

HEAVY ALUMINUM WIRE WEDGE BONDING ON LTCC SUBSTRATE FOR AUTOMOTIVE ELECTRONICS

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Abstract

This paper will discuss the substrate and package design issues that should be considered when developing a ultrasonically heavy aluminum wire wedge bonding process which are widely used for electrical and signal/power interconnections for automotive electronics. With electronic packages getting denser and thermal management more critical, wire bonding that is one of the main forms of interconnection of die to substrate and substrate to DBC or housing should have higher reliability characteristics. The present work is an investigation concerning the effect of bond pad of substrate and metal finishing on the bondability of ultrasonic aluminum wedge bonding, as well as the effect of wire and bonding parameters. Firstly, it was found that the thickness of the base metal (Ag surface conductor) of low temperature co-fired ceramics (LTCC) substrate played a critical role on bondability. And secondly, the surface metal finishing which is electroless Ni/Pd/Au plating (ENEPIG) system is superior to that of electroless Ni/Au (ENIG) plating.

Key words

LTCC, Wedge bonding, Automotive electronics, Package, Reliability. ENEPIG

I. Introduction

Low temperature co-fired ceramics (LTCC) technology has been widely used for module or substrate in mobile/RF, wireless communication, and automotive electronic fields. LTCC has stronger characteristics than other solution as organic substrate; thermal dissipation property, miniaturization, multilayered 3D package structure, and harsh environmental operating aspects. In spite of these advantages, some technical issues are still remained uncertain. As shown the typical package structure of automotive electronics in Fig. 1, initial stage of package design, module or substrate and packaging should be considered the materials (encapsulant, EMC molding compound, overcoat), interconnection method (wire bonding, flip chip), surface mounting (soldering, conductive epoxy), and thermal adhesive, etc. In recent years, packages are more complex and multifunctional due to combination of different technologies. Especially in automotive electronics, the package interconnection which are combined with various technologies must be fully proven and have higher reliability characteristics than other applications. Wire bonding the microelectronic interconnection technique was most widely used in the IC-package, module, and board level packaging. There are three methods generally used for making wire interconnections.

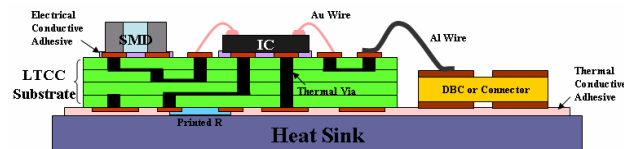


Fig. 1. Package structures in automotive electronics

These are ultrasonic bonding, thermo-compression bonding, and thermo-sonic bonding as the bonding energy style. Ultrasonic energy wedge bonding is room temperature interconnection techniques which decrease the bonding force and temperature dramatically, by which the bond formed lower loop profile, finer pitch, higher reliability, and no limitation to the wire diameter. Therefore, many automotive electronics and optoelectronic devices used this method to realize the power and signal transmission. There have been many reports of the ultrasonic wire bonding mechanism, but still not fully understood [1]-[3]. Main factors affecting bondability are shown in Fig. 2.

In package concept designing, one of the critical factors is metallurgical system of substrate. Generally, bonding materials are gold or aluminum metal wires and die metallization is aluminum pad. And, surface metallization of

LTCC substrate is typically electroless Ni/Au plating on the Ag conductor. Using heavy aluminum wire, Au/Al bonding metallurgy system is constructed at the substrate side. It is well known that Au-Al wire bonding system easily forms various intermetallic compounds; AuAl, AuAl₂, Au₅Al₂, Au₂Al, and Au₄Al [4].

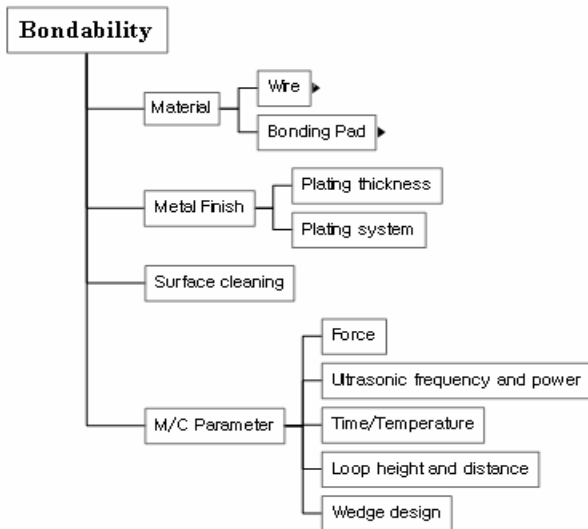


Fig. 2. Critical factors of wire bondability

The formation of IMC which is associated Kirkendall voids can be accelerated by the temperature and time of operating. Furthermore, these intermetallic compounds are brittle, so vibration or thermal cycling test may lead to bond failure by induced interface fatigue and stress cracks [5].

