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Au thin film wafer bonding after degas annealing for MEMS packaging

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Abstract

This study investigated the bonding of Au films after a degas annealing process for hermetic sealing of MEMS devices. The bonding experiment of Au/Ti/Si substrates after the annealing process at 200 °C for 10 min indicated that the bonding strength was greatly reduced to 0.062 J/m^2 due to the thermal diffusion of Ti to the free surface. However, the bonding strength of Au/Pt/Ti/Si substrates bonded after annealing was 2.4 J/m^2, which is similar to the bulk strength of Si (2.5 J/m^2) since the Pt layer acted as a barrier layer for the Ti diffusion. The bonding of Au films using the Pt layer is thus suitable for the long-term stable hermetic packaging with the degas annealing process.

1. Introduction

A major current for micro-electro-mechanical systems (MEMS) studies focuses on not only the design of devices but also packaging techniques [1] because the packaging plays an important role for MEMS, including hermetic sealing, easy handing and protection of movable parts. Several applications, such as mechanical resonators for gyroscopes and alkali gas cells for MEMS atomic clocks, require hermetic packaging in order to control damping and guarantee accuracy. For the MEMS packaging technique, atomic diffusion bonding (ADB) [2] is a promising candidate process because it achieves strong bonding similar to bulk strength of bonded material even at room temperature. In the ADB process, thin metal films are sputter-deposited onto the surfaces to bond and the deposited-film surfaces are brought into contact together. The metal film surfaces then bond over the entire bonded area, resulting from self-diffusion of metal atoms at grain boundaries and the bonding interface. Most of metal, including Au, Pt, and Ti, can act as the bond films in the ADB process. In particular, Au films are successfully bonded even after exposure to ambient air because Au has high self-diffusion coefficient (3.3 x 10^{-29} m^2/s at 300 K) and is rarely covered with oxide layer. Many researches thus have been proposed for the MEMS packaging techniques using the bonding of Au films [3].

Hermetic packaging for MEMS requires an annealing step before bonding because gas molecules adsorbed on MEMS components and gas atoms in deposited films, such as hydrogen, cause outgas and spoil the components after a long period. Q. Li and others have demonstrated that a high temperature pre-anneal, which implies annealing before packaging, greatly reduces outgassing from deposited metal layers [4]. However, it remains unclear how annealing before bonding effects on the quality of bonding of Au films by ADB. This study demonstrates bonding of Au films after the degas annealing procedure using Au/Ti/Si substrates and Au/Pt/Ti/Si substrates.

2. Experimental

In this study, homogenous bonding of Au/Ti/Si substrates as well as Au/Pt/Ti/Si substrates were performed after an annealing step at 200 °C for 10 min in our vacuum bonding system (WAP-1000 from Bondtech Co., Ltd.,), as shown in Fig. 1. Ti is commonly used as an adhesive layer for the Au deposited layer. Additionally, Pt acts as a barrier layer for thermal-diffusion of metals during processes at high temperatures. Ti, Pt, Au layers were sputter-deposited on Si substrates in a thickness of 5, 10, 12 nm, respectively. After annealing, the substrates were brought into contact and pressed at 200 °C under 30 kPa load for 1 min. After bonding, the bonding strength was measured using Maszara blade test[5]. Subsequently, the fracture surfaces were investigated via X-ray photoelectron spectroscopy (XPS) to determine the loci of failure.

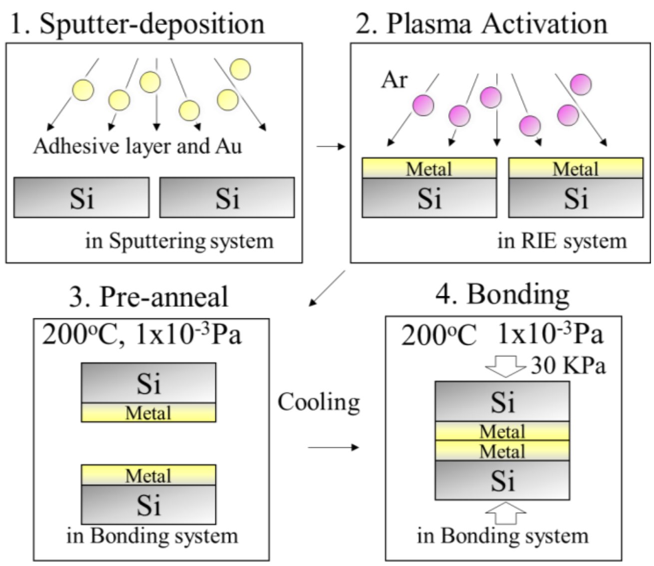

Figure 1. Bonding procedure in the bonding of Au films with the degas annealing step.

