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SAW Bumpless Bonding at Low Temperature in Ambient Air

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1. Introduction

In the assembly of surface acoustic wave (SAW) components, flip-chip technique realizes the requirement of high-integration and miniaturization. Thermocompression and thermosonic bonding are two conventional methods in the flip-chip assembly of SAW components through the connection between Au stud bumps and Au or Al metalized pads. However, both of them require a bonding temperature higher than 150°C [1,2]. High temperature results the mechanical or thermal stress on the piezoelectric substrate significantly affect the center frequency of SAW filters. A low-temperature bonding process is necessary to achieve a good matching of the thermal expansion coefficients of the substrate and connected materials [3].

Surface activated bonding (SAB) method is a solution of interconnections at low temperature. The idea of the SAB method is based on the very strong covalent bonding energy between two atomic clean surfaces. The clean surfaces can be obtained by performing dry process such as argon fast atom beam, ion beam, or Ar radio plasma pretreatment in a certain vacuum condition [4]. Various materials, including metals and their alloys, ceramics, and semiconductors, have been bonded successfully with high bond strength not only at room temperature in vacuum or N_2 under atmosphere but also at low temperature in ambient air [5-6].

The aim of this research is to study the bonding feasibility of miniaturized SAW components by thin Au pads without bump structure at 25 and 100°C using the SAB method in ambient air. Influences of the surface activated process on the bonding as well as the necessary bonding pressure were investigated. Die shear test and electrical test were performed to determine the mechanical and electrical properties of the bonded samples.

2. Experimental

The size of $LiTaO_3$ substrates is 2.45×3.45 mm^2 with the thickness of 250 μm, and the size of GaAs chips is 1.162×0.853 mm^2 with the thickness of 203.2 μm. Sixteen Au pads were formed trough electron beam evaporation on $LiTaO_3$ substrates and GaAs chips respectively. The pad size on substrate side is 60×60 μm^2 with the thickness of 0.5 μm, and the pad on chip side is with 100×100 μm^2 with the thickness of 1.1 μm. The surface roughness of Au pads was measured by atomic force microscope (AFM). The rms surface roughness is around 10 nm. The under-bump metallization (UBM) beneath Au pads on substrate is 0.02-0.03μm-thick Ti and Al. In the peripheral area, corresponding sets of probing pads were fabricated for the electrical test.

The bonding experiments were carried out using a SAB flip-chip bonder. The accuracy of alignment, mounting, and the parallelism of this bonder may reach submicron level [6]. The bonding procedure started from irradiating the substrate and the chip by Ar RF plasma (100W) in a pretreatment chamber to activate the sample surfaces under 7.5 Pa pressure. The plasma pretreatment time was 30 s. After that, the bonding pair was transferred into the bonding chamber, and then the alignment was performed. Finally, the bonding pair was bonded at 25 or 100°C under a certain load for 30 s in ambient air. For comparison, the experiments using thermocompression method without Ar plasma pretreatment was performed at the same condition.

The bonded samples were performed die shear test using a die shear tester and electrical characteristic test using a network analyzer. The bonded interfaces and fractured surfaces were observed using optical microscope, scanning electron microscope (SEM) and energy dispersive X-ray spectrometry (EDX).

3. Results and Discussion

Mechanical Properties

Using the SAB method, the assembly achieves a high bonding strength, whereas the assembly is failed or with a weak strength even under larger bonding pressure using thermocompression bonding at 25 and 100°C. The comparisons of the bonding strength are shown in Fig. 1. The atomic forces are assumed to be the main contribution to the SAB bonding. Ar plasma pretreatment is a surface activated process. It can remove the contaminants to achieve activated surfaces. Although there are re-contaminants grown in ambient air before bonding, it is thinner than the initial one, and can be easily overcome by the deformation during bonding.

Necessary bonding pressure can enlarge the bonding area and destroy the re-contaminant barrier layer grown on the activated surfaces after Ar plasma pretreatment to allow a sufficient contact. When the bonding pressure is around 600 MPa at 100°C or 1200 MPa at 25°C, the bonding yield reaches 100% and the die shear strength of the bonded samples is above 25 MPa. According to the requirement of the die shear strength in method 2019.7 of MIL-STD-883G, the

bonded sample with all bonding area smaller than $5x10^{-4}$ IN^2 (or 0.32 mm^2) shall withstand a minimum fore of 0.04 $kg/10^{-4}$ IN^2 (or 6 MPa). In this study, the total bonded area is 0.054 mm^2, therefore a strong bond is confirmed by die shear test in this case.

