Microelectronics Reliability 81 (2018) 143–149

Contents lists available at ScienceDirect

Microelectronics Reliability

journal homepage: www.elsevier.com/locate/microrel

A new hermetic sealing method for ceramic package using nanosilver sintering technology

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ARTICLE INFO

Keywords:
Harsh environments
Nanosilver
Sintered
Lid
Stress

ABSTRACT

High reliable packaging materials are needed for electronics when they work at harsh environments. Among which, the nanosilver material has been widely studied and applied in power electronics due to its low processing temperature and high reliability. This paper investigates the bonding properties of nanosilver sintered hermetic cavity. There are two kinds of lids used in this study, including copper lid and silicon lid. The X-ray and C-Mode Scanning Acoustic Microscopy (C-SAM) results revealed that delamination tended to happen in Cu lid sintered cavity as the recovery of deformed Cu lid was hindered by sintered dense Ag layer. However, no delamination or cracks were found in Si lid sintered cavity. Finite element analysis (FEA) method was used to investigate the effects of lid materials on the stress distribution of lid. The results indicated that the Cu lid sintered cavity showed a much higher stress than the Si lid sintered cavity under the sintering parameters of 250 °C and 10 MPa. There is no obvious change in the stress distribution areas on Cu lid with the increasing of pressures from 5 to 30 MPa. However, the distribution area of stress on Si lid expanded obviously only when the sintering pressure increased to 30 MPa. With the increase of sintering pressures from 5 to 30 MPa, the maximum stresses on Cu lid are almost the same, while increasing trend was found on Si lid.

1. Introduction

Electronics, operating at harsh environment, are usually suffering extremely high/low temperature shock and high pressure, when they are applied in the area of renewable energy, aerospace engine, oil and gas drilling and production [1–4]. Some of these electronics need to be hermetically sealed to prevent the deterioration of function and reliability.

The hermeticity is usually achieved by using various sealing methods, such as thermocompression bonding [5–7], soldering [8–10], glass frit bonding [11,12], seam welding [13] and anodic bonding [14,15]. Among these methods, the Au-Sn eutectic soldering technology is one of the widely used hermetic seal methods due to its favorable mechanical strength, flux-free process, and hermeticity [16,17]. Zhang et al. [18] designed an electrical test method to monitor the bonding quality of AuSn eutectic soldered micro-electro-mechanical systems (MEMS) cavities. They found that the sample with a lower resistivity owned a thicker (Au, Ni)$_3$Sn$_2$ phase at the bonding interface and a lower bonding strength. Demir et al. [19] fabricated the thermal evaporated Au and Sn layers as a seal ring in MEMS cavity. The bonding was achieved by the formation of Au-Sn intermetallic compounds (IMC) and the average shear strength can reach 23 MPa. Rautiainen et al. [16] used the Au-Sn seal ring for bonding silicon wafers and caps through solid–liquid interdiffusion (SLID) method. The bonded wafers with Ni layer between the TiW adhesion layer showed quite high shear strength while voids were found at the shear and tensile fracture surface.

However, the processing temperature (over 300 °C) of Au-Sn eutectic solder is quite high, which may introduce the thermal induced stress concentration and damage in the electronic components. Although the Au-Sn stacked metal layers in SLID method can be processed at temperatures around 235 °C, the complicated deposition procedure and processing technology limit its further application.

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https://doi.org/10.1016/j.microrel.2017.12.030
Received 8 September 2017; Received in revised form 15 November 2017; Accepted 15 December 2017
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Furthermore, the excessive growth of IMC may decrease the bonding strength of joint because of its brittle nature [20,21]. In addition, the cost of Au-Sn eutectic alloy is also quite high. So there is an urgent need for developing a new sealing material that can work steadily at harsh environments.

Recently, the nanosilver sintering technology has attracted a lot of attention in the die attach process of power semiconductor fields. This process can be achieved at low temperature around 250 °C and served at relative high environment temperatures over 200 °C [22,23]. Comparing with the traditional Au-Sn eutectic soldering method, the nanosilver sintering technology offers relatively lower processing temperature and higher reliability. Until now, there are few publications report the application of nanosilver sintering technology in hermetic sealing process.

This paper investigated the bonding properties of nanosilver sintered hermetic cavity. The bonding qualities of sintered Ag layer were analyzed by using X-ray and C-SAM imaging methods. The effects of lid materials and sintering pressure on the stress distribution of sintered cavity were investigated by FEA method.

2. Experiments

2.1. Sample preparation

The ceramic cavity (Al_2O_3) with a gold (Au) coating layer (10 μm) on the top surface was used in this paper. The sealing material was nanosilver film (Ag film), which has a thickness of 65 μm (from Alpha Assembly Solutions). The Ag film was cut by laser into hollow square shape with a width of 0.22 mm according to the sealing area on the top surface of the cavity. There are two kinds of lids used in this study, including copper (Cu) and silicon (Si) based ones. Both two kinds of lids were coated with silver on the top surface of sealing area. The materials are shown in Fig. 1.

