1. INTRODUCTION

Currently in the field of microelectronics the most serious reliability problem with respect to metal interconnects is electromigration. In flip chip packaging technology, as the number of input/output contact pads on a chip is increased, the diameter of solder bumps has decreased. Consequently, the current density through the contact area of the solder bumps has increased dramatically. Thus, the current density is expected to be in the order of $10^4 \text{A/cm}^2$. The current density of solder is about two orders of magnitude smaller than that of Al or Cu interconnects. However, electromigration in flip chip solder occurs at low current density\,[1-4], since the melting point of solder is low and its diffusivity is high. The electromigration characteristics of a solder bump differ from those of Al or Cu interconnects. The solder alloys are binary, ternary or even quaternary. However, chip interconnects are composed of a major element (e.g. Al or Cu) with only a small amount of alloying elements. This is a key difference between interconnect and solder.

Furthermore, owing to environmental considerations, demand for Pb-free solder has increased\,[1]. Among the Pb-free solders, eutectic SnAgCu solder appears to be the most promising candidate for replacing eutectic SnPb solder. Indeed, the National Electronics Manufacturing Initiative (NEMI) has recommended replacing eutectic SnPb alloy with eutectic SnAgCu alloy. Nevertheless, electromigration of SnAgCu has not been heavily studied.

In this work, the electromigration of Sn$_{96.5}$Ag$_{3.0}$Cu$_{0.5}$ was assessed with an edge drift structure. The edge drift structure proposed by Blech and Herring\,[5] has been widely used to examine electromigration behaviors. Although the edge drift structure is different from the conventional flip chip solder ball bumps in shape, the use of this structure simplifies measurement of both the edge displacement and the change in concentration of solder due to electromigration on the top-view SEM observation. Moreover, the temperature and current density profiles are more uniform in this structure. Several studies have addressed the electromigration parameters (drift velocity, $E_a$, $Z^*$, threshold current density) of eutectic SnPb\,[4,6,7], but the relevant parameters of electromigration of SnAgCu solder are still unknown. In the present work, we observe the electromigration behaviors and activation energy of SnAgCu solder lines.

2. EXPERIMENT

A 3000-Å-thick Ni thin film was patterned into a line structure with two contact pads. A SiO$_2$ layer with a thickness of 1 mm was deposited on the Ni line and the contact pads were removed. However, in order to separate the solder line from the contact pads, the SiO$_2$ “walls” were intentionally left between the contact pads and the line. The width and length of the line were 100 $\mu$m and 1000 $\mu$m, respectively. A small amount of Sn$_{96.5}$Ag$_{3.0}$Cu$_{0.5}$ solder paste was dropped on the exposed Ni area and reflowed at 220 °C for about 5 s. The solder was then polished down until the thickness of the SnAgCu lines reached approximately 3 - 5 $\mu$m. Figure 1 shows a schematic diagram of the cross-section
The testing temperatures were 110, 125, 140, and 160 °C. Each sample was annealed for 4 hours at each testing temperature before the electromigration test in order to stabilize the microstructure and the formation of intermetallic compounds between Ni and the solder. The 3000-Å-thick Ni underlayer was fully converted into a (Ni$_x$Cu$_{1-x}$)$_3$Sn$_4$ layer before the electromigration test$^8$. Since the current flows through both the SnAgCu solder and the (Ni$_x$Cu$_{1-x}$)$_3$Sn$_4$ underlayer, the effective current density of the SnAgCu line was calculated using a parallel model$^{3,7,9}$. It was reported that the electromigration resistance of Cu-Ni-Sn alloy$^{10}$ is much larger than that of SnAgCu solder. Therefore, it was expected that the effect of the (Ni$_x$Cu$_{1-x}$)$_3$Sn$_4$ underlayer on the solder electromigration behavior should be negligible during the electromigration tests. The effective current density applied to the SnAgCu solder line was 4.5 × 10$^4$ A/cm$^2$.

Scanning electron microscopy (SEM: JSM-5600) was employed to observe the interruptive edge displacement of the solder line due to electromigration. In-situ SEM (Hitachi 2500C) was configured for real-time evolution of the solder line. The in-situ SEM equipment consists of a regulated DC power supply, a heat plate, and a digital multimeter in a SEM chamber.

3. RESULTS AND DISCUSSION

3.1. Electromigration behaviors of SnAgCu solder line

The electromigration behaviors of the SnAgCu solder lines were observed at 4.5×10$^4$ A/cm$^2$ and 140 °C. Figure 2 shows in-situ SEM images of the region near the cathode of the SnAgCu lines as a function of time. Measurement of the edge displacement of the depleted region at the cathode was carried out using an image processing system. The edge displacements were measured from the images shown in Fig. 2, and are plotted as a function of time in Fig. 3. SnAgCu solder line begins to move shortly after the current is turned on and drifts at a constant rate (Fig. 3). The electromigration behaviors of the SnAgCu lines were different from those of eutectic SnPb solder lines. Figure 4...