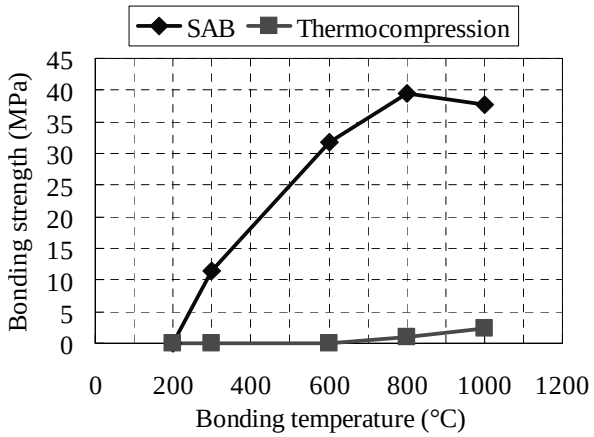

Fig. 1 Comparative bonding strength using the SAB method and thermocompression method at 100°C.

Electrical Characteristic

The samples bonded at 25 and 100°C passed the electrical tests. All of the four filters with different frequency (850, 900, 1800, and 1900 MHz) export the right responses, which were similar to those of the samples bonded by thermosonic bonding above 150°C using additional stud Au bumps. One group of the comparative frequency response (850 MHz) is shown in Fig. 2.

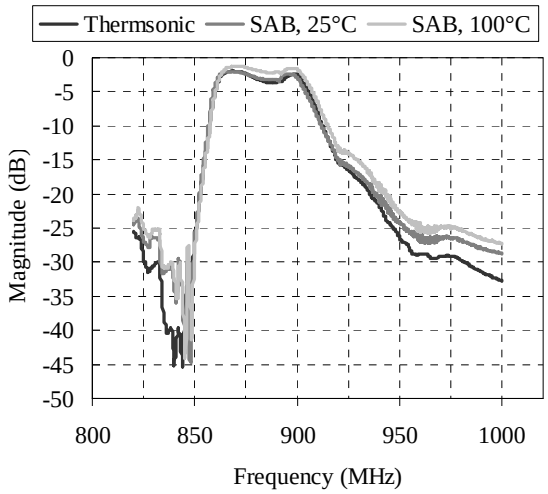

Fig. 2 Comparative frequency response of the samples bonded using the SAB method at 25 and 100°C, and using thermosonic bonding above 150°C.

Bonded Interface and Fractured Surfaces

Figure 3 shows the optical cross-sectional images of the interconnections bonded at 100°C under 800 MPa. The fractures of the bonded samples partly or mainly happened between the Au pads and the UBM of substrate side but not the bonded interfaces after die shear test. The transferred area of the Au pads from the substrate side to the chip side was enlarged with the bonding pressure increasing. The bonded interconnections and fractured surfaces of Au pads transferred from the substrate side to the chips side were observed by SEM and analyzed by EDX. The material on fractured place is Au. Nearly no Au-Al intermetallic compounds (IMC) formed on substrate side during bonding.

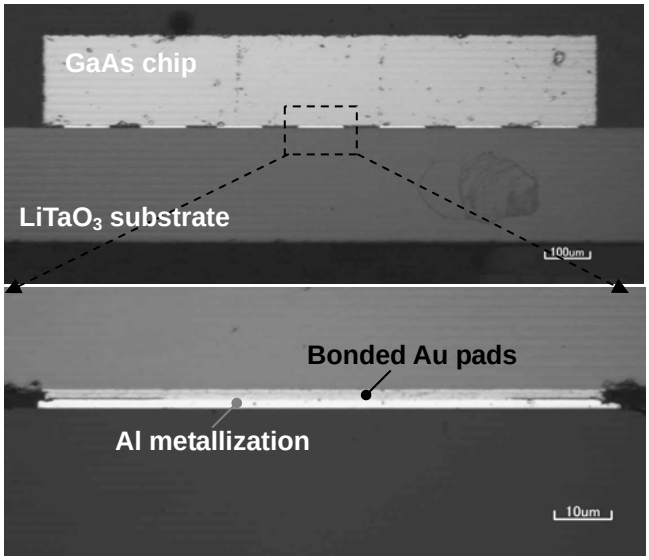

Fig. 3 Cross-sectional images of the interconnections bonded at 100°C under 800 MPa.

4. Summary

The feasibility of SAW bumpless bonding is confirmed at 25 and 100°C using the SAB method in ambient air.

- Ar plasma pretreatment is an essential factor.
- The necessary bonding pressure is 600 MPa at 100°C and 1200 MPa at 25°C.
- The die shear strength is as high as 25 MPa.
- The electrical property of SAW bonded by the SAB method at 25 and 100 °C in ambient air is fairly well, and it is similar to those bonded by thermosonic bonding at a temperature above 150 °C.
- The fractures after die shear test occurred partly or mainly at the UBM. Nearly no Au-Al IMC formed.

Acknowledgements

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