

Study of Stress Measurements Technique for Internal Electrical Connection of Printed Circuit Boards using Synchrotron Radiation

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ABSTRACT

Measurements of residual stress in a printed circuit board, which consists of copper foil, silver alloy and thermo plastic resin, were conducted under a thermal cycle. The printed circuit board was given a ten-layer repeat of prepreg and made by thermocompression bonding. Experiments suggested the possibility of measuring surface residual stress of copper circuits and the internal residual stress of metallic connections by synchrotron radiation of Spring-8. FEM analysis of the printed circuit board during a thermal cycle was conducted, and the result was adjusted to X-ray stress using absorption correction. X-ray stress during a heat-cycle obtained by synchrotron radiation showed good agreement with stress calculated by FEM analysis.

INTRODUCTION

With the demand for compact, lightweight, and low-cost electronic devices, the march toward higher density built-in components and more compact semiconductor packages continues unabated. This has led to the widespread use of high-density multi-layered printed circuit boards for compact packages¹⁾. Printed circuit boards are subject to various temperatures because of temperature changes in their service environment, and also due to factors such as the self-heating properties of built-in components and their power supply being turned on and off. Therefore, it is important for printed circuit boards, which are laminated structure of materials with different coefficients of thermal expansion, that connection reliability is secured for the thermal cycle of the interlayer connection (via). To secure connection reliability, it is necessary to clarify the residual stress during the manufacturing process and the thermal cycle process.

X-ray stress measurement is widely used for metal material in industry and known as a non-destructive testing methods. However the X-ray stress measurement apparatus normally used in test labs has a shallow X-ray penetration depth and weak diffraction intensity, so it cannot be used to evaluate the stress in the interlayer connection, which has a sandwich construction joined by copper wiring.

Recently, X-ray stress measurement methods using high energy X-rays from a synchrotron radiation source has been applied to the internal parts of laminated structures²⁾⁻⁴⁾. Suzuki et. al²⁾, measured the internal stress in the bond coat through the top coating in the thermal barrier coating. Washimi et. al³⁾, measured the fuel electrode under an SOFC electrolyte film. They used flat plate-shaped specimens, not 3-dimensional shapes like via, and what is more, they did not compare their results with FEM analysis results. In this study, high-energy X-rays at SPring-8 (Super Photon ring-8GeV) were used to measure the residual stress in the copper wiring and via in multi-layered printed circuit board. The behavior of the stress variations in the thermal cycle process was compared with FEM result.

EXPERIMENTAL METHOD

SPECIMENS

The printed circuit board used in the test was a multi-layered prepreg made of copper, thermoplastic resin, and silver alloy, and its shape were formed by thermocompression bonding. The external appearance of the board is shown in Fig. 1. Vias were arranged only under the copper wiring in the areas enclosed in square. Cross section A-B in Fig. 1 is shown in Fig. 2. The board was configured so that the shape of the copper wiring was the same from the 1st to the 10th layer and vias were

arranged in series from the surface layer to the 7th layer. The copper wiring, plastic, and via thickness were approximately 18, 50, and 50 μm , respectively. Also, via cross-sectional shape was trapezoidal with bottom diameter of 200 μm and top diameter of 150 μm .

INSTRUMENTS AND METHOD

The SPring-8 beam line BL46XU was used in the stress measurements. The measurement area inside the board was determined by using 4-quadrant slits on the incident side and the receiving side. The copper wiring and via on the surface layer of the board were measured. The incident slits were 0.5 mm in height and 0.5 mm in width, and the receiving slits were 0.6 mm and 0.5 mm respectively. In addition, the energy level of X-ray was set at $E=22\text{keV}$, which was determined from the brightness of the beam line. Oscillation of the θ axis, which was selected by constraint in goniometer were executed within the range of $\pm 1^\circ$. The measurement conditions are shown in Table I. A self-made specimen holder with a ceramic heater on the XYZ stage was provided for the specimens. Figure 3 shows a schematic view of goniometer.

The printed circuit board was heated from 25°C to 125°C , and cooled off to 25°C afterwards. In this time, the stress measurements were taken after confirming that the temperature had become constant. Since temperature changes caused the specimens to warp, height adjustment by direct beam and position adjustment by video microscope were executed prior to taking measurements.

