures that would dramatically change the material properties. With a Hysitron TI 900 Triboindenter, the nano-hardness of the coated Al_2O_3 and ZrO_2 was measured to be 12.07 ± 1.33 GPa and 6.25 ± 1.38 GPa, respectively. The hardness of ZrO_2 is only about half of that of Al_2O_3 .

The thick aluminum wire bonding head HBK05 was provided by Hesse Mechatronics GmbH. The natural frequency of the transducer in the bonding head is around 60 kHz and was driven by an in-house developed digital phase controller (Ille and Twiefel, 2015) and a B&K 2713 amplifier. The oxide removal process was observed by a real-time observation system. The real-time observation system consists of a high-speed camera Phantom v710 and an 18X reverse-lens magnification

system. The recording window size, resolution and the frame rate of the observation system used in this work were 640 \times 480 pixel, 1.1 $\mu\text{m}/\text{pixel}$ and 20,000 fps, respectively. The recording time as well as the bonding process time were set as 400 ms for all the tests. To gain sharp images, the exposure time was set as 2 μs . A laser source JOLD-45-CPXF-1P was applied to provide illumination on the observed area (704 \times 528 μm) within the extremely short exposure periods.

3. Results and discussion

3.1. Mechanisms

3.1.1. Cracking, detachment and milling

Due to the extremely high hardness of Al_2O_3 , cracks were supposed to occur. This could be observed on the wire specimens where a 50 nm Al_2O_3 layer was deposited. As shown in Fig. 2 (a), obvious cracks formed after a normal force of 5 N was loaded onto the coated wire. The processing time of 0.00 ms in Fig. 2 indicates the moment when US vibration started. The cracks exhibited a direction which was perpendicular to the wire direction and distributed at the peripheral contact region. The intensity of the cracks was higher at the two end regions than in the middle region. This indicates that stresses concentrated at the peripheral contact region due to the large strain and large stress gradients in the wire direction, especially at the two end regions. The material flow during this stage did not cause the detachment or the removal of oxides. As the cracking is associated with pre-deformation, it normally takes less than one millisecond, as reported by (Unger et al., 2014).

When US vibration (1.4 W) was activated, the discretized oxides started to detach from the pure metal surface in the form of flakes, which can be observed by the motion of the oxides in the red rectangular from Fig. 2(a) and (b). In fact, the detachment of the local oxide took place at the moment when it moved from its initial place. In other words, it took less than one millisecond and happened before the time of (b). Due to the different relative motion amplitudes at different locations of the wire/substrate interface, the detachment started from the peripheral region, especially the two end regions. Unexpectedly, the detached oxide flakes moved from the two ends towards the middle contact region instead of moving outwards, which is in contradiction to

Download English Version:

<https://daneshyari.com/en/article/7176324>

Download Persian Version:

<https://daneshyari.com/article/7176324>

[Daneshyari.com](https://daneshyari.com)