In this study, we firstly focused on the metallurgical systems which are electroless Ni-P emersion gold (ENIG) and electroless Ni-P electroless palladium emersion gold (ENEPIG) in LTCC substrate. There have been some reports that ENEPIG is better than ENIG plating system in aspect of long term reliability in case of the soldering type of package [6]-[8]. But, there were no reports that the effect of ENEPIG system to the ultrasonically aluminum wedge bondability. Secondly, wire bonding pad thickness effects on the wire bondability are studied. Differing from PCB in view of material properties, LTCC substrate has higher modulus, hardness, density, surface metals, and etc. So, it is different wedge bonding property that of LTCC surface metal structure. As previously mentioned, we designed the experiments that are combination of two main factors and two level DOE. Evaluation is conducted in the view of bondability and reliability.

II. Experimental Procedure

A. Materials and process

Experimental designs and test board layout of this study are shown in Table 1, and Fig.3. LTCC is conventional glass ceramics and constrained sintered substrates are used. Bonding pad was formed by post printing and firing process. The conductor thickness of bonding pads was controlled by the screen mesh and emulsion thickness. Electroless Ni-P immersion gold (ENIG) and electroless Ni-P electroless Pd immersion gold (ENEPIG) methods are used. The target thickness of Ni-P was 5.0 ± 1.0 μm , and gold is $0.05 \sim 0.1$ μm , and Pd was $0.05 \sim 0.1$ μm , respectively. FIB and XRF were used to observe the thickness of plated layer.

Table 1. Experimental design of substrate

Factors	Level	
1) Conductor thickness (μm)	Thin (5~8)	Thick (15~20)
2) E'less plating	ENIG*	ENEPIG**

* ENIG : Electroless Nickel Immersion Gold

** ENEPIG : Electroless Nickel Electroless Immersion Gold

Ultrasonic wedge bonder was M3600 series made by Orthodyne. Used Al wire, AL-H11CR, was 12mil in diameter and 99.99% Al produced by Heraeus. Wedge bonding was carried out on test board with various options in Table 1 and machine parameters are set up by DOE. As shown in Fig. 3, test board size is 50mm x 50mm and thickness is 0.6mm. Bonding pad size is 1.0mm x 1.5mm and pad spacing is 3.0mm

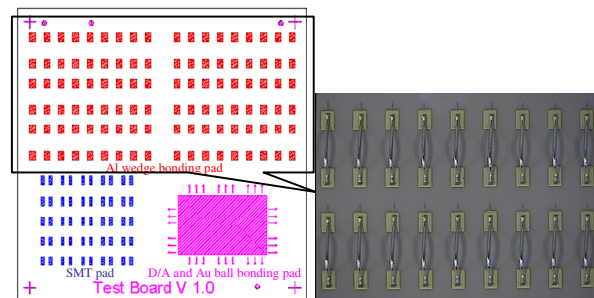


Fig. 3. Test board layout

B. Evaluation

Table 2 shows the evaluation items and methods of reliability. Bondability and degradation behaviors of wedge bonding during accelerated environment and thermal fatigue tests were evaluated by measuring visual inspection with optical microscope and scanning electron microscopy (SEM) and destructive wire pull and shear strength test with Dage series 4000 tester.

Table 2. Reliability Test Condition

Items	STD/Method
Thermal shock	MIL-STD-202/Method 107
Humidity	MIL-STD-202/Method 106
Vibration	AEC-Q100-REV
Low temp. storage	MIL-STD-202/Method 108
High temp. storage	JASO-D0001-94

III. Result and Discussion

A. Effect of Bonding Pad Thickness on Wire Bondability

In this experiment, the heavy aluminum wire was bonded to thin (5~8 μ m) and thick (15~20 μ m) bonding pad. Bonding pad thickness means base metal (Post fired Ag paste) thickness after firing except for the plating (ENIG) thickness on LTCC substrate. Parameters of wire bonder are set as following; force = 430g (start), 570g (end), power = 80mW (start), 90mW (end), and time = 50ms. Fig. 4 shows the effect of bond pad thickness on the wedge bondability by measuring the shear strength and fracture mode after wire shear test, respectively. In case of thinner bonding pad, pads lifts off occurred and shear strength was lower than that of thick bonding pad at about 60%.

