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온도 변화에 지배되는 LLCC Solder 접합부에서 균열이 일어난 계면에 대한 불순물 편석

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IMPURITY SEGREGATION ON CRACKED GRAIN BOUNDARIES IN LLCC SOLDER JOINTS DURING THERMAL CYCLING

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초 록 1시간 주기로 −35℃에서 +125℃까지의 온도 변화에 지배되는 Leadless Ceramic Chip Carriers(LLCC'S)의 Solder접합부에서 균열이 계면을 따라 일어났다. 이런 균열이 계면을 취약하게 하는 어떤 불순물에 의한 것이 아닌지를 Scanning Auger Microprobe(SAM)을 이용해 조사했다. 그 결과 계면을 따라 일어나는 균열이 계면의 산화에 의해 일어날 수 있다는 것이 발견되었고, 그에 따라 산화에 취약해진 계면을 따라 일어나는 이런 종류의 피로 파괴현상에 대한 모델을 제시했다.

Abstract A large number of grain boundaries were seen to crack in near-eutectic solder joints of leadless ceramic chip carriers (LLCC's) during thermal cycling at temperature ranges from −35℃ to +125℃ with 1hr time period[1,2]. One potential explanation for this type of cracking might be the presence of embrittling species on the boundary. Although there do not appear to be any instances reported in the literature of solders being embrittled by small amounts of contaminating species, the possibility of such an occurrence exists. The potential presence of impurities located at crack surfaces was inspected using Scanning Auger Microprobe(SAM) and it was found that intergranular cracking could be accomplished by the oxidation of the grain boundary. A physical model for fatigue crack growth was introduced, in which grain boundary separation took place under oxidation facilitated by sliding.

Introduction

Solder, mostly Pb-Sn based, has been used for joining metals for over 6000 years, ever since the Bronze Age. It is often claimed, however, that scientific studies on the relevant mechanical properties have only taken place in the very late 20th century−1980 and afterwards. Whether or not this claim is true is detectable ; what is not detectable is that recent trends in microelectronics have motivated, more that ever, a need to understand the mechanisms of deformation and oxidation and the related mechanical failure in solders and solder joints. These is rarely such a thing as "electrical" failure in modern electronic devices ; most often such failures stem from a combination of mechanical and corrosion effect[3~5]. Imagine the problems of thermal fatigue when one places 10^5 solder joints, each $5\mu m$ in dimensions, on a single device of $1 cm^2$ area!

Since room temperature is 2/3 the melting point of the eutectic solder, which means that high temperature mechanisms will dominate, it is interesting to note that solder joints exhibit, at room temperature, many of the same intergranular deformation and failure phenomena as do superalloys at temperatures around 1000℃.

It has been reported that intergranular cracking in near-eutectic solder joints of leadless ceramic chip carriers(LLCC's) during thermal cycling was associated with grain boundary sliding[1,2]. However, the details of intergranular cracking associated with sliding are uncertain although an environmental effect is considered to be involved in the light of the experimental observations that grain boundary cracks initiated from the solder fillet[2] and fatiguing the specimen inside even a moderate vacuum of 1.3×10^{-3} torr resulted in substantial increase in fatigue life[6]. Therefore, in this work, an intergranular failure mechanism is suggested throughout the investigation of oxidation on cracked grain boundary in LLCC solder joints.

Experimental Procedure

Near eutectic solder joints between leadless ceramic chip carriers (LLCC) and printed circuit boards were tested in this work. Specimens were cycled in a Tenney-5 thermal cycle chamber under one (nominal) range of temperature : -35℃ to $+125$℃. The frequency of the thermal cycle was 1hr(Figure 1). LLCC samples were cycled between 0 and 1000 times prior to removal for inspection of the presence of impurities located at crack surfaces using SAM. To prepare solder joints for SAM examination, the packages were cut from the printed circuit boards using a diamond saw, being careful not to touch or damage the solder. A small area of printed circuit board remained surrounding the package and solder joint. The non-conducting material surrounding the solder joint was subsequently wrapped with aluminum foil, then a conducting bridge of silver paint was applied to establish an electrical connection between the solder and the aluminum foil.