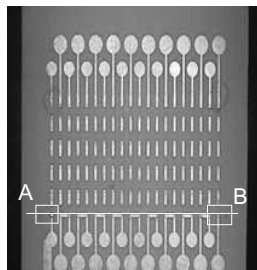


Fig.1. Schematic of specimen

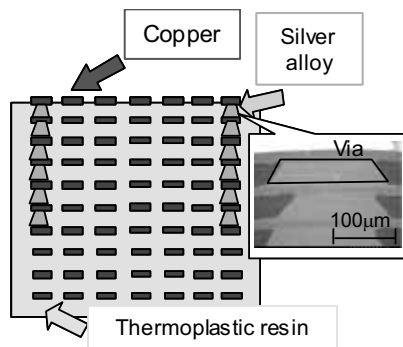


Fig.2. Cross section of A-B

STRESS ANALYSIS METHOD

Vertical strain in the direction inclined only ψ from the specimen surface normal line is expressed by the following equation^{5,6)}

$$\varepsilon_{\psi} = \frac{d_{\psi} - d_0}{d_0} = \frac{\sin \theta_0}{\sin \theta_{\psi}} - 1 \quad (1)$$

where, d_{ψ} is lattice spacing of ψ direction, d_0 is unstrained lattice spacing, and θ_0 and θ_{ψ} are diffraction angle given by Bragg's law as follows

$$\lambda = 2d_0 \sin \theta_0 = 2d_{\psi} \sin \theta_{\psi} \quad (2)$$

where, λ is X-ray wave length. The diffraction angle θ_0 is called as strain free diffraction angle and usually obtained by powder specimen. Also the vertical strain ε_{ψ} is expressed by following equation under the stress conditions shown in Fig. 4.

$$\varepsilon_{\psi} = \frac{1+\nu}{E} (\sigma_x - \sigma_z) \sin^2 \psi - \frac{\nu}{E} (\sigma_x + \sigma_y) + \frac{1}{E} \sigma_z \quad (3)$$

where, E is Young's modulus, ν is Poisson's ratio, and they are dependent on the diffraction plane. The X-ray stress could be calculated from equation (1) and (3). In this study, a number of X-ray diffraction measurements are made at various tilt angle ψ . A gradient of $\varepsilon - \sin^2 \psi$

Table I. X-ray conditions for stress measurement

	Cu	Ag alloy
X-ray energy (keV)	22	
Divergent slit (mm)	width=0.5, height=0.5	
Receiving slit (mm)	width=0.5, height=0.6	
Diffraction plane	111	012,211
Diffraction angle (deg)	15.517	14.232 14.306
Oscillation axis	θ	
Oscillation angle (deg)	± 1	

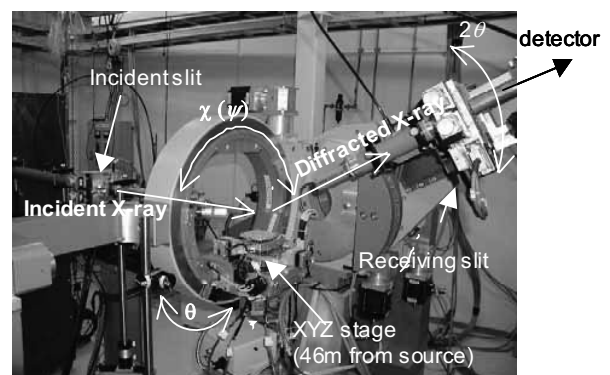


Fig. 3. Overview of Goniometer

curve obtained with equation (3) is used to determine the stress $\sigma_x - \sigma_z$.

The other stress components could be measured using X-ray. However surface copper wiring prevents measurement of σ_y in via. The surface vertical stress σ_z was largely affected by the value of stress free lattice spacing and seemed to be poor accuracy. So, only $\sigma_x - \sigma_z$ was measured. With the X-ray stress measurement using high-energy X-rays from synchrotron radiation, normal stress σ_z in equation (3) cannot be ignored. In the FEM analysis described below, it was summarized in the form of $\sigma_x - \sigma_z$. Of course, the surface copper wiring is plane stress state and σ_z can be ignored.

FEM ANALYSIS METHOD

ANALYSIS METHOD

Figure 5 shows analysis model in this study. Only the area around via was extracted as an axisymmetric 2-dimensional model. The element discretization of the copper and via on the surface layer was densified, and that was performed so that the copper would be 2 μm in the thickness direction and via would be square of approximately 5 μm on one side. The element type was 8-node 2-dimensional element, the number of element was 2145, and the number of nodes was 6640.

