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Influence of different plasma treatments on low-temperature Au-Au bonding and its application to hermetic packaging

Michitaka Yamamoto[1], Eiji Higurashi[2, 3], Tadatomo Suga[2], Renshi Sawada[4] and Toshihiro Itoh[1]

[1] The University of Tokyo
Graduate School of Frontier Sciences, 5-1-5 Kashinoha, Kashiwa-shi, Chiba 277-8563, Japan
Phone: +81-4-7136-4636 E-mail: myamamoto@s.h.k.u-tokyo.ac.jp
[2] The University of Tokyo
School of Engineering, 7-3-1 Hongo, Bunkyo-ku, Tokyo 113-8656, Japan
[3]National Institute of Advanced Industrial Science and Technology (AIST),
1-2-1 Namiki, Tsukuba, Ibaraki, 305-8564, Japan
[4] Kyushu University
Faculty of Engineering, 744 Motooka, Nishi-ku, Fukuoka 819-0395, Japan

Abstract

Au thin film bonding and Au stud bump bonding were performed after different plasma treatments at low temperature (25 or 150 ºC). Atmospheric-pressure (AP) plasma using three different types of gases (Ar+H_2, Ar+O_2, and N_2) and low-pressure (LP) plasma using Ar gas were used in this study. Ar+H_2 AP plasma treatment and Ar LP plasma treatment were effective for increasing the bonding strength. Based on these results, hermetic packaging using Au sealing rings was demonstrated in ambient air by using Ar+H_2 AP plasma at bonding temperature of 150 ºC.

1. Introduction

For hybrid integration of materially different optical components, Au-Au bonding is a key technology because it can be used not only for electrical interconnections but also for sealing [1]. As a low-temperature Au-Au bonding method, surface activated bonding (SAB) has been studied [2,3]. Ar low-pressure (LP) plasma treatment is widely used for surface activation of Au surfaces. However, it requires an expensive vacuum system and has the problem of increasing process time for the vacuum processing.

Recently, atmospheric-pressure (AP) plasma was applied to Au-Au SAB alternative to Ar LP plasma. By using AP plasma for surface activation, whole bonding process including surface activation and bonding can be achieved in ambient air. For example, Au thin film–Au micro-bump bonding using Ar+H_2 AP plasma or Ar+O_2 AP plasma at bonding temperature of 150 ºC [4], Au thin film–Au Stud bump bonding using Ar+H_2 AP plasma at 25 ºC [5], Au thin film–Au stud bump bonding using N_2 AP plasma at 150 ºC [6] were successfully performed. However, the influence of different types of plasma, sample structure, and bonding temperature has not been systematically studied.

In this study, Au thin film bonding and Au stud bump bonding were performed after surface activation by four types of plasma (Ar+H_2, Ar+O_2, N_2 AP plasma and Ar LP plasma) at different temperature (25 or 150 ºC). Furthermore, as the application of Au-Au SAB using AP plasma, hermetic packaging in ambient air was demonstrated.

2. Experiment method

Atmospheric-pressure (AP) plasma using three different types of gases (Ar+H_2, Ar+O_2, and N_2) and low-pressure (LP) plasma using Ar gas were prepared for surface activation. The details of plasma conditions are shown in table 1.

The schematic diagrams of bonding samples are shown in Fig. 1. As bonding samples, Au thin film–Au thin film and Au thin film–Au stud bumps were prepared. Au stud bumps were flattened by coining process. The detail of fabrication process of coined Au stud bumps is described elsewhere [5].

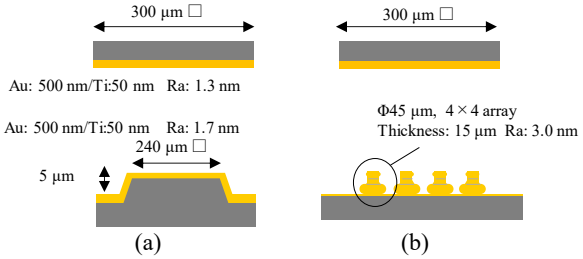

Fig. 1. Schematic diagrams of bonding samples.
(a)Au thin film–Au thin film, (b) Au thin film–Au stud bumps.

Table 1. Plasma treatment conditions

	Ar LP plasma	Ar+H_2 AP plasma	Ar+O_2 AP plasma	N_2 AP plasma
Pressure	7.9 Pa	Atmospheric-pressure	Atmospheric-pressure	Atmospheric-pressure
Gas flow Ratio	Ar: 5 ccm (=8.4×10^{-5} L/min)	Ar: 2.14 L/min H_2: 0.03 L/min	Ar: 2.14 L/min O_2: 27.0 mL/min	N_2: 5 L/min
Power	100 W	150 W	150 W	8.5 kV
Frequency	13.56 MHz	13.56 MHz	13.56 MHz	20 kHz
Plasma treatment time	60 s	30 s	30 s	180 s

