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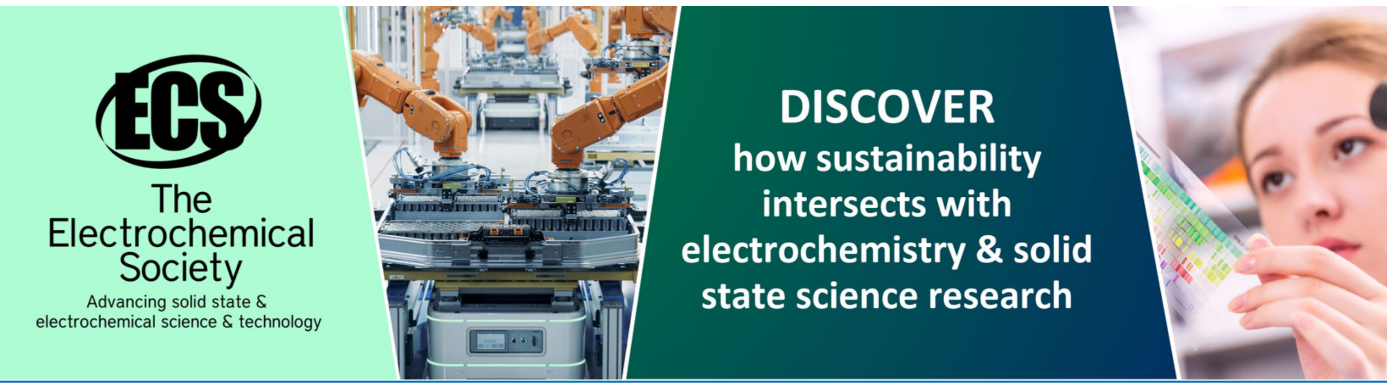

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Analysis of high-temperature aging and microstructure of FC LED solder joints of a silver conductive layer bonded using SAC solder

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Abstract. Flip-chip (FC) light-emitting diode (LED) filaments with a silver conductive layer are impeded by heat dissipation, with the flip-chip junction temperature of reaching up to 423.15 K. To overcome this problem, we simulated aging of SAC305 solder joints at a high temperature of 433.15 K. Scanning electron microscopy was performed to analyze the changes in the microstructure of the solder joints with aging time. Moreover, energy-dispersive X-ray spectroscopy was performed to analyze changes in the element content of the solder joints with aging time. The shear force of solder joints was measured using a strength tester. Results revealed that the Ag/Au content of the solder joints increased under the high-temperature conditions, resulting in the formation of cracks and holes in the solder joints. Furthermore, the reliability of the FC LED filaments was affected by the maximum shear stress that can be tolerated by the solder joints.

1. Introduction

Compared with traditional light sources, light-emitting diode (LED) light sources, based on third-generation semiconductor materials such as SiC and GaN, have advantages such as high luminous efficiency, reduced energy consumption, environmental friendliness, and a long lifetime. At present, LEDs are mainly packaged using LED chips and wire bonding technology [1-3]. However, they have disadvantages such as poor heat conductivity, low production efficiency, and low yield. In addition, the blocking of light by the lead wire or electrode of the LED chip can negatively affect the luminous efficiency of the LED [4-10].

Flip-chip (FC) LED technology overcomes the shortcomings of the traditional LED chip, thereby improving the reliability and service life of LED products. At present, the FC LED packaging technology mainly includes conductive adhesive bonding and eutectic welding. Low- and medium-power FC LEDs can be bonded with conductive silver glue. The thermal conductivity of conductive silver adhesive is low, leading to a very high junction temperature of the chip, which in turn affects the performance and reliability of the light source [11-14]. At present, only a few enterprises in China use low- and medium-power FC LED solid crystalline materials. In addition, the literature shows that FC LED chips with conductive adhesive have poor impact resistance and increased contact resistance with Cu in high-humidity environments [15-17]. Compared with conductive adhesive bonding, bonding of

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LEDs with AuSn eutectic solid crystals is stronger and provides excellent conductivity, thermal conductivity, corrosion resistance, and creep resistance. The AuSn eutectic interconnect process results in the FC LED having lower thermal resistance and more stable light output. However, AuSn eutectic welding equipment is expensive, and the solid crystal efficiency is low in the eutectic welding process. Therefore, it is necessary to exert pressure on the chip, which easily causes chip damage. Because the cost of LEDs is decreasing daily, a low-cost, high-efficiency, and high-reliability solid crystal process is required for FC LEDs. The lead-free solder reflow welding process is widely used in the electronics industry; SAC305 is a new-generation lead-free solder with good wettability, high joint reliability, and low cost. Therefore, the SAC305 lead-free solder reflow process has become a feasible method for producing FC LED solid crystals [18-19].