Thermo-elastoplastic creeping was treated as this analysis from the testing result of the stress-temperature properties of the constituent materials, and MSC.Marc2005r2 was used to carry out the analysis. Table II shows material properties of specimen.

In order to faithfully reproduce in the tests temperature history and holding time of the analysis, the temperature history was given as initial temperature $\rightarrow 25^\circ\text{C} \rightarrow 125^\circ\text{C} \rightarrow 25^\circ\text{C}$. The initial temperature was determined by inverse analysis from the shape of the board and it was 140°C .

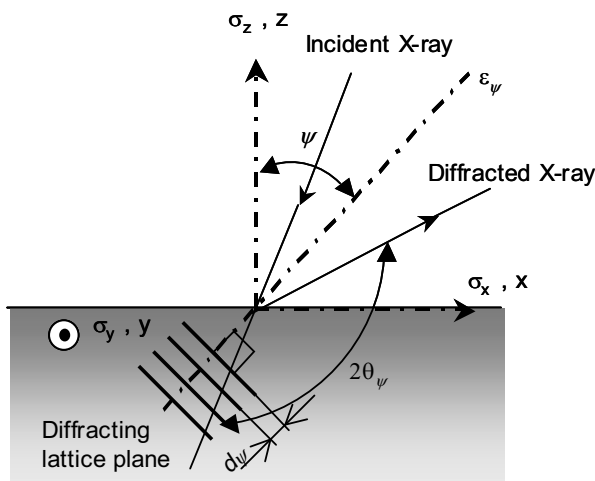


Fig.4. Principle of measurement

AVERAGE STRESS CALCULATION METHOD

The stress obtained with equation (3) is a weighted average in the depth direction, and effective penetration depth is t , the sample thickness is h , and the stress at a certain depth z is $\sigma(z) = (\sigma_x(z) - \sigma_z(z))$, then weighted average stress $\sigma(t)$ is expressed by the following equation⁷⁾.

$$\sigma(t) = \frac{\int_0^h \sigma(z) e^{-z/t} dz}{\int_0^h e^{-z/t} dz} \quad (4)$$

This equation indicates that the denominator is the total diffraction intensity and the numerator is an integration of stress $\sigma(z)$ at a certain depth z and the diffraction intensity at that depth, with the total thickness h . In other words, stress measurement using X-rays requires consideration of how to attenuate the intensity inside the material. The method for determining this $\sigma(z)$ consists of measuring $\sin^2 \psi$ across a wide range from approximately 0 to 0.9 and obtaining the stress distribution from the nonlinearity of the $\varepsilon - \sin^2 \psi$ curve. As the ψ angle increases, however, the irradiation area becomes broader, making it unacceptable for the purpose of taking measurements in specific locations. In this report, therefore, the procedure was reversed and $\sigma(z)$ was obtained from the FEM analysis and weighted average stress $\sigma(t)$ was determined, and the values were compared with actual measured values obtained using X-rays. The calculation method is described in detail in the following.

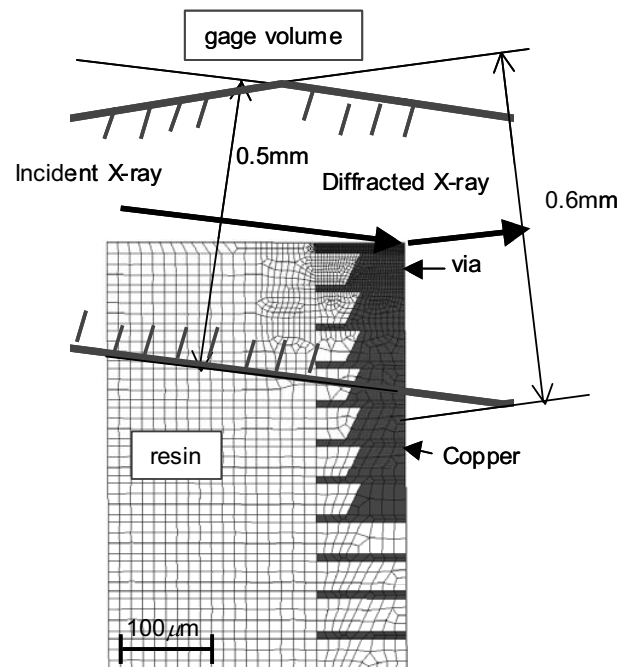


Fig.5. FEM model of Print-circuit Board around via