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Effect of Stress on the Electrical Resistivity of Solder

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The electrical resistivity of tin-lead eutectic solder was found to increase upon tension. The effect was partially reversible. The fractional change in resistance per unit strain was 60. The irreversible part of the effect was due to plastic deformation.

Key words: Solder, electrical resistivity, electrical resistance, stress, piezoresistivity, tin, lead

INTRODUCTION

Soldered joints are widely used for electrical interconnections in electronic packaging. In case that the components that are joined are different in the coefficient of thermal expansion (CTE), temperature excursions result in variations in the thermal stress. As a result, thermal cycling causes thermal fatigue, which can cause work hardening in the solder and even failure in the soldered joint. Due to the large number of soldered joints in an electronic package, the reliability of soldered joints is of great concern to the electronic industry.

Because solder tends to encounter thermal and mechanical stresses during use in a solder joint, the effect of stress on the electrical resistivity of solder deserves investigation. Previous work has emphasized the effect of stress on the quality of soldered joints[1–11] much more than the effect of stress on the solder itself.[12–19] Concerning the effect of stress on the solder itself, previous work has addressed the mechanical behavior and the thermomechanical behavior, but not the electrical behavior. On the other hand, Vaynman et al.[20] studied the effect of an electric current on the fatigue life of 60Sn-40Pb solder and Conrad et al.[21–25] studied the effect of an electric field on the mechanical behavior of various metals other than solder.

The electrical behavior is relevant to the use of solder as an interconnection material. In addition, as the electrical behavior is affected by the microstructure, the electrical behavior provides an indicator of the microstructure, such as the texture. In contrast to mechanical testing, electrical measurement is nondestructive and is thus attractive for monitoring in real time during cyclic loading. Real-time monitoring enables observation of both reversible and irreversible effects, whereas post-monitoring enables observation of only irreversible effects.

In this work, the electrical resistivity of 63Sn-37Pb eutectic solder was monitored during cyclic tension, while the longitudinal and transverse strains were simultaneously measured.

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EXPERIMENTAL

The solder was 63Sn-37Pb eutectic alloy (E-LEE) from Lee Solder Inc., Seagoville, TX.

Cyclic tensile loading was conducted on dogbone-shaped solder specimens prepared by machining. The narrow portion of the dogbone shape was of length 100 mm, width 10 mm, and thickness 1 mm, as shown in Fig. 1. A screw-action mechanical testing system (2/D, Sintech, Stoughton, MA) was used under load control to provide cyclic tensile stress of amplitude 6 MPa, as shown in Fig. 2. Longitudinal and transverse strains were simultaneously measured during loading, using separate strain gages (EA-06-120LZ-120, Measurements Group, Inc., Raleigh, NC), which were bonded to the centers of two opposite sides of the specimen (Fig. 1). During loading, the electrical resistance of the specimen in the longitudinal direction was measured by using the four-probe method. In this method, four electrical contacts, in the form of silver paint in conjunction with copper wire, were applied

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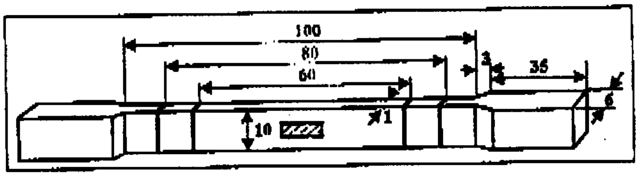

Fig. 1. Specimen geometry. The shaded region is a strain gage. Two strain gages were used, one on each side, for longitudinal and transverse strain measurement. All dimensions are in mm.