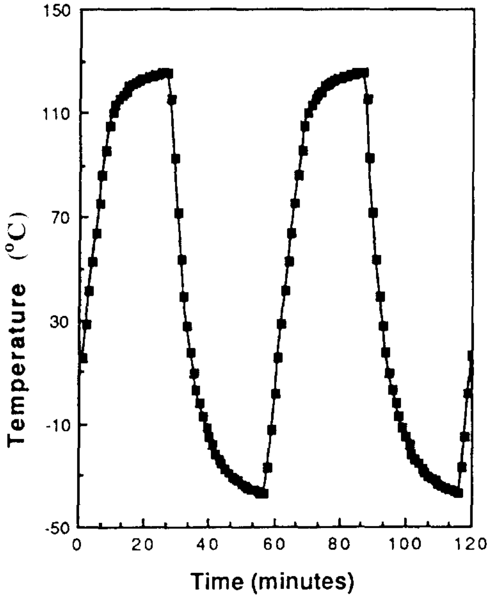
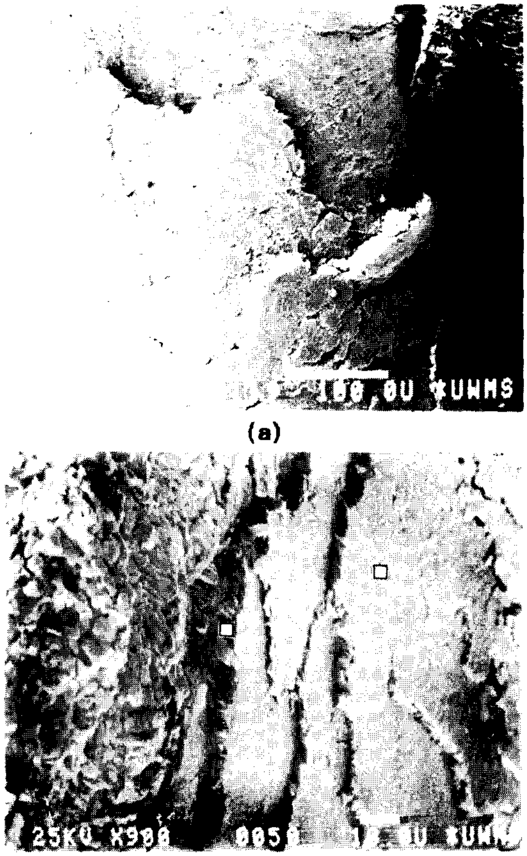


Fig. 1. Temperature vs. time profiles for the thermal cycle tests.

In Auger electron spectroscopy, the elemental sensitivity factors were obtained by comparing the Auger peak heights for pure elements with those of a standard[7]. The Auger parameters used are as follows : 30 nA beam current, 3keV beam voltage, 5eV/s scan rate, 2eV modulation, and 0.1 second time constant. The Auger data were always obtained in dN/dE broad-scan mode, meaning that the first derivative of the electron current with respect to energy was recorded, from 50 to 550eV. The composition vs. depth profiles were obtained by argon ion sputtering followed by an Auger broad-scan. Two different ion guns were used for sputtering : The first system required that the Auger chamber be backfilled with argon to a pressure of 5×10^{-5} torr during sputtering. The sputtering parameters were as follows : 1.5keV sputtering voltage, 15MPa argon pressure, and a raster size of $6\times6mm^2$. The sputter rate of the oxide is probably comparable, since the effect of the lower atomic mass of oxygen is negated by its higher binding energy to the metal.

Results and Discussion

It was possible, near the surface of the fillet, to inspect the chemical composition of the material on the fatigue crack surface and to



(a)

(b)

Fig. 2. Secondary electron images (SEI's) of solder joints after thermal cycling ; a) 50 cycles and b) 500 cycles.

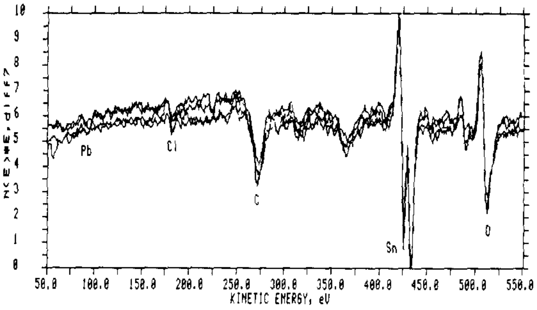


Fig. 3. Auger electron spectroscopy surveys of fatigue crack surface.

locate any obvious evidence of segregation of embrittling elements to the grain boundaries (candidates for embrittlers would include all elements that might be present, other than what could result from atmospheric contamination). Two areas where the Auger spectroscopy were used are shown in Figure 2. The actual sizes of the regions inspected were much smaller than the boxes shown. Left one of these boxes contains a crack surface, the object of inspection, while the other was randomly chosen from the surface of the fillet. Auger electron spectroscopy surveys of fatigue crack surfaces are compared with those from the randomly chosen areas in Figure 3. In all cases, the only obvious evidence of species other than Pb and Sn are from Cl, C, and O, all of which could be explained by environmental contamination. Among these species the oxygen element was chosen as a potential candidate for embrittling the boundary because the oxygen can not only introduce a type of stress corrosion phenomenon but also act to prevent the surfaces of the cracks from welding together during the compression part of fatigue[8].

