Extended Abstracts of the 2013 International Conference on Solid State Devices and Materials, Fukuoka, 2013, pp480-481

Heavy Ribbon Wire Bonding for Advanced Power Module Packages

Semin Park, Shijo Nagao, Tohru Sugahara and Katsuaki Suganuma

Inst. Sci. Indus. Res., Osaka Univ.,
Mihogaoka 8-1, Ibaraki, Osaka 567-0047, Japan
Phone: +81-6-6879-8521, E-mail: seminpark@eco.sanken.osaka-u.ac.jp

Abstract

Metal ribbon wiring attracts much attention for next-generation power-electronics interconnection technology, which requires wider capacity of electrical current in smaller package. The bonding methods of metal ribbons are to be optimized suitable for the larger bonding area than conventional thin string wires, and also for the more harsh operating conditions achieved by wide-gap semiconductors. We here use ultrasonic bonding for Al ribbon (1500×200 µm) on to electroless Ni immersion gold (ENIG) finished cupper substrate, and optimize the bonding process parameters to minimize the heat damage with sufficient bonding strength. Aging tests of the bonded specimens at 200 °C are ongoing, together with the interface microstructure observations.

1. Introduction

Interconnections in high power electronic devices generally require a wide capacity of electric current, while both the miniaturization and high-temperature stabilities become the issues for next generation wide band-gap semiconductors like SiC and GaN. Heavy ribbon wiring is emerging in the field to replace the thin string metal wires that are popularly used in integrated semiconductor device packaging [1-3]. The wide cross-section area of metal ribbon wires increases the maximum current through the wire, without increasing the total package size. However, bonding method of ribbon wires have not yet been established, particularly for high temperature stability in power devices.

Ultrasonic wire-bonding method is popularly used in the device packaging, applying acoustic energy to wire bonding interface under the pressure by a tool tip (see Fig. 1**a**). During the bonding process, temperature elevation is undesirable to avoid degradation of facing metal parts between wire and substrate, particularly for Al wires of which mechanical strength may be affected by grain growth at high-temperature. It is thus important to optimize the bonding parameters like tool pressure and acoustic power.

In this study, we perform precise pull tests to evaluate the mechanical reliability of Al ribbon bonding on ENIG finished cupper substrate, and optimize the process parameters at room temperature. It is found that sound bonding can be achieved without heating, showing no lift-off fracture due to heel cracking. We would suggest the optimized bonding parameters of ultrasonic bonding of heavy Al ribbon wiring.

2. Experimental

Al ribbon bonding on ENIAG finished Cu substrate

Heavy ribbon bonding process that uses a flat form metal wire rather than thin metal string is a kind of wedge bonding process, and typically employs a bonding machine equipped with rectangular shaped tool head (see Fig. 1**a**). In our case, TPT HB-30 (http://www.tpt.de/) semiautomatic ribbon bonder is used to maintain a certain bonding shape (Fig. 1**b**) as well as automated alignment and positioning. The machine is arranged in capable of thermocompression, thermosonic, and pure ultrasonic bond process of heavy metal ribbons like 1500×200 µm cross-section of Al or Cu

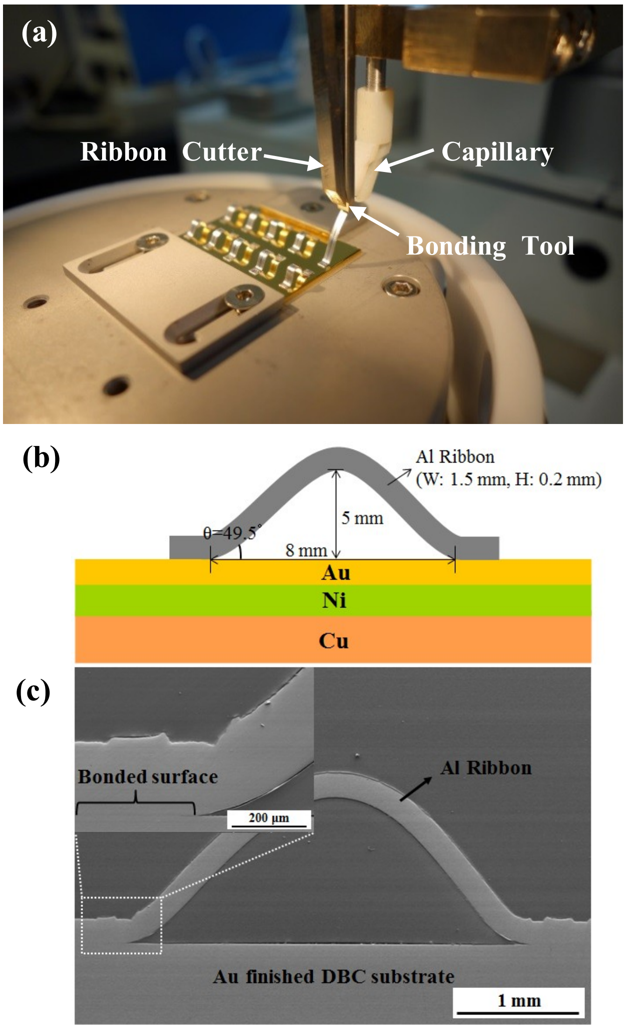

Fig. 1 Schematics of (a) heavy ribbon bonding method; (b) our standard design of ribbon wiring loop, and (c) SEM observation image of a cross-sectioned sample.

wires.