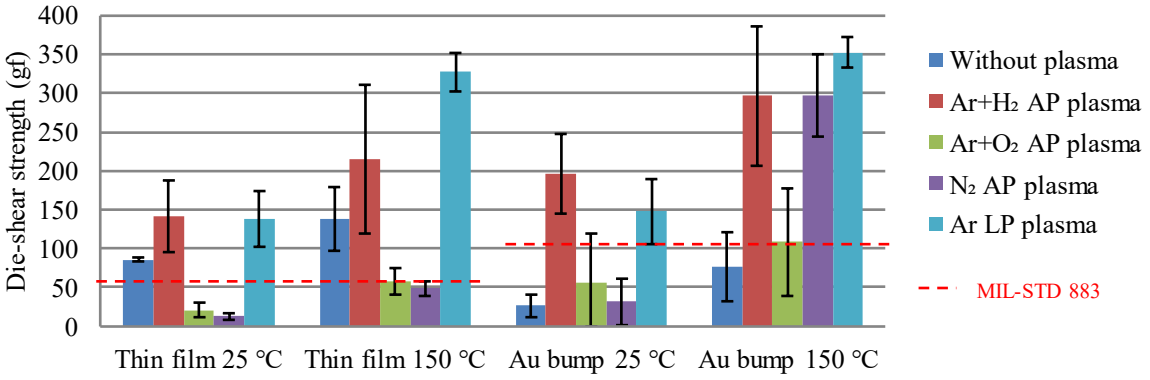

Fig. 2. The results of die-shear test with differences of plasma types, sample shapes and bonding temperature

After plasma treatment, bonding was performed with contact load of 680 gf at bonding temperature of 25 or 150 ºC. The contact load corresponds to the contact pressure at 116 MPa for thin film and 403 MPa for stud bumps. The pressure of stud bumps was calculated based on the bumps area before bonding. Bonding strength was measured by die-shear test.

As the application of Au-Au bonding using AP plasma, hermetic packaging was performed. In previous study using Ar LP plasma, hermetic packaging was succeeded at bonding temperature of 150 ºC with contact load of 313 MPa or bonding temperature of 300 ºC with contact load of 156 MPa [1]. In this study, Si substrate with cavity and glass substrate were bonded through the Au sealing rings with contact load of 30.6 kgf (=300 MPa) at bonding temperature of 150 ºC after $Ar+H_2$ AP plasma treatment. The sealing performance was evaluated by measuring the resonance frequency of the cantilever placed in the cavity before and after vacuuming. The detail of evaluation method is described elsewhere [7].

3. Experiment result

The results of die-shear test are shown in Fig. 2. $Ar+H_2$ AP plasma treatment and Ar LP plasma treatment increased bonding strength and the strength exceeded the failure criteria of MIL-STD-883 (56 gf for Au thin film–Au thin film and 112 gf for Au thin film–Au stud bumps). On the other hand, N_2 AP plasma treatment increased bonding strength only in the case of using Au stud bumps at bonding temperature of 150 ºC, and $Ar+O_2$ AP plasma did not increase bonding strength.

To investigate the surface conditions after plasma treatments, x-ray photoelectron spectroscopy (XPS) analysis of Au surfaces before and after plasma treatment was performed. From the relative peak intensity of carbon (at C 1s region), all plasma decreases carbon contaminants on Au surfaces. From the relative peak intensity of oxygen (at O 1s region), $Ar+H_2$ AP plasma treatment did not change the peak clearly. On the other hand, N_2 AP plasma treatment formed hydroxyl (OH) groups, and $Ar+O_2$ AP plasma treatment formed gold oxide (Au_2O_3) on Au surfaces. It means that hydroxyl (OH) groups and gold oxide prevent Au-Au bonding, but hydroxyl (OH) groups are unstable enough to be removed by plastic deformation of Au stud bumps at 150 ºC.

Hermetic packaging was performed using Au-Au SAB using $Ar+H_2$ AP plasma. The resonance frequency of the cantilever placed in the cavity did not change before and after vacuuming, it means that cavity was sealed by the Au sealing rings. The calculated leak rate was below 7.4×10^{-10} Pa·m^3/s, it satisfied the failure criteria of MIL-STD-883 ($< 5.0\times10^{-9}$ Pa·m^3/s).

4. Conclusions

$Ar+H_2$ AP plasma and Ar LP plasma increased bonding strength of both Au thin film bonding and Au stud bump bonding at bonding temperature of 25 ºC and 150 ºC. On the other hand, N_2 AP plasma increased only Au stud bump bonding at bonding temperature of 150 ºC and $Ar+O_2$ AP plasma did not increase bonding strength for any cases. From XPS analysis, cleaning of organic contaminants on Au surface without the formation of hydroxyl groups and gold oxide seems to be important for low temperature Au-Au bonding. As the application of Au-Au surface activated bonding using $Ar+H_2$ AP plasma, hermetic packaging in ambient air was demonstrated at bonding temperature of 150 ºC.

References

[1] S. Yamamoto, E. Higurashi, T. Suga, and R. Sawada, Journal of micromechanics and Microengineering, vol. 22, no. 5, (2012), 055026.

[2] E. Higurashi, R. Sawada, and T. Suga, IEICE Transactions on Electronics, vol. E92C, no.2, (2009), pp. 231-238.

[3] E. Higurashi, D. Chino, T. Suga, and R. Sawada, IEEE Journal of Selected Topics in Quantum Electronics, vol. 15, no. 5, (2009), pp. 1500-1505.

[4] R. Takigawa, E. Higurashi, T. Suga and R. Sawada, 2009 International Conference on Electronic Packaging Technology & High Density Packaging, (2009), pp. 475-477.

[5] E. Higurashi, M. Yamamoto, T. Sato, T. Suga, and R. Sawada, IEICE Transactions on Electronics, vol. E99C, no. 3, (2016), pp. 339-345.

[6] S. Matsuoka, M. Yamamoto, E. Higurashi, T. Suga, and R. Sawada, 2015 International Conference on Electronic Packaging and iMAPS All Asia Conference, (2015), pp. 850-853.

[7] S. Yamamoto, E. Higurashi, T. Suga, and R. Sawada, IEICE Transactions on Electronics (Japanese Edition), vol. J93C, no. 11, (2010), pp.509-515