Solid State Sciences 13 (2011) 72–76

Contents lists available at ScienceDirect

Solid State Sciences

journal homepage: www.elsevier.com/locate/ssscie

HRTEM and X-ray diffraction analysis of Au wire bonding interface in microelectronics packaging

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ARTICLE INFO

Article history:
Received 20 April 2010
Received in revised form
2 September 2010
Accepted 21 October 2010
Available online 2 November 2010

Keywords:
Wire bonding
Interface
Microstructure
Intermetallic

ABSTRACT

Interfacial microstructures of thermosonic Au wire bonding to an Al pad of die were investigated firstly by high-resolution transmission electron microscopy (HRTEM) and X-ray micro-diffractometer. The equal-thickness interference structures were observed by HRTEM due to diffusion and reaction activated by ultrasonic and thermal at the Au/Al bond interface. And X-ray diffraction results showed that three different interplanar crystal spacings ('d' value) of the interfacial microstructures were 2.2257 Å, 2.2645 Å, and 2.1806 Å respectively from the high intensity of diffraction to the low intensity of diffraction. These indicated that the intermetallic phase $AlAu_2$ formed within a very short time. It would be helpful to further research wire bonding technology.

1. Introduction

The wire bonding technology is widely used in microelectronics packaging interconnection. As most of the failure results from the bond interface, the interface features have always been concerned [1–3]. The long-term thermal reliabilities of an aluminum wire wedge bonding on aluminum and Au/Ni/Cu pads were detected by using energy dispersive X-ray (EDX) testing results of Scanning Electron Microscopy (SEM), and the interfacial intermetallic compounds (IMC) generated at bond interface after aging in air at 200 °C for 240 h [4]. Generally, a gold (Au) wire is bonded to an aluminum (Al) pad of die by using a ball bonder. Actually, with the improving of wire bonding technology, Au ball wire bonding is finished only within 5–15 ms (ms), so, the IMC of bonding interface may be a very thin layer with thickness of several tens of nanometers, then the IMC can't be observed by many packaging engineers with optical microscopy and SEM [5].

Recently, the reactant of thermosonic Flip Chip bonding was identified as the intermetallic phase (Au_4Al) by using scanning transmission electron microscopy (STEM) by Li et al. [6,7]. EDX testing results only shown their composition of Au–Al, while lattice structure of IMC wasn't proven, and the same composition may form different lattice structures. IMC of ultrasonic Al–Si wire wedge bonding to a Au/Ni/Cu pad was reported as Al_3Au_8 by using transmission electron microscopy (TEM) by Geiβler [8], Karpel Adi [9]and Ji [10]et al. However, none of the above intermetallic phases is firmly identified on atomic scale concerning no matter ball or wedge bond interface, and is still debated [10,11]. As we all know, X-ray diffraction spectra of lattice structure is like one's fingerprint, and can give more precise microstructure parameters than TEM.

So, in our study, the interfacial characteristics of Au wire ball bonding to an Al pad of die were investigated firstly by using the high-resolution transmission electron microscopy (HRTEM) and the X-ray diffractometer. Based on captured images and data, microstructure of the Au–Al interface layer was discussed.

2. Experimental

In the experiment, the bonding agent was applied with a K&S 8028 Au wire bonder. Bonding tool was ceramic capillary series 07-01, and the 25 μm diameter Au wire was ball-bonded on a 2 μm thickness Al pad of die which substrate is the single crystal silicon (Si) as shown in Fig. 1. The bonding parameters were as follows: 125 mA ultrasonic current (resonant frequency 123 kHz), 25gf (1gf = 9.8 mN) bonding force, 15 ms bonding time and 160 °C bonding temperature.

Since the standard sample for the HRTEM is thinned 3.0-mm diameter disc, and thickness should be thinned enough to be

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doi:10.1016/j.solidstatesciences.2010.10.011

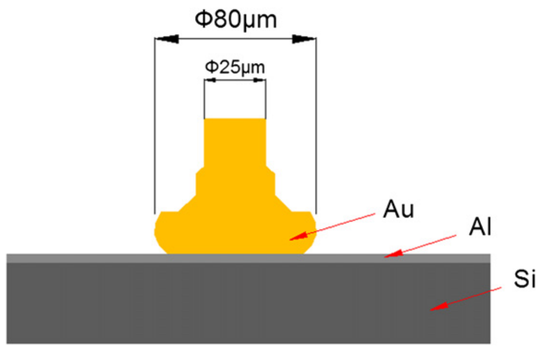

Fig. 1. Au Wire bonded on an Al Pad.

electron-transparent, HRTEM samples of the bonding interfaces were prepared by embedding in the epoxy, punching, grinding and ion-sputter thinning. Then the bonding interface was detected with FEI Tecnai F30 field emission HRTEM that resolution is 0.14 nm at 300 kV.