3. Results and discussion

The Maszara blade test was performed on the bonded Au/Ti/Si substrates and the bonded Au/Pt/Ti/Si substrates. Figure 2 indicates the bonding strength of both samples. A 100-µm-thick razor blade was inserted between the bonded sample and bonding strength was calculated from the length of crack. It is noteworthy that Au/Ti/Si substrates that are bonded without an annealing step was so strongly bonded that fracture occurs from the Si substrate, indicating the bonding strength is equivalent to the bulk strength of Si. For the Au/Ti/Si substrates that were bonded after the annealing step, however, the razor blade was easily inserted and the crack length was 20 mm, indicating the bonding strength of 0.064 J/m^2. On the other hand, the Au/Pt/Ti/Si substrates were strongly bonded even they were bonded after the degas annealing process. It was relatively difficult to insert the blade between the Au/Pt/Ti/Si sample and the crack length was 8 mm, indicating that the bonding strength of 2.4 J/m^2. Since the Si bulk strength is 2.5 J/m^2, the bonding of this sample is thus sufficiently strong for a reliable packaging.

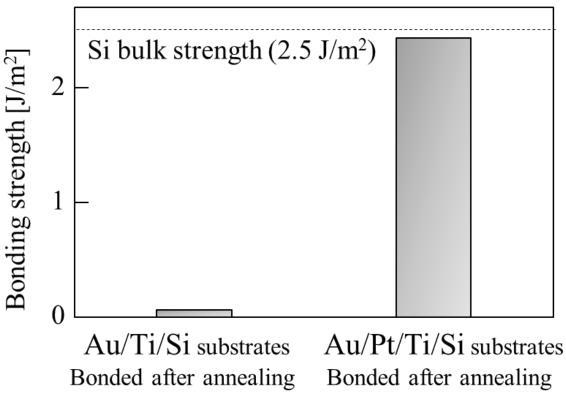

Figure 2. Bonding strength of Au/Ti/Si substrates and Au/Pt/Ti/Si substrates, which are bonded after the degas annealing process. The bonding strength of Au/Pt/Ti/Si substrates were similar to the Si bulk strength and sufficiently high for packaging applications.

The surface of debonded samples were investigated via XPS to understand the reason for the difference in bonding strength. Figure 3 shows the XPS spectrum of debonded surfaces of Au/Ti/Si substrates and Au/Pt/Ti/Si substrates. It is notable that the debonded surface of both samples seemed the surface of Au film in appearance. However, Ti was detected on the fracture surface of the Au/Ti/Si substrate. The atomic ratio of Ti is 8 %, suggesting the thin Ti layer formed by thermally diffused Ti atoms to the free surface and prevent bonding. On the other hand, no trace of Ti was detected on the fracture surface of the Au/Pt/Ti/Si substrate.

It has been reported that Ti atoms used in an adhesion layer diffuses to the Au free surface and form Ti oxide, including anatase and rutile [6]. The detailed XPS spectrum of debonded surfaces of Au/Ti/Si substrates revealed that the Ti peak position is 458.0 eV, suggesting the existence of Ti oxide on the surface. On the other hand, Pt acts as diffusion barrier for thermal diffusion [7], resulting in the Au surface with extremely small amounts of impurities. Thus, it is concluded that Au films with a diffusion barrier layer is the preferable bonding agent for the hermetic packaging process with the annealing process before packaging.

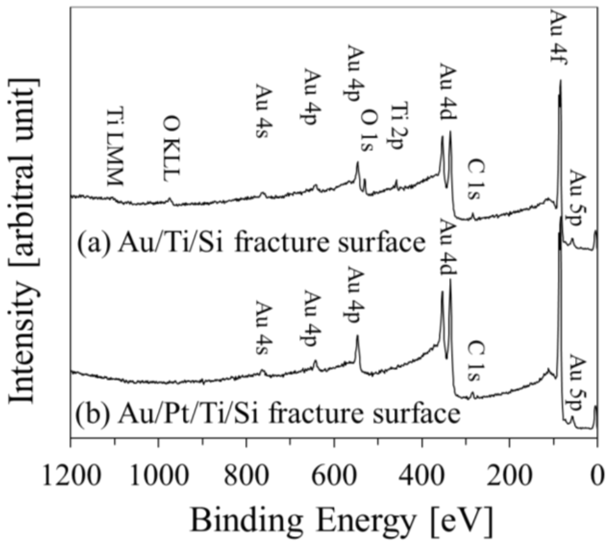

Figure 3. XPS spectra of the fracture surfaces of (a) the Au/Ti/Si substrate and (b) the Au/Pt/Ti/Si substrate. The peak of Ti 2p (458.0 eV) was detected on the Au/Ti/Si substrate, but no Ti was detected on the Au/Pt/Ti/Si substrate, indicating thermally diffused Ti results in poor bonding strength.

4. Conclusions

This study investigated a bonding of Au films using ADB method after a degas annealing step. Although the bonding strength of Au/Ti/Si substrates were greatly reduced when they were bonded after annealing, Au/Pt/Ti/Si substrates were strong as the sample without the degas annealing process. XPS surface analysis revealed that thermally diffused Ti atoms form a Ti oxide layer on Au films, and the Pt layer acted as a barrier layer for the Ti diffusion. The Au film bonding with a diffusion barrier layer is thus preferable for the tight sealing with degas annealing for MEMS packaging.

Acknowledgements

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