ENIAG finished cupper substrates for our tests are electroless plated by Au (0.1 µm) /Ni (3 µm), which is a low cost chemical plating without introduction of electricity. Basically the principle of the electroless plating is that the reduction reactions are performed on the activated solid solution's surface [4-6].

Applied bonding parameters are ultrasonic frequency and bonding time. The detailed parameter of ultrasonic frequency is varied from 1 to 2 kHz. The bonding time are extended from 1 to 2 sec. The bonding pressure applied by the tool tip is fixed to 1 N. Since the ribbon bonding area is bigger than that of string wire, such long bonding time and high ultrasonic frequency are required for successful bonding.

Mechanical evaluation by pull test

Pull tests are popularly accepted for mechanical strength evaluation of wire bonding, and are generally useful to indentify a source of reliability problems triggered by mechanical failures. Our ribbon bonding samples are also tested by pull tests (DAGE, XD-7500) to evaluate the tensile strength and the features of wire bonding process. It is noteworthy that pull tests for ribbon bonding have not been standardized yet. Therefore, we have maintained the same shape of bonded wire loop shown in Fig. 1**b** and 1**c**, aiming to establish a standard test conditions of ribbon wire pull test.

Ribbon bonding parameters optimized by lift-off failure

Our results of ribbon bonding strength are plotted in Fig. 2 for various bonding conditions of ultrasonic frequency and processing time. Several samples are tested in each bonding conditions, and the error bars show the standard deviations. Figure 2 obviously displays that higher frequency of ultrasonic results in higher tensile strength, while the process times longer than 1.6 sec exhibit no improvement in the strength.

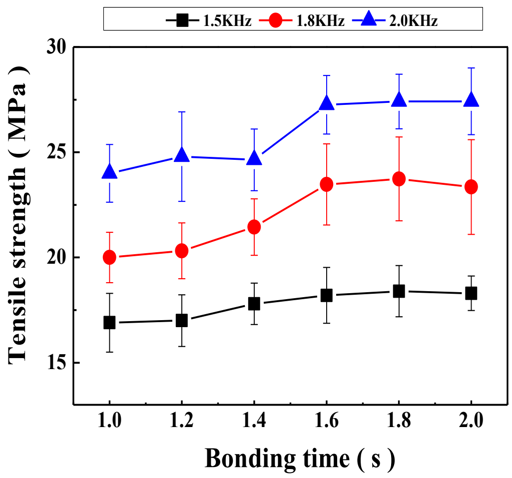

Fig. 2 Tensile strength values of evaluating the pull test in different bonding conditions.

Table I Lift-off rate of pull tests

Ultrasonic frequency (kHz)	Bonding time (sec)					
	1.0	1.2	1.4	1.6	1.8	2.0
	Lift-off rate (%)					
1.5	100	100	100	100	100	100
1.6	100	100	100	100	100	100
1.7	100	100	100	90	100	90
1.8	100	90	100	80	90	80
1.9	90	80	90	40	30	20
2.0	80	60	40	10	0	0

Each pull test ends in two failure modes, i.e. ribbon fracture and "lift-off". The latter mode means failure of bonding process, often triggered by "heel cracking" at the inside edge of the bonding interface. The possibilities of lift-off failures are summarized in Table I. No lift-off failure happens when 2.0 kHz ultrasonic is applied over 1.8 sec. The complete bonding is only achieved under these conditions, and the resulting strength exceeds 28 MPa (see Fig. 2). On the other hands, lift-off failure always occurs under the 1.8 kHz of ultrasonic frequency, and the strength remains less than 25 MPa. This means the Al ribbon used in the present study fractures at this tension, when our bonding loop geometry is adopted.

Understanding the heel fracture behaviors are complex and thus out of our scope in the present study. Further investigation of reliability tests like thermal cycling may be necessary to clarify the issue. The authors are carrying out more reliability tests on the Al ribbons, hoping to explain the heel cracking mechanisms under stress.

3. Conclusions

Optimizations of Al ribbon bonding process have been achieved by evaluating mechanical strength by pull tests. The lift-off phenomenon at the bonding area mainly depends on the acoustic frequency of the ultrasonic, and a sound mechanical strength about 28 MPa between Al ribbon and ENIG finished Cu substrate can be obtained by 1.6 sec processing of 2.0 kHz ultrasonic.

Acknowledgements

The present work is partially support by Grant-in-Aid for Scientific Research (S); Grant Number 24226017.

References

[1] M. Li *et al.*, *Ultrasonics* **45** (2006) 61-65.
[2] A. Shah *et al.*, *J. Appl. Phys.* **106** (2009) 013503.
[3] X. Liu *et al.*, *The International Journal of Microcircuits and Electronic Packaging* **23** (2000) 407-413.
[4] H. Clauberg *et al.*, *Microelectronics Reliability* **51** (2011) 75-80.
[5] C. Biasotto *et al.*, *The society for solid-state and electrochemical science and technology* **39** (2011) 385-392.
[6] H. Xu *et al.*, *Intermetallics* **19** (2011) 1808-1816.