Figure 4 shows composition vs. depth profiling, which was used to estimate the thickness of oxidation layer from the sputtering time. From the known sputter rate, 0.05nm per second, the thickness of oxidation layer after thermal cycles was estimated. Figure 5 shows the thickness of oxidation layer as a function of the number of thermal cycles. Here, it can be noticed that the oxidation on the cracked surface occurs very fast up to 200 thermal cycles and then slows down. A physical model for intergranular cracking associated with such a fast oxidation of the grain boundary in the early stages of thermal cycling is introduced below.

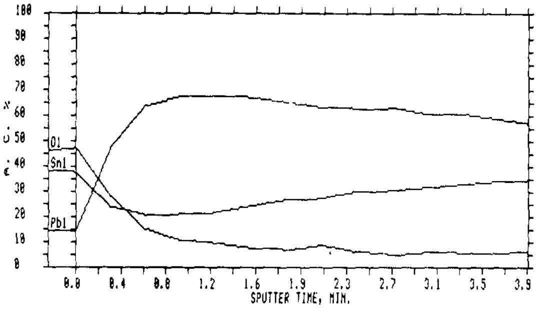


Fig. 4. The thickness of oxidation layer changes as a function of the sputtering time.

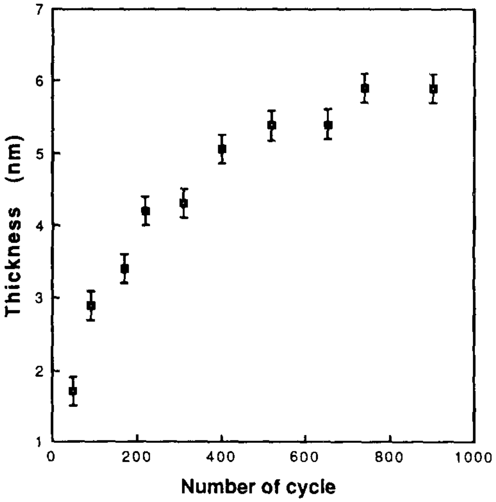


Fig. 5. The thickness of oxidation layer on the cracked surface as a function of the number of thermal cycles.

It appeared that grain boundary sliding continuously exposed the crack tip to the atmosphere as shown in Figure 2. Figure 2a shows that the surface of fillet has roughened considerably due to relative sliding between grains. Figure 2b reveals the resulting intergranular failure after further thermal cycling. Since grain boundary sliding is driven by shear stresses acting in the planes of the boundary[9], boundaries at 45° to the fillet surface (on which the shearing stresses are greatest) are most susceptible to sliding and so have the greatest tendency toward cracking. Based on the experimental results, I suggest a physical model as the following. The sequences in the model are provided in conjunction with