For X-ray diffractometer sample, the bonding interface must be revealed. A sample with 200 Au-balls bonded to a 2 × 2 mm Al pad of die was embedded in the resins, and was ground carefully until the bonding interface was found as shown in Fig. 2. Then the bonding interface was performed with RIGAKU RAPID X-ray micro-diffractometer at 48 kV voltage, 250 mA current, 50 um beam size, 30 min exposure time.

3. Results and discussion

Fig. 3 shows cross-sectional low magnification HRTEM image of the Au–Al bonding interface. It exhibits the cross-section of the bond Au wire joined to the Al layer. The darker area shows Au bond wire, and the brighter indicates Al layer. The irregular shades between the dark and the bright represent a bonded interface.

Fig. 4 shows a two-dimensional lattice image of the interface and the reactant. It clearly demonstrates the presence of inter-diffusion and reaction at Au–Al bonding interface. Some equal-thickness interference structures may present the microstructure of Au–Al intermetallic compound, and their intervals are regular. The atomic inter-diffusion and reaction of bonding interface possibly results in a change of lattice structure at the bond interface. These micro-characteristics indicate the formation of the metallurgically bonded joints.

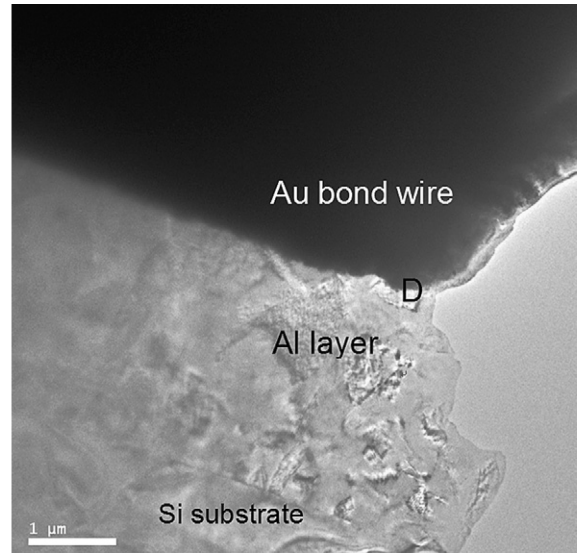

Fig. 3. Low magnification image of the bonding interface.

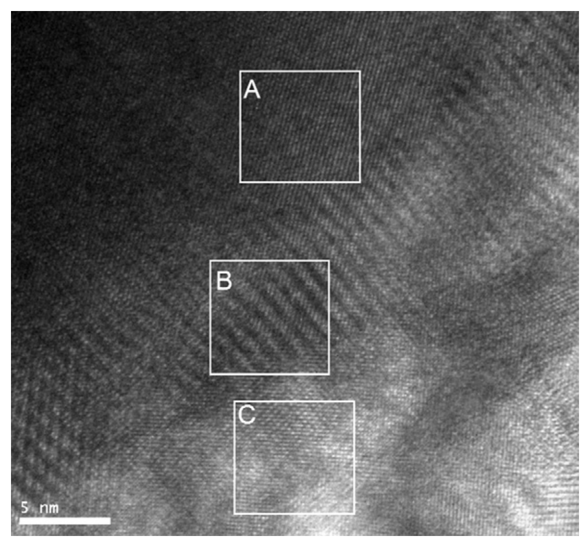

Fig. 4. Two-dimensional lattice image of interfacial characteristics taken from the region D in Fig. 3.

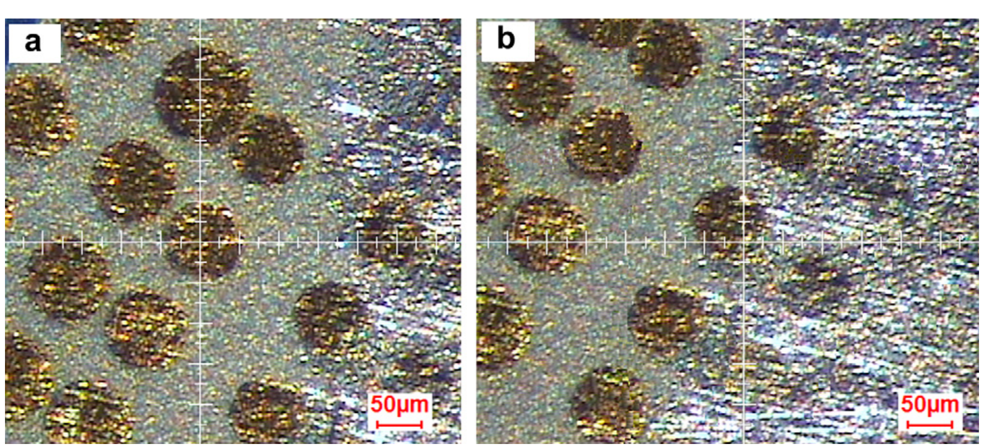

Fig. 2. X-ray analysis location. (a) the unrevealed bonding interface in the region, and (b) the revealed bonding interface in the region.