THE EFFECT OF DWELL TIME VARIATION DURING MICROHARDNESS TESTING

Wolfgang H. Müller, Mohamad Sbeiti, Holger Worrack

Technical University of Berlin, Faculty of Mechanical Engineering and Transport Systems,
Institute of Mechanics, Chair of Continuum Mechanics and Material Theory
Sekr. MS2, Einsteinufer 5, 10587 Berlin, Germany

Corresponding author: m.sbeiti@tu-berlin.de

1. Introduction

Operation of microelectronic components at higher temperatures and for long periods is one of the major reasons for technical failure of solder joints due to creep effect. This effect also has an influence on the determination of local mechanical material properties via nanoindentation tests. It generally occurs during the dwell time of the indentation procedure. In order to analyze its influence on the measured values of Young's modulus several nanoindentation tests were performed at different elevated temperatures for a eutectic lead-free solder material, namely Sn24Bi58, which has its melting point at 138°C. In these tests the dwell times were varied between 30 and 240 seconds.

2. Principles of Nanoindentation

The tests were performed with the nanotest-system from Micro Materials Ltd. The integrated indenter is a three-sided diamond pyramid known as Berkovich indenter and has a face angle of 78.9°. In order to determine the mechanical properties at elevated temperatures the indenter is modified by a hot-stage, where the indenter and the specimen can be heated up to a temperature of 500°C.

The displacement of the indenter in the specimen and the respective load are recorded during the nanoindentation process and plotted in a characteristic load vs. displacement curve (Fig. 1). This curve can be separated into three parts: loading, dwell time and unloading. According to Oliver and Pharr [1] the slope of the unloading curve at peak load

$$S = \frac{\mathrm{d}P}{\mathrm{d}h} \qquad (1)$$

can be used to determine a so-called reduced Young's modulus of the investigated sample material

$$E_r = \sqrt{\frac{\pi}{A}}\frac{S}{2} = \frac{1}{2}\sqrt{\frac{\pi}{A}}\frac{\mathrm{d}P}{\mathrm{d}h} \qquad (2)$$

By means of Equation (3) Young's modulus, E, of the sample material is calculated by using indenter material properties as follows

$$\frac{1}{E_r} = \frac{1-\nu^2}{E} + \frac{1-\nu_i^2}{E_i} \qquad (3)$$

where E_i = 1141 GPa and ν_i = 0.07 [2] denote Young's modulus and Poisson's ratio of the indenter material, respectively. ν refers to Poisson's ratio of the sample material and has to be known for the analysis. For solder materials the value for ν can be assumed to be approximately 0.35.

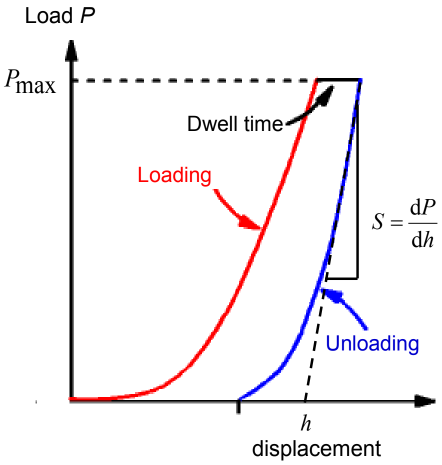

Fig. 1: Schematic load-displacement curve

3. Experimental Setup and Performance

Hot-stage nanoindentation tests were performed at given temperatures of 30°C, 80°C and 130°C. The measured values on the sample surface were 29.5°C, 76°C and 125°C. Furthermore, the dwell times at each temperature level were adjusted to 30 s, 60 s, 120 s and 240 s, respectively. The specimens (including a fused silica specimen for calibration) were attached to the sample holder by means of a temperature resistant cement (Fig. 2). Twenty indents were made for every combination of temperature and dwell time in order to obtain a sufficient number of data points so that statistical errors are of little consequence.

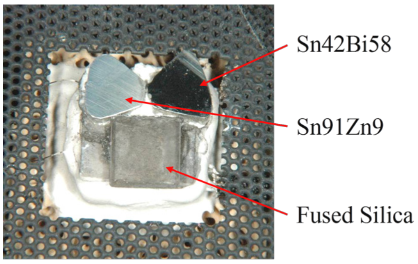

Fig. 2: Specimens on hot stage holder

4. Experimental Results

In Fig. 3 the effect of the dwell time on the unloading curves is presented for Sn42Bi58 at a surface temperature of 125°C. The curve of the 30s dwell time measurement (blue curve) shows considerable discrepancies to the ideal unloading behavior presented in Fig. 1. Due to non-ideal shape of the unloading curve it must be assumed that the analysis procedure of the nanoindentation software is not able to determine the correct gradient S of the unloading part, which, consequently, will lead to incorrect values for Young’s modulus. Furthermore it is clearly visible that an extended dwell time (up to a factor of eight of its initial value) reduces the influence of creep effects on the shape of the unloading part and the behavior becomes closer to the ideal one.

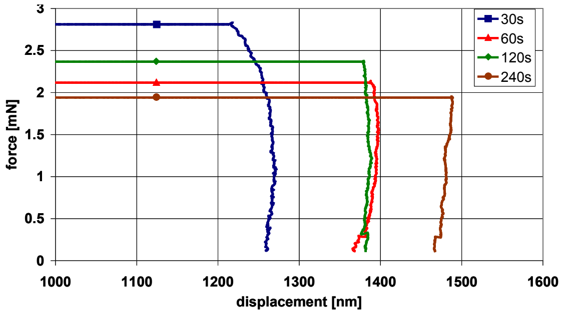

Fig. 3: Unloading curves at different dwell times

A comparison of our experimentally determined values of Young's modulus with the literature [3] is shown in Fig. 4. It shows results for Young’s modulus that were generated automatically with the evaluation software of the nanoindentation system. The results show that the values obtained by using longer dwell times are closer to literature data when compared to those obtained at shorter dwell times. Within accuracy of the measurements the beneficial effect of longer dwell times becomes also obvious for the 76°C results. However, at 125°C (homologous temperature = 0.96) our results differ considerably from the literature. This could be related to the fact that at this high temperature the material becomes extremely soft and the penetration of the indenter often exceeds its calibrated measurement range, which ends nearly at 1300 nm. For this reason only some measurements result in numerical values for Young’s modulus and the accuracy of these values cannot be guaranteed. In addition to the positive effect on the average values of E by prolonging the dwell times the increase also influences the standard deviation of the experimental results. At 240 s of dwell time the deviations from the average values are considerable smaller than at 30 s.

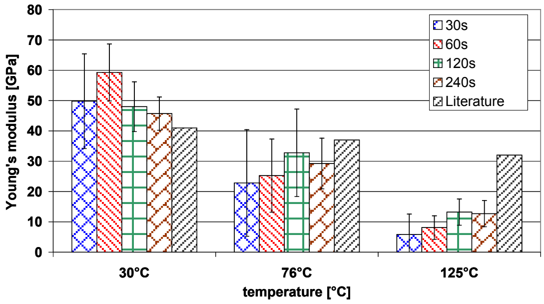

Fig. 4: Young’s modulus vs. temperature at different dwell times

References

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