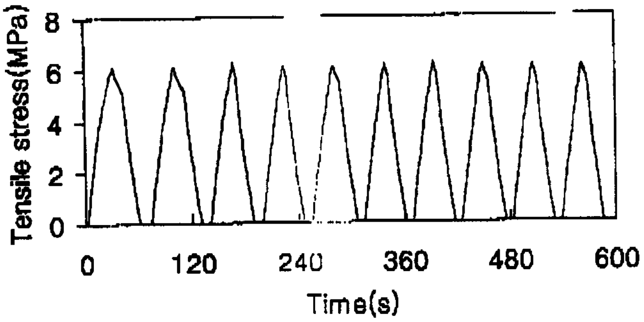

Fig. 2. Tensile stress vs. time during cyclic tensile loading.

around the entire perimeter of the specimen at four planes that were perpendicular to the longitudinal direction and were within the narrow portion of the dogbone shape (Fig. 1). The outer two contacts, 80 mm apart, were for passing a DC current. The inner two contacts, 60 mm apart, were for voltage measurement. A digital multimeter (2001, Keithley Inc., Cleveland, OH) was used for the resistance measurement. The resistivity was obtained from the resistance, longitudinal strain and transverse strain.

RESULTS AND DISCUSSION

Figure 3 shows the longitudinal and transverse strains during the cyclic tensile loading described in Fig. 2. The longitudinal strain (positive) increased (elongation) while the transverse strain (negative) decreased (shrinkage) as tension was applied. Both strains were largely reversible upon unloading, except for a gradual increase of the longitudinal strain baseline cycle by cycle and a decrease of the transverse strain baseline in the first two cycles.

Figure 4 shows the longitudinal resistance and resistivity during the cyclic tensile loading described in Fig. 2. Both the resistance and resistivity increased quite reversibly upon tension, though the noise was substantial (due to the low resistance values around 1 mW). The fractional change in resistance per unit longitudinal strain is 60. This large piezoresistivity effect is probably due to a reversible microstructural change which occurs upon loading. The microstructural change may be associated with the texture of the phases in the eutectic solid.

Both resistance and resistivity baselines increased gradually as cycling progressed. This is consistent with the shift in the longitudinal and transverse strain baselines (Fig. 3) and is attributed to plastic deformation and its irreversible effect on the micro-

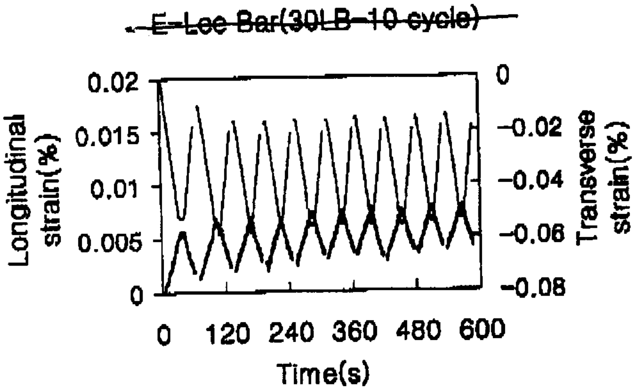

Fig. 3. Longitudinal strain (thick curve) and transverse strain (thin curve) during cyclic tensile loading.

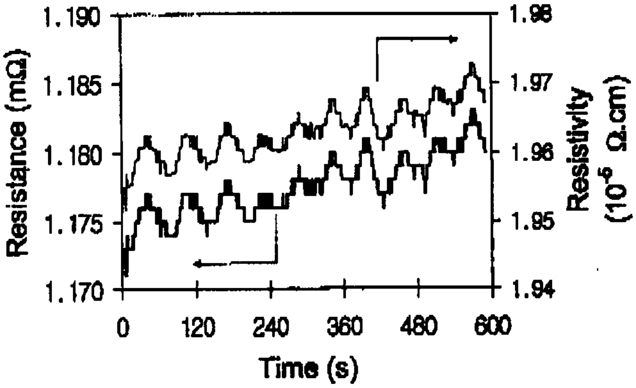

Fig. 4. Longitudinal resistance (thick curve) and resistivity (thin curve) during cyclic tensile loading.

structure.

The reversible and irreversible resistivity changes observed in this work suggest that the resistance of a soldered joint changes in a partially reversible manner as the stress (mechanical or thermal) changes.

CONCLUSION

Piezoresistivity was observed in Sn-Pb eutectic solder. The resistivity in the stress direction increased upon tensile loading, such that the effect was partially reversible. The fractional change in resistance per unit strain was 60. The irreversible part of the effect caused the resistivity baseline to shift upward as load cycling progressed, and is attributed to plastic deformation. The reversible part of the effect is probably related to a reversible microstructural change.

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