The *In-situ* Stress Measurement on Tin Strip and Flip-chip by Using Synchrotron Radiation X-ray Scattering

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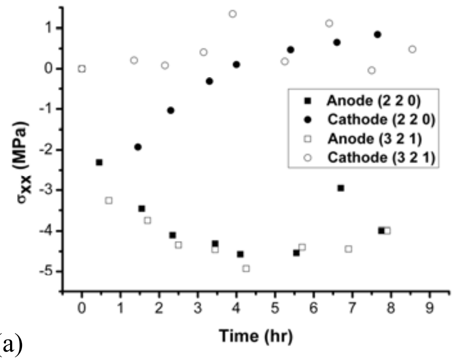
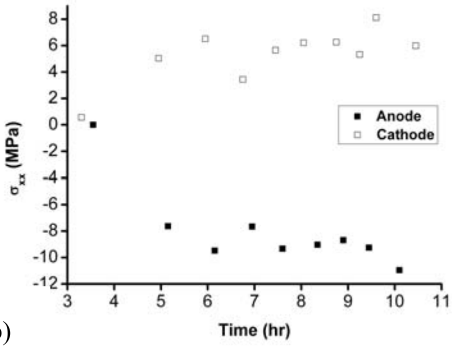
The stress distribution under electromigration in low melting materials, such as tin, is minute and is difficult to be measured by conventional X-ray. Furthermore, the stress of silicon die in flip chip at elevated temperatures is influenced by different layers of materials, it is crucial to obtain the intrinsic stress in the die. Due to high brightness and small beam size, synchrotron radiation X-ray provides the capability to investigate the stress evolution *in situ* in tin strips under electromigration and the stress distribution in silicon die under thermal effects.

In the first experiment, tin strips were placed on the heating stage with their position controlled precisely using stepping motors, and the strips were under the current densities of $1\text{x}10^3$ and $5\text{x}10^3$ A/cm^2. The results show that the electromigration induced different back stresses gradient with 5.5 and 16.5 MPa/cm, respectively. The results were plotted in Figs. 1(a) and 1(b). Both figures were presented in time versus in-plane stress.



(a)



(b)

Fig. 1: (a) Stress versus current stressing time for the sample with current density of $1\text{x}10^3$ A/cm^2. (b) Stress versus current stressing time for the sample with current density of $5\text{x}10^3$ A/cm^2.

When the atoms are under electron wind and diffuse from cathode to anode, the protective oxide layer would block the stress relaxation during electromigration and cause tin atoms accumulate at the anode that results in compressive stress. The cathode would be tensile due to the back flow of vacancies. The stress gradient across the strip allows us to calculate the diffusivities of atoms. The calculated values are about two orders higher than the expected self-diffusivity of tin. We proposed that the electroplated tin has small grain size. Consequently, grain boundary diffusion should be taken into consideration.

Another experiment was to measure the stress distribution under thermal effect of silicon die in flip chip. The sample was calibrated the stress-free temperature with the warpage test and we found that the die was near zero warpage at near 100^{o}C. Therefore, we set 100^{o}C as the reference temperature. In the *in situ* X-ray experiment, five positions on the sample at regular intervals along the edge of the silicon die were scanned from left to right (A to E). The results are plotted in Fig. 2. The center of the die edge exhibits the largest in-plane strain than at the corners. At 25^{o}C, the out-of-plane strain was the most compressive and the in-plane was the most tensile. As the temperature increased, the flip chip became less warped, and the in-plane dilation decreased. Hence, the in-plane strain was less tensile. Therefore, the die experienced a less compressive strain in the out-of-plane direction upon heating.

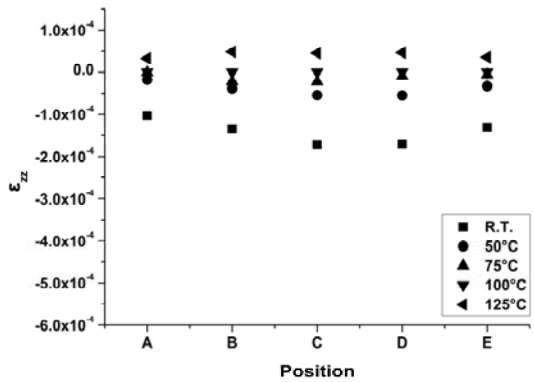


Fig. 2: As-scanned out-of-plane strain, ε_{zz}, versus scanned position at various temperatures

Notably, if the die is regarded as a thin film, the well-accepted biaxial thin-film model would be applied and the film should be compressive when the film is convex. However, the results were contradictive to the conventional concept. Stoney's model is based on the assumption that the thickness of the film is smaller than that of the substrate; the neutral plane is located at the center of the substrate. However, this assumption does not hold for flip chip. The thickness of the die in the experiments was approximately 700μm. Accordingly, the neutral plane may lie within the die. Since the warpage of the die is a critical issue in the advanced packaging technique, such as 3D TSV, this experiment yields valuable information by using synchrotron radiation X-ray.