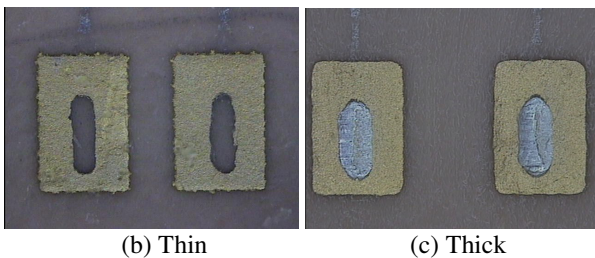
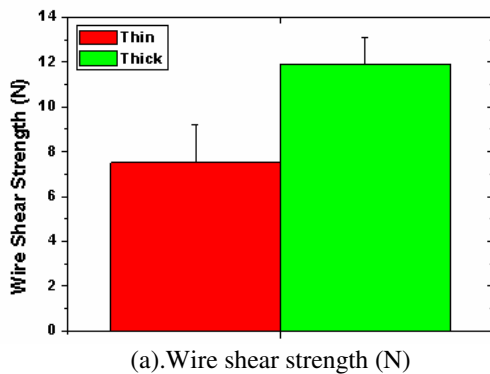


Fig. 4. Shear strength (a) and fracture mode (b), (c) after wire shear test as a function of conductor pad thickness.

During the wedge bonding process, mechanical force and ultrasonic energy are the primary driving force to form inter-metallic bonding. It is very important that matching of

two different metals which are wire and bond pad; hardness, atomic diffusivity, thermal expansion coefficient, etc. Considering with the bonding parameters, bonding energy as previously mentioned was applied to the wire and pad simultaneously and pass through the interface between substrate and conductor pad that cause damage to the interface in case of thinner conductor pad. As a result, it is very critical factor that the thickness of conductor pads to the aluminum wire wedge bondability in the LTCC substrate and conductor pad system. Schematics that could explain the effect of base metal thickness on wedge bondability are shown in Fig. 5.

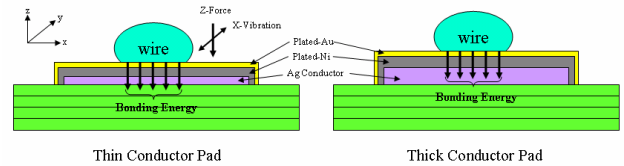
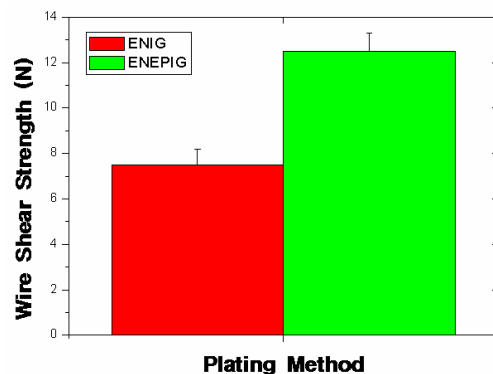


Fig. 5. Schematics of the conductor thickness effect on Al wire wedge bondability.

B. Effect of Substrate Metal Finishing on Wire Bondability

Fig. 6 shows the effect of metal finishing method (electroless plating) on the aluminum wire wedge bondability. Conductor thickness of the bonding pad was $16 \pm 1 \mu$ m in both case. The only difference in this study is the metal layer structure as previously mentioned. Electroless Ni-P immersion gold (ENIG) system shows lower wire shear strength than that of electroless Ni-P electroless Pd immersion gold (ENEPIG), and the fracture mode is different. For the latest industrial and technical trends, the most challenging issue for the reliable multipurpose packaging is to find a suitable surface finishing solution [6], [7].



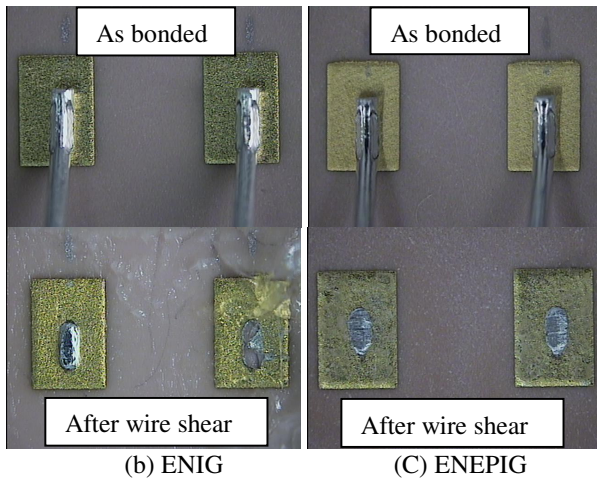


Fig. 6. Shear strength (a) and fracture mode (b), (c) after wire shear test as a function of metal finishing method

