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Improving accuracy of filling performance prediction in microvia copper electroplating

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ABSTRACT

To understand the effects of the decomposition of a suppressor on the filling performance for microvias on a printed circuit board, the characteristics of copper (Cu) electroplating solutions were investigated using linear sweep voltammetry (LSV) and galvanostatic measurements (GMs). As a suppressor, polyethylene glycol (PEG) was utilized. With conducting Cu electroplating, the filling performance was lowered and the PEG molecular weight (MW) was decreased as a result of the decomposition. When fresh PEG was added to the aged solution, the cathodic potential at a given current density recovered to the initial value but $\Delta\eta$ measured at two different rotating speeds was negligibly affected. When PEG with small MW (MW $\leq$ 600) was added to a plating solution containing PEG with large MW (MW $\geq$ 2000), the filling performance was lowered, exhibiting an unaffected cathodic potential and a reduced $\Delta\eta$ value. The more negative cathodic potential could be associated with the higher filling. However, when the filling performance is higher than 82% or the cathodic potential shifted negatively below a certain level (-0.18 V, in this work), the filling performance was found to be more closely related to $\Delta\eta$; a larger value of $\Delta\eta$ brings better filling performance. Based on these results, an electrochemical method that more accurately predict the filling performance of the solution during continuous Cu electroplating is suggested.

1. Introduction

As electronic devices become slimmer and multifunctional, the filling of microvias is becoming a vital technology in the fabrication of multilayer printed circuit boards (PCBs), especially integrated circuit (IC) package substrates and high density interconnections (HDIs) [1,2]. Fully filled microvias enable package densification by reducing the pad size in multilayer PCBs. Microvias are filled with copper (Cu) using an electroplating process to take advantages of high reliability, high productivity and low cost [1,3–7]. Microvia-filling proceeds through a bottom-up plating, also called as superfilling; Cu selectively fills only the microvias rather than is deposited on the substrate surfaces. A reliable bottom-up plating is one of the crucial steps in manufacturing multilayer PCBs [8–11].

For microvia-filling, the basic copper plating solution (BCPS) is used with the addition of a low concentration of chemical additives such as a suppressor, an accelerator, and a leveler [9,10,12,13]. The BCPS consists of copper sulfate, sulfuric acid, and tens of ppm of chlorine ion. As a suppressor, polymers with a large molecular weight (MW) such as polyethylene glycol (PEG) [14–19], polypropylene glycol (PPG), and their block-copolymer (PEG-PPG) [7,20–23] can be utilized. Typically used accelerators are sulfur compounds such as bis (3-sulforpyl) disulfide (SPS) and 3-mercapto-1-propanesulfonate (MPS) [24,25]. As a leveler, quaternary ammonium cation compounds such as Janus Green B (JGB) can be employed [26–31]. In general, the plating solutions contain hundreds of ppm of suppressor and <10 ppm of an accelerator and leveler. With the highest concentration, suppressors have the most significant effects on the microvia-filling performance among the additives [19,20,32].

To achieve high microvia-filling performance, Cu reduction should occur quickly only in the microvias [16,23,30,33–35]. PEG, a typical suppressor, combines with Cl^- to form the complex of PEG-Cu-Cl^- [21,36], which adheres to the substrate surface thereby strongly inhibiting Cu reduction on the substrate surface. Thus, PEG with a larger MW inhibits the Cu reduction on the substrate surface more effectively, leading to higher filling performance [19]. However, during the electroplating process, PEG molecules are decomposed through a hydrolysis reaction at the cathode [37–39]. Accordingly, the PEG MW is reduced and the filling performance degrades. Therefore, to keep the filling performance high, the plating solution must be carefully monitored in terms of the PEG MW and replenished with fresh suppressors if necessary [38,40–42]. As a monitoring technique, a Hull cell and cyclic voltammetry stripping (CVS) have been widely employed in commercial manufacturing processes [41,43]. However, when using these techniques, it is difficult to measure the concentrations

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