[Short Note]

QFP/quartz Adhesive Bonding with Surface Treatment for Physical Security of Edge Artificial Intelligence Devices

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Abstract

We studied a method of quad flat package (QFP)/quartz adhesive bonding. This bonding technology is required for developing physical security of edge artificial intelligence (AI) devices using a nanoartifact metrics (NAM) chip. Relationships between contact angle and bonding strength of QFP/adhesive or quartz/adhesive were investigated under several surface treatment methods including vacuum ultraviolet (VUV) treatments, and plasma treatments. VUV irradiation in the presence of nitrogen gas (VUV/N₂) treatment reduced the contact angle of the QFP and quartz surface from 99.2° to 5.0°, which improved QFP/adhesive bonding strength 5.7 times. Furthermore, the bonding strength of QFP/adhesive/quartz bonding with the VUV/N₂ treatment shows a shear strength of 14.2 MPa. It is 2.4 times higher value than that without the treatment. These results are a promising step for highly reliable QFP/quartz bonding.

Keywords: Adhesive Bonding, VUV, Atmospheric Pressure Plasma, Edge AI Security

1. Introduction

Artificial intelligence (AI) is important for the information society where the amount of data exceeds human processing capacity. In recent years, concept of edge AI, which means AI algorithms are processed locally on each device, has attracted much attention. Security of the edge AI is one of the important factors to evolve AI merging society.[1] The edge AI device requires both software security and hardware security. Especially, the security for hardware has just begun to consider. There is a research about mounting of artifact metrics as a hardware security. [2] In this paper, we examined the mounting technology on the integrated circuit (IC) package, which is an AI edge device with using a nanoartifacts metrics (NAM) chip. The concept was shown in Fig. 1. The NAM chip physically provides high clone tolerance because of utilizing nanoscale pattern which is difficult to replicate. It is possible to add a security function in a post process by mounting the NAM chip in a bare state. However, the method of NAM chip mounting on the IC package with high reliability has not been studied yet.

In this study, we investigated a method of quad flat pack-

age (QFP)/NAM chip adhesive bonding. A QFP is usually surface mounted on a printed wiring board with solder. Therefore, it is practical and has an advantage to add a security function with an exposed NAM chip after mounting of QFP. However, the bonding strength with sufficient durability of exposed QFP/NAM chip structure is an important factor. In a realistic edge AI device mounting structure, the size of the QFP molding area is 14 mm square, and of the pattern area of the nano-artifacts met-

Fig. 1 Concept of physical security for AI edge devices using a NAM chip with an adhesive bonding method.

rics is 20 μm square.[3] In our experiment, we used the same size QFP and the bare quartz chip (5 mm square) instead of a NAM chip for simplicity. Aiming to improve the bonding strength, four types of surface treatments were performed before applying the adhesive: vacuum ultraviolet (VUV) irradiation in the presence of nitrogen gas (VUV/ N_2), VUV irradiation in the presence of oxygen gas (VUV/ O_3), Ar/ O_2 plasma, and Ar plasma. The hydrophilicity of the treated surfaces was evaluated by measuring the contact angle of water droplets. The bonding strength of QFP/adhesive and quartz/adhesive was examined by a shear test to clarify the effects of surface treatments on the each material. Further, QFP/adhesive/quartz bonding was also performed to evaluate the bonding strength.

2. Experimental Procedure

A. Surface treatment

After organic cleaning with ultrasonication, four type of surface treatments were performed. The conditions of the surface treatments were summarized in Table 1. The VUV treatment system (UER 20-172, Ushio, Inc.) consists of a lamp house and an irradiation chamber.[4] The VUV light directly reach and react with the sample surface in VUV/ N_2 treatment. On the other hand, in VUV/ O_3 treatment, the VUV light was absorbed by O_2 to generate ozone and excited oxygen atoms, which react with the sample surface. Ar and Ar/ O_2 plasma treatment was performed at atmospheric pressure (SHUTECH Co., Ltd.). All surface treatments were performed at a room temperature.

B. Measurement of contact angle

The hydrophilicity of the QFP and the quartz with and without surface treatments were measured by contact angle of distilled water drop (LCD-400S, Kyowa Interface

Science Co., Ltd.). The contact angles were measured within 5 minutes after the surface treatments.

C. Shear test for measuring bonding strength of QFP/adhesive, quartz/adhesive, QFP/adhesive/quartz

We investigated the effects of surface treatments on the shear strength of QFP/adhesive, quartz/adhesive, and QFP/adhesive/quartz bonding. An adhesive of thermosetting resin was cured gradually at 120°C for 30 min, 150°C for 1 h, and then 180°C for 4 h. After the adhesive was completely cured, the bonding strength of QFP/adhesive, quartz/adhesive, QFP/adhesive/quartz were measured by a digital shear strength indicator (DPX-50T, IMADA).

3. Results and Discussion

Figure 2 shows the results of contact angle measurement. Initial contact angle of the QFP and the quartz surface were 99° and 49°, respectively. The all treatment method reduced the contact angle of both QFP and quartz surfaces and realized hydrophilic surfaces. Especially, the QFP surface with the VUV/ N_2 treatment showed the minimum contact angle of 5.0°. On the other hand, the all surface treatment method realized reduction of the contact angle less than 5° for the quartz.

Figure 3 shows relationship between the contact angle and the bonding strength of QFP or quartz/adhesive bonding samples. The shear strength of QFP/adhesive bonding samples with all surface treatments increased in comparison to that without the treatment. The shear strength of QFP/adhesive bonding increased with decreasing the contact angle. Especially, VUV/ N_2 treatment, which minimized the contact angle of the QFP surface, maximized the shear strength of QFP/adhesive bonding 5.7 times. Although value of the bonding strengths of quartz/adhesive samples were not correspond with the value of the contact angle as previously

Table 1 Detailed condition of surface treatment.

Surface treatment method	Process gas	Process power
VUV/ N_2	N_2 gas (20 mbar)	Power: 10 mW/cm ² Time: 10 min Wavelength: 172 nm
VUV/ O_3	O_2 gas (500 mbar)	
Ar plasma (Atmospheric pressure plasma)	Ar: 8 slpm	Power: 200 W Speed: 10 mm/s 14 times
Ar/ O_2 plasma (Atmospheric pressure plasma)	Ar: 8 slpm O_2 : 2 sccm

Fig. 2 Contact angle changes of QFP and quartz.

reported.[5] QFP/adhesive/quartz bonding results with and without VUV/N₂ treatment were shown in Fig. 4. The bonding strength of QFP/adhesive/quartz bonding with

the VUV/N₂ treatment shows a shear strength of 14.2 MPa. It is 2.4 times higher value than that without the treatment.

Fig. 3 Relationship between contact angle and shear strength of (a) QFP/adhesive and (b) quartz/adhesive bonding samples.

Fig. 4 Shear strength of QFP/adhesive/quartz bonding without and with VUV/N₂ treatment.

4. Conclusion

In this study, we reported adhesive bonding method with surface treatment for a NAM chip mounting on an IC chip. The maximum bonding strength of QFP/adhesive was achieved with VUV/N₂ treatment which achieved the minimum contact angle. The proposed QFP/quartz bonding is promising for physical security of edge AI devices. In the future, we intend to investigate further the correlation between surface treatment and the bonding strength.

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