In our experimental result, ENEPIG solution is better for heavy aluminum wedge wire bonding. Metallization of substrate (in case of LTCC) is typically electroless Ni/Au plating on the substrate. So, Au and Al wire bonding metallurgy system is constructed at the substrate surface side. It is well known that Au-Al wire bonding system easily forms various intermetallic compounds due to the different thermal diffusion coefficient of each component [4]. In ENEPIG system, Pd deposits played a role of barriers that prevent Ni-P from diffusing into Au layer and retard the diffusivity of Al. That is important factor in soldering and wire bonding reliability. Fig 7 shows the schematics of metal finishing system.

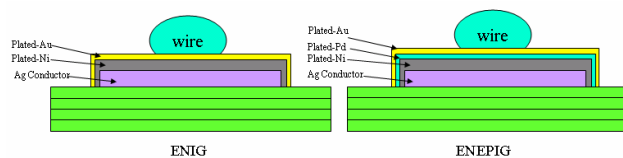


Fig. 7. Schematics of metal finishing solution effect on Al wire wedge bondability.

C. Reliability

Previously mentioned in table 2, the long term environmental reliability is tested in case thicker base metal and ENEPIG solution which is best solution of our study. Evaluations are conducted by fracture mode and wire shear strength in refer to MIL-STD-883 and EIA/JESD22-B116. Fig. 8 shows the shear strength of wedge bonding, and fracture mode is wire in all case. In case of 12-mil Al wire wedge bonding, shear strength is not specified in test standard. So, we setup the preliminary LSL value at 5N in our system by experimental results corresponding to fracture mode. All of the reliability

test items meet the requirements (min. 7N) and no failure, but, shear strength was lowered as the test term.

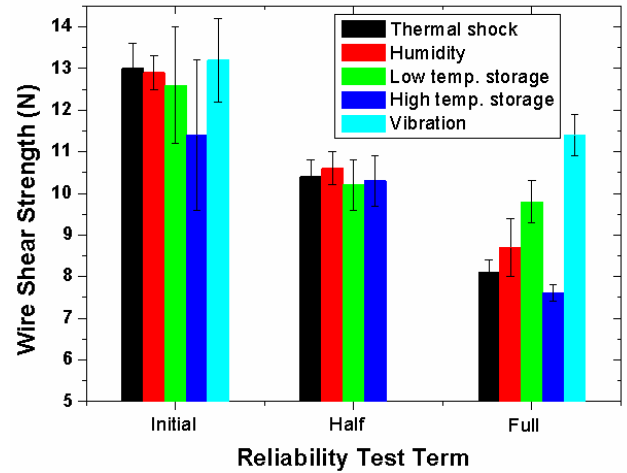
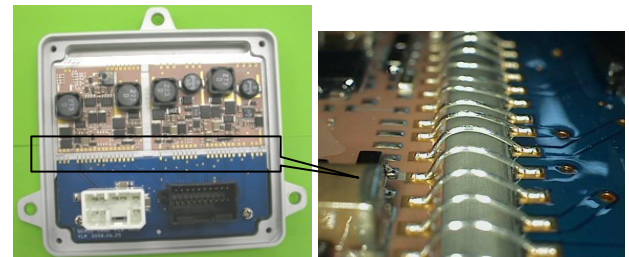
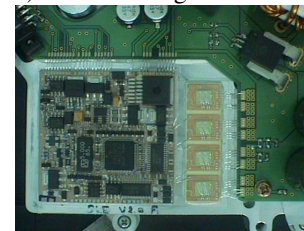


Fig. 8. Shear strength as a function of reliability test items and terms.

Fig. 9 shows the LTCC modules for automotive electronics in developing by SEMCO. Heavy aluminum wire bonding that previously described technology was applied between LTCC substrate and PCB.



a) LED Head light drive module



b) EPS module

Fig. 9. LTCC modules for automotive electronics.

IV. Conclusion

This study shows that the effect of bonding pad of LTCC substrate and metal finishing solution are critical on heavy aluminum wire wedge bonding ultrasonically. Firstly, it was found that the thickness of the base metal

(Ag surface conductor) of low temperature co-fired ceramics (LTCC) substrate played a critical role on bondability. And secondly, the surface metal finishing which is electroless Ni/Pd/Au plating (ENEPIG) system is superior to that of electroless Ni/Au (ENIG) plating. Furthermore, it's a cost-effective solution for the multipurpose LTCC package.

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