The whole manufacture process includes two steps: firstly, the Ag film cut by laser was laminated on the gold layer of the cavity at 130 °C for 2 min with a pressure of 5 MPa. Secondly, the lid was assembled on the laminated cavity and then the whole cavity was placed in the mold inside of the sintering equipment. Note that the lid was placed on the bottom side and the cavity was placed on the top side. The whole cavity was then directly sintered at 250 °C for 5 min by a precisely controlled and monitored system from Boschman Technologies. The sintering process was achieved at the atmosphere. In order to get a dense microstructure and high mechanical strength, a pressure of 10 MPa was applied through the dynamic insert during the sintering process. This dynamic insert can help to ensure a uniform pressure through a real time feedback system. After sintering, the package was cooled down to room temperature at the atmosphere for 3 min. The sintering equipment and the two processing steps were shown in Fig. 1.

After sintering, the sample was taken out from the equipment and cooled down to room temperature. The sintered cavity was further detected in X-ray imaging system to check the cracks in the bonding layer. The sintered cavity was also examined through C-SAM test to determine whether delamination existed or not. Finally, the bonding quality of nanosilver sintered cavity was evaluated through the captured images in the two tests.

2.2. Finite element analysis method

The FEA method was used in this paper to determine the residual stress in the sintered cavity during sintering process. Some assumptions are applied to the 3D model to save computational time without affecting the accuracy of the solution:

- The 3D model was regarded as a symmetrical one, so only a quarter of the model was built for simulation.
- The surface coatings on the Cu and Si lid were neglected in the 3D model.
- The sintered silver layer was considered as a uniform and constant material.

The structure of the cavity is shown in Fig. 2, it consists of four layers: lid (Cu or Si), sintered Ag layer, Au coating and cavity (Al_2O_3). During simulation, the package was first heated up to 250 °C from room temperature within 1 min and then kept at 250 °C for 5 min. Then the package was cooled down to room temperature within 3 min. The sintering pressure of 5 (or 10, 20, 30) MPa was applied on the back side of the cavity during heating and sintering. The large deflection function was turned on to better predict the deformation of lid. The general material properties that are used for simulation were summarized in Table 1.

Since the processing temperature is quite high, so the elastic-plastic models are applied for sintered Ag layer and Cu lid. The Garofalo law is

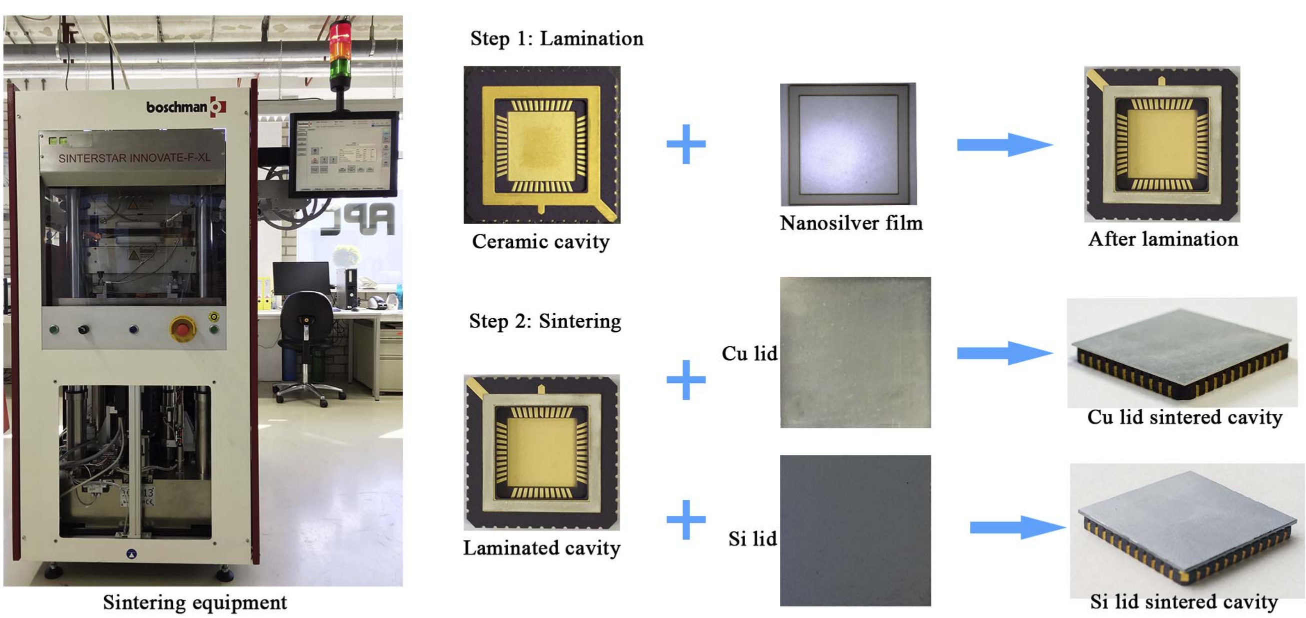

Fig. 1. Sintering equipment and sample preparation.

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