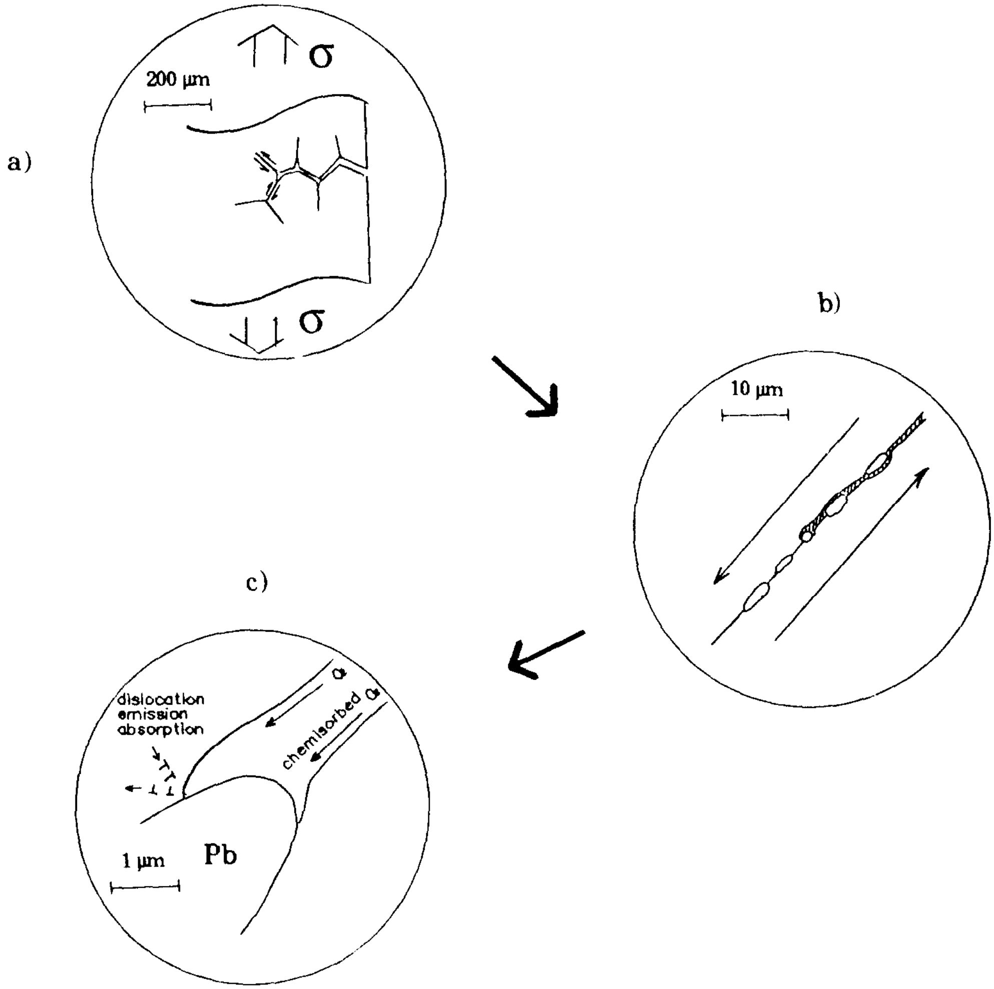


Fig. 6. Sequences showing intergranular failure under oxidation facilitated by sliding.

a intergranular failure under oxidation facilitated by sliding in Figure 6. Grain boundary sliding at properly-oriented boundaries in advance of the crack tip (Figure 6a) generates stress concentrations at Pb particles along the grain boundary⁹⁾ (Figure 6b). Chemisorbed O_2 (or for shallow cracks, O_2 in the gas phase) diffuses along the (already oxidized crack surface until reaching the tip of the crack. The Pb/Sn interface is a high energy one, and formation of Pb and Sn oxides is thermodynamically favored at this interface. In regions of where the boundary consists of a Sn-Sn interface, oxidation is favored as well although the interfacial energy is a lower one (because of large stress concentration along the boundary). According to Figure 6, grain boundary diffusion of O_2 is not rate-limiting for crack advance. Instead, it can be presumed that the amount of crack advance per cycle is related to the grain boundary sliding displacement per cycle, which in turn is influenced by the strain concentration brought about by the crack tip. Figure 7 shows the growth of crack which appears to be associated with the above mechanism. The experimental observations showing that grain boundary cracks initiate at the solder surface (as shown in Figure 7) and many reports identifying the important role of oxidation by showing the improvement of fatigue life in high vacuum⁴·⁵⁾ support the mechanism for intergranular cracking associated with oxidation.

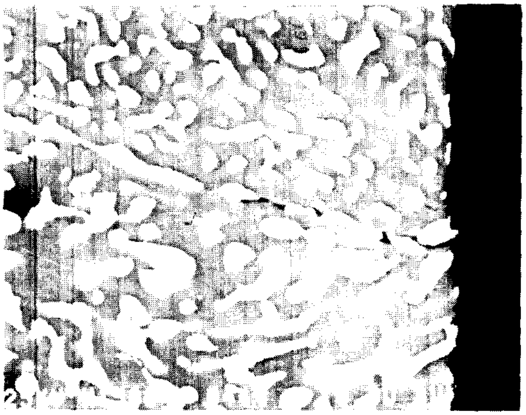


Fig. 7. **Secondary electron image (SEI) showing intergranular cracking**

Conclusions

Based on the experimental observations showing that moderate vacuums could significantly improve fatigue life and the cracked grain boundary was rapidly contaminated by the oxygen element in the early stages of thermal cycling, a mechanism for intergranular cracking associated with oxygen penetration was proposed, whereby chemisorbed oxygen penetrates along the crack face, attacking the Pb-Sn and Sn-Sn interfaces on the boundary. A damage phenomenon (i.e intergranular cracking from the surface) observed in near-eutectic solder joints of leadless ceramic chip carriers (LLCC's) during thermal cycling was characterized based on the mechanism.

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