Direct Evidence of Au Segregation in Laser Welded Au-Coated Invar Material

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Evidence of the Au segregation within the crack region in laser welded Au-coated Invar material for semiconductor laser packaging is investigated. Results obtained from the metallography, scanning electron microscope (SEM) mapping, energy dispersive spectrometer (EDS) line profile, and Auger electron spectroscopy find that the cracks in the welded joints occur around the Au rich boundaries. The SEM Au mapping and EDS line profiles show that Au accumulates at the crack region. This direct observation indicates that one of the primary causes of cracks in laser welded Au-coated materials is due to the segregation of Au in the final stage of solidification. Detailed knowledge of the defect formation mechanisms in laser welded Au-coated materials is important for the practical design and fabrication of reliable optoelectronic packaging.

Key words: Au coating, Invar material, laser welding, optoelectronic packaging

INTRODUCTION

To minimize the stresses and alignment changes caused by thermal expansion in housing materials for microelectronic and optoelectronic packages, housing materials with a low coefficient of thermal expansion (CTE) are required.[1] Consequently, Invar[2] with its very low CTE ($1.5 \times 10^{-6}/°C$), is used as housing materials for optoelectronic packaging. The housing material of Invar in optoelectronic packaging is often coated with Au to promote good solderability for chip bonding. Using laser welding technique for packaging of optoelectronics, both solder joints and weld joints in the same housing material are necessary. However, an inadequate thickness of Au coating on housing materials in laser welding process can cause undesirable reactions that may reduce laser beam penetration[3] or generate defects[4–6] in the welded region. Detailed knowledge of the effect of Au coatings thickness on the laser-welded housing materials, which gives both the highest weld strength and good solder adhesion, is essential for the practical design and fabrication of reliable optoelectronic packaging.

The Invar alloy which contains approximately 64% Fe and 36% Ni provides good weldability material for the laser welding technique. According to the phase diagrams of Au-Ni and Au-Fe, the solubility of Au in the phase of Fe and Ni is limited.[7] Hence, Au has a tendency to segregate at the grain boundaries of the major Invar constituents during the solidification process, resulting in the generation of cracks in the welded joints.[4–6] The solidification cracks of the laser

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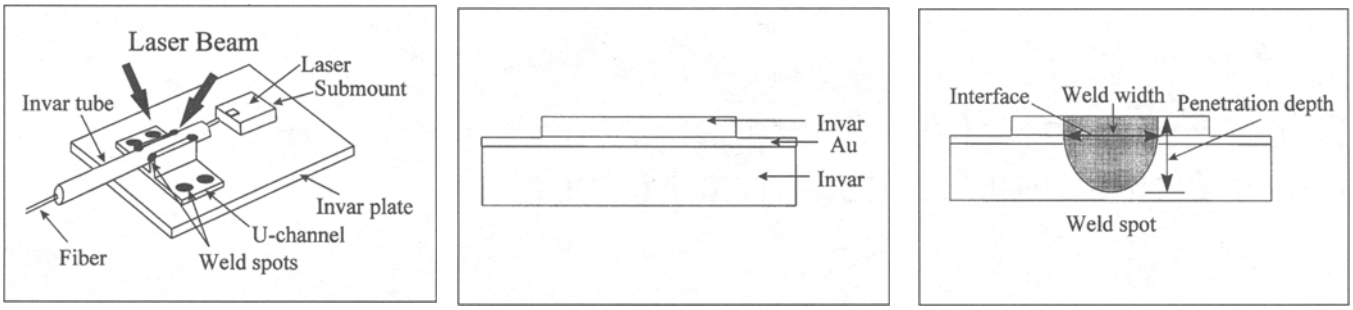

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Fig. 1. (a) Top view of a dual-in-line v package showing the pigtail fiber to laser connection, (b) Invar plate-to-Invar plate joint, and (c) the penetration depth and weld width of weld spot.