Although many studies have investigated the interfacial diffusion between SAC solder and substrates with electroless nickel immersion gold or Cu with organic solderability preservative surface finishes as the most commonly used substrates for FC LED filament production, only a few studies have investigated SAC solder and substrates printed with a silver conductive layer. Because of the effect of the packaging of fluorescent glue on FC heat dissipation in daily use, the FC junction temperature increases to 423.15 K or higher with time, and this increase is accompanied by the phenomenon of dead lights. To simulate the aging process of solder joints, after a typical reflow process, the FC LED filaments were maintained at the same high temperature. For different aging times of the filaments, as one of the most important factors for evaluating the reliability of solder joints, the shear strength of the FC LED packages was evaluated through a shear test. In addition, the microstructure of the solder joints was observed and analyzed to identify the reason for fracture.

2. Sample preparation and testing

2.1. Sample preparation

Enraytek EA0820A FC LED chips with Au diodes were soldered to a ceramic substrate that was printed with a silver conductive layer,the size of the chip is 8mil×20mil, working voltage is 3.1-3.2V, wavelength is 452.5-455.0nm.Moreover, an ASM-AD860-type solid crystal machine and Sn-3.0Ag-0.5Cu (SAC305) solder wire were used. SAC solder was used with a typical reflow process, in which the peak soldering temperature was 553.15 K. After the reflow process, the samples were cooled to room temperature. Isothermal aging of the samples was conducted at 433.15 K for 0, 70, and 170 h. A portion of the samples were collected after the aging process and fixed with epoxy resin. The samples were then polished until the sample cross section was smooth. The remaining samples were used for shear testing. The FC LED chip is shown in figure 1(a) and the microstructure of the FC LED chip soldered to the silver conductive layer using the SAC305 solder and reflow soldering process is shown in figure 1(b).

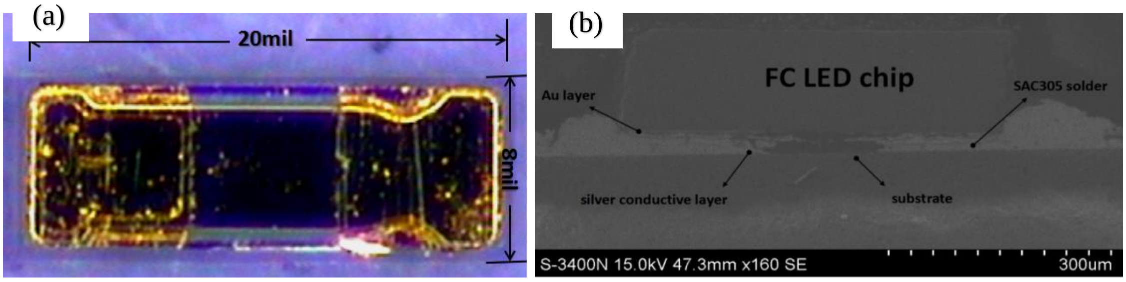

Figure 1. a:FC LED chip b:FC LED chip soldered to silver conductive layer using SAC305 solder and reflow soldering process.

2.2. Sample testing

The shear test was conducted using an XYZTEC strength tester. Scanning electron microscopy and energy dispersive spectrometry (EDS) were performed to observe the microstructure of the solder joints, analyze the reason for the fracture of the solder joints, and observe the distribution of major elements.

3. Results and discussion

The microstructure of the solder joints, the relative content and distribution of the main elements, and the distribution map of shear force were obtained using the aforementioned methods after high-temperature aging for different times. Subsequently, the obtained data were analyzed and compared, and the microchanges and reason for failure of the solder joints at different aging times were determined.

3.1. Microstructure and failure analysis of solder joints

Figure 2 shows the microstructure of SAC305 solder joints at different high-temperature aging times. With an increase in the aging time, the microstructure of the SAC305 solder joint interface between the FC LED chip with Au diodes and the substrate changed considerably, with cracks appearing and increasing in the solder joint gradually,the thickness of the solder layer is also increasing. This is because with the high-temperature aging time, Sn/Au/Cu in the solder reacted with the Au diodes and silver conductive layer on the substrate, forming different intermetallic compounds (IMCs), changing the composition of the solder joints, and thus resulting in cracks and voids.

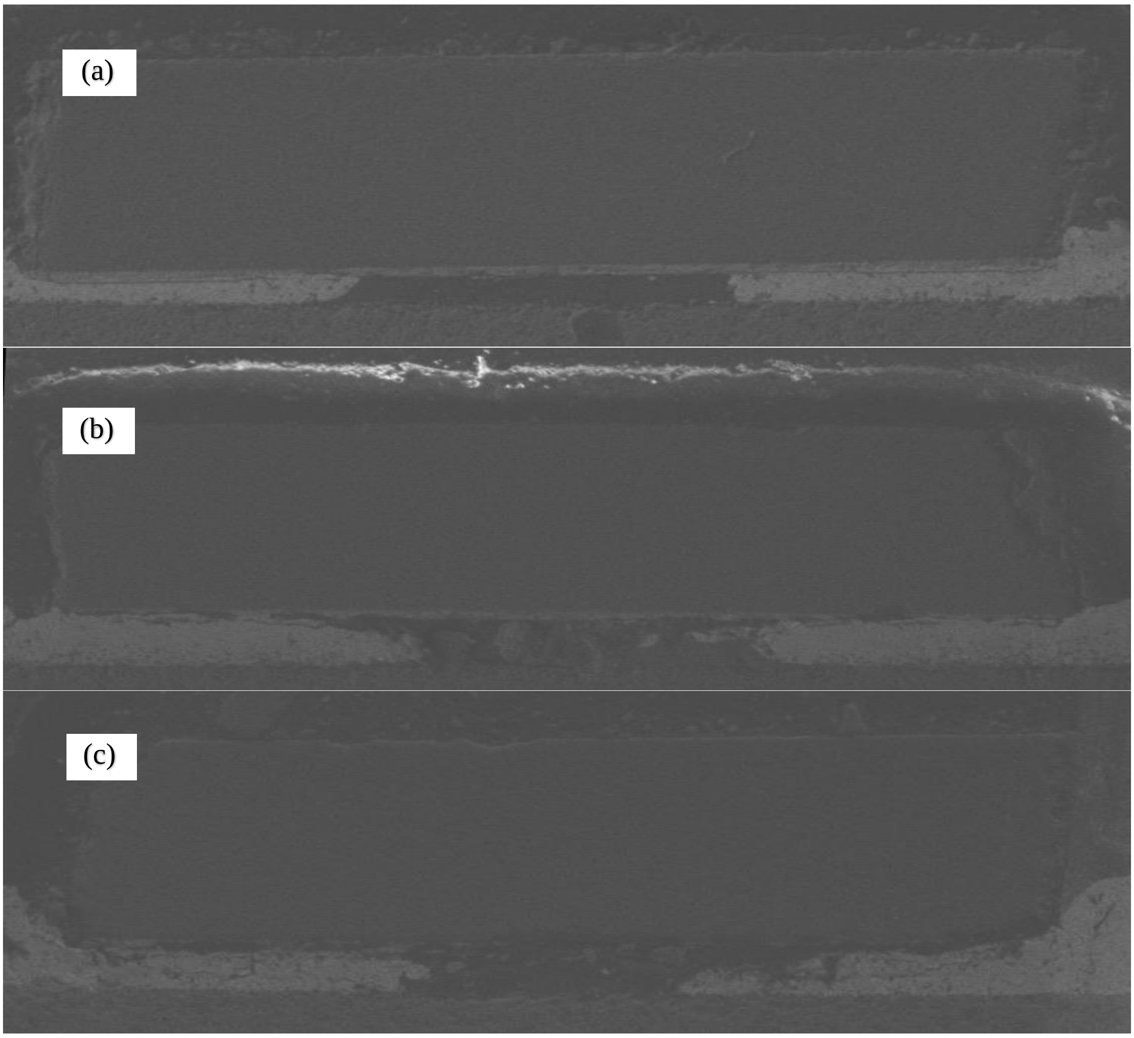

Figure 2. Microstructure of SAC305 solder joints at different high-temperature aging times (a: 0h, b:70h, c:170h).

Figure 3 shows the EDS analysis results for different aging times at the same position of the solder main element content. The results reveal that the solder joints mainly comprised Sn, followed by Au and Ag, and then Cu. With an increase in the high-temperature aging time,the relative content of Sn decreased, the relative content of Ag and Au increased, the relative content of Cu has been little change. This is because with the aging time, the high temperature increased the chemical reaction rate; Sn reaction between the Au chip and silver conductive layer in Ag became faster, resulting in the formation of IMC, which produced the Au and Ag content in the solder joints.And the content of Cu in SAC305 solder is very small,so with the aging time the relative content of Cu has been little change.

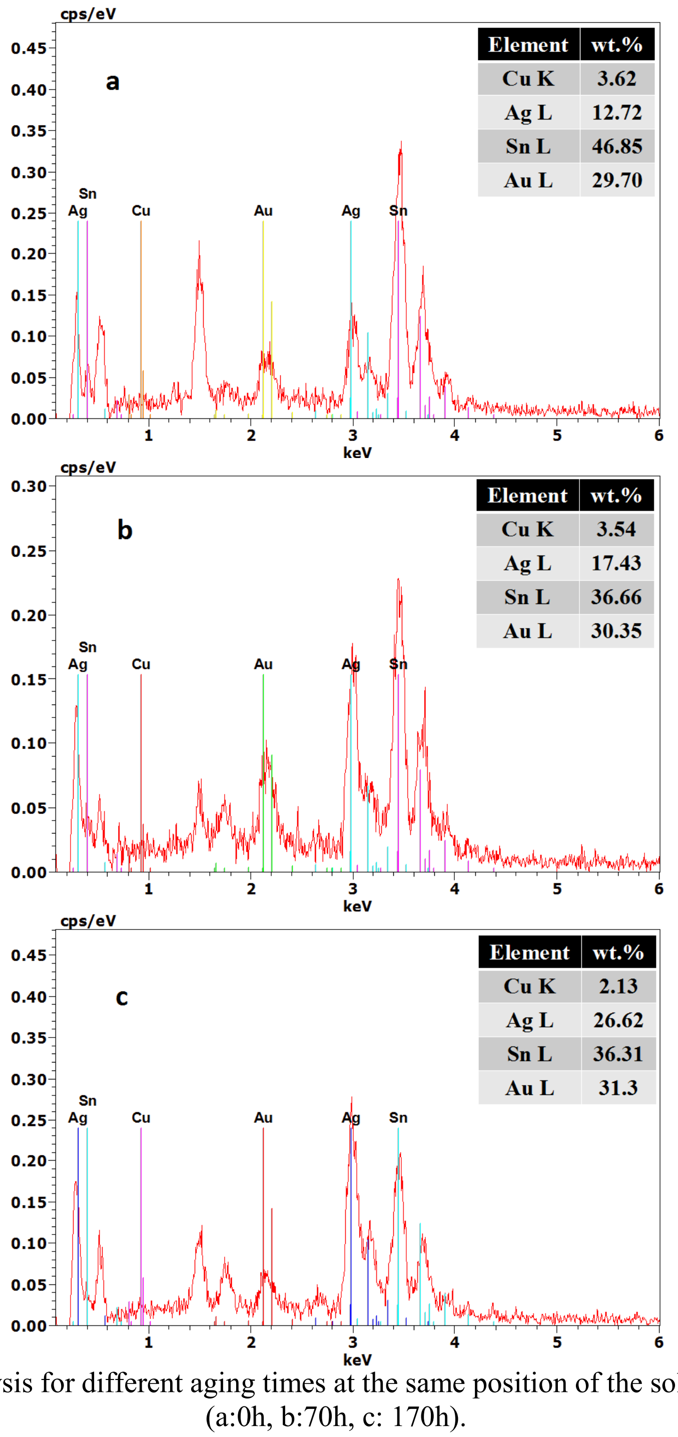

Figure 3. EDS analysis for different aging times at the same position of the solder element content (a:0h, b:70h, c: 170h).

3.2. Shear test and analysis

Figure 4 is the scatter plot of the shear force of the samples after high-temperature aging for different times. The average shear force of the solder joints after aging for 0, 70, and 170 h was 405.0, 266.4, and 145.9 gf, respectively. With an increase in the high-temperature aging time, the shear force of the solder joints decreased. This is because the high-temperature aging process caused cracks and holes in the solder joints, resulting in lower ability of the solder joints to withstand the shearing force. Figures 3 and 4 show that the increase in Au and Ag content in the solder joints had a negative effect on the shear force of the chip.

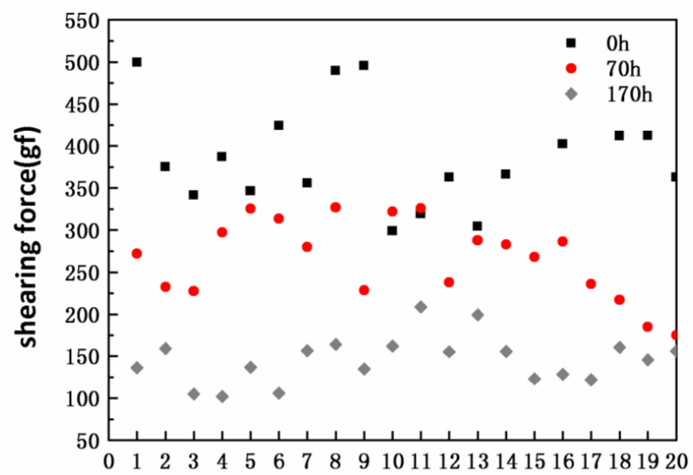

Figure 4. Scatter plot of the shear force of the samples after high-temperature aging for different times.

4. Conclusions

By analyzing the microstructure of SAC305 solder joints at 0, 70, and 170 h after high-temperature aging, the following conclusions can be drawn: the high-temperature heat caused by the Au diodes and substrate in Ag caused cracks and voids in the solder joints under the given circumstances. This had a negative impact on the ability of the chip to withstand maximum shear force, which directly affected the reliability of the FC LED filament.

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