Characterization and Metrology Development of a Copper Plating Bath for High Performance Glass Substrate Interconnect

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Glass is considered as a promising base material used in semiconductor manufacturing. Compared to traditional organic substrates, glass substrates offer excellent physical, mechanical, and optical properties, that enable more transistors connected in one package, higher signal stability at high frequency ranges with lower electrical loss, and better scaling for larger chiplet complexes [1]. These advantages lead to their wide use in various processes of semiconductor manufacturing, such as 3D integration, also known as through glass via (TGV). Since silicon is a semiconductor material, the carriers around through silicon vias (TSV) can move freely under the action of electric field or magnetic field, which will interfere with adjacent circuits or signals and affect chip performance. The glass material does not have free moving charges, and there is no need to deposit an insulating layer. It has excellent dielectric properties. Meanwhile, the thermal expansion coefficient of glass can be adjusted, reducing the thermal mismatch with different materials. Due to the easy availability of large-sized glass panels, the glass cost is about 1/8 of that of silicon substrates. With strong mechanical stability, even when the thickness is less than 100µm, the warpage is still small [2].

Void-free interconnect metallization has been identified as one of the most fundamental processes in TGV due to the concerns of RC delay and reliability [3]. Direct copper plating presents an excellent technique for TGV metallization, because of faster processing, easier implementation, and cost advantages, compared to other wet and dry processes [4]. Due to a high aspect ratio structure, it is common to use complex plating additives to achieve bottom-up filling in direct copper plating [5]. However, the mixed and synergistic effects of organic additives in complex chemistries pose a great challenge to develop robust methods for bath monitoring. Comparing to traditional TSV plating bath, TGV has higher copper concentrations approaching solubility limit, causing bath to operate at elevated temperatures. To obtain accurate results and enable reliable performance