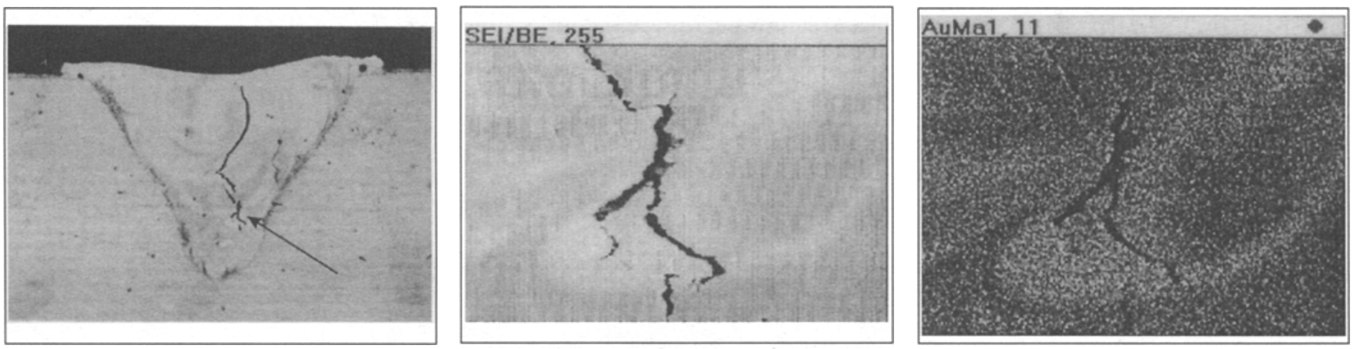

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Fig. 2. (a) Metallographic photo of laser welded Au-plated Invar, (b) SEM photo of crack region, and (c) SEM mapping of Au element signal along the crack region.

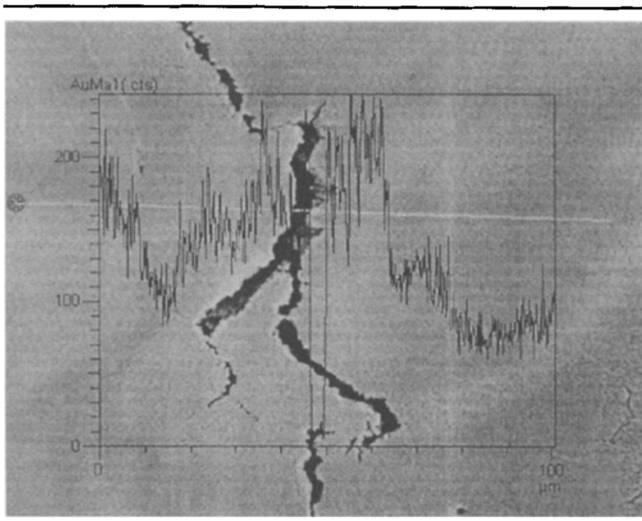

Fig. 3. An EDS line profile of Au element along the crack surface.

welding defects on various stainless steels are well documented in the welding literature.[8] One of the known causes of cracks is embrittlement due to the segregation of impurities such as P and S to the grain boundaries. Despite numerous studies on the laser welding technique for large joint applications, only limited information is available for optoelectronic joining applications in which crack defect is the prominent issue involved in package reliability. The Invar and Kovar alloys are the common base materials for use in optoelectronic packages. Recently, the segregation of Au in laser-welded Au-coated Kovar alloy has been reported.[4] A similar Au segregation in Invar alloy can also be interested for optoelectronic package investigation. In this study, we experimentally investigate the crack formation mechanisms in spot-welding techniques for laser welded Au-coated Invar alloy using metallography, scanning electron microscope (SEM) mapping, energy dispersive spectrometer (EDS) line profile, and Auger electron spectroscopy (AES). This work has led to an important understanding of the primary causes for the cracks in laser welded Au-coated materials which may affect package reliability.

EXPERIMENT

The dual-in-line package (DIP) with fiber pigtail is widely used for laser-based transmitters in light wave communication systems. In the process of fabricating a DIP, a dual-beam laser welding is used for pigtail fiber assembly to the semiconductor laser. The laser welding system consists of a pulsed Nd:YAG laser and a fiber optic beam delivery system. The DIP consists of a 1.3 μm semiconductor laser, a diode housing, a TE cooler, and a single-mode fiber as shown in Fig. 1a. The diode house comprises of all Invar materials including the Invar plate, u-channel, and Invar tube. There were a total of four welded spots on the laser-welded Invar tube-to-u-channel or u-channel-to-Invar plate joints as shown in Fig. 1a. To simplify the study of the laser welding process in DIP, the Invar tube-to-u-channel and u-channel-to-Invar plate joints were substituted by the Invar plate-to-Invar plate joints as shown in Fig. 1b. The Invar plates with and without

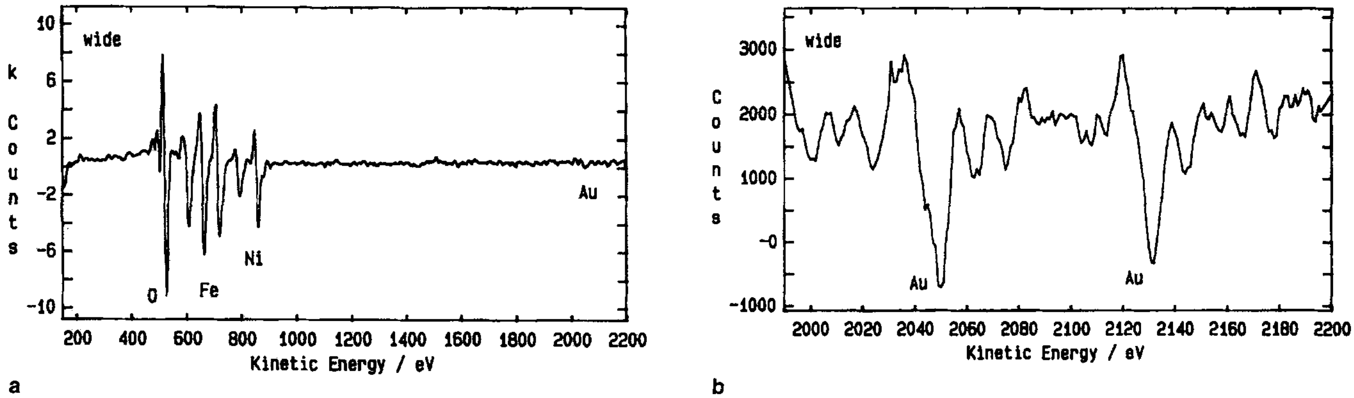

Fig. 4. An AES result of (a) Fe, Ni, and Au scanning elements, and (b) a magnified portion of Au scanning element.

Au plating were studied, and the thickness of Au plating was in the range of 1 to 20 μm. A 4 μm Ni underlayer was used on all Au-plated Invar plates. Figure 1c shows a laser-welded spot. A circular spot of average 0.75 mm in diameter was produced by a well-focused laser pulse on the Invar plate. The diameter of the welded spot would decrease as the laser pulse energy decreased. Characteristics of the Au segregation in laser-welded spots for Au-plated Invar materials were investigated by using metallography, SEM, EDS, and AES.

MEASUREMENTS AND RESULTS

Figure 2a shows a metallographic photograph of the cross section of laser-welded Au-plated Invar with 12 μm Au thickness. Cracks are observed in the fusion zone. Figure 2b shows an SEM enlarged photo as indicated by the arrow mark in Fig. 2a. An SEM mapping of Au element signal along the crack section is shown in Fig. 2c. The bright contours in Fig. 2c indicate heavy concentration of Au atoms. Figure 2c clearly shows that the bright contrast in Fig. 2b represents gold rich content. The results indicate metallographical differences in the gold rich area. This may be due to etching resistant of the Au content.

An EDS trace on the cross section involving the crack region is investigated. The relative intensities of the trace elements of Fe, Ni, and Au show a discontinuity within the crack region. Figure 3 shows an EDS line profile of Au element along the crack region of Fig. 2b. The EDS analysis results show the significantly higher levels of Au accumulation in the crack region than those of area without cracks. Figures 2 and 3 clearly demonstrate that one of the primary causes of cracks in laser welded Au-coated materials is the segregation of Au at grain boundaries in conjunction with the high stresses generated by rapid cooling.

A quantitative analysis of the concentration of Au segregation along the crack region with different thicknesses of Au-plated Invar materials was also investigated by the AES. The scanning spot was 500 A diameter and the total accumulation time was 215 s with an accumulation period of 2ev/step. Figure 4a shows the Fe, Ni and Au elements spectrum of the scanning points as indicated in Fig. 2b. Figure 4b shows a magnified portion for the counts of two peaks of Au element in the spectrum from 1.8 to 2.2 kev. Figure 4 clearly supports the metallographic observation that Au exists within the crack region. Different thicknesses of Au-plated Invar materials are studied. The concentration of the Au segregation increases as the bulk Au coating thickness increases.

CONCLUSION

In summary, the segregation of Au within the crack region was observed when the Invar was laser-welded to Au coated Invar during the packaging of semiconductor lasers. This direct evidence indicates that one of the major causes of cracks in laser welded Au-coated material is due to the segregation of Au in the final stage of solidification. However, the exact crack formation mechanism in laser welded Au-coated materials may relate to the combination effect from the Au segregation and solidification stresses. Detailed knowledge of the residual stresses in laser welded Au-coated materials in conjunction with high stresses generated by rapid solidification is necessary and currently under investigation by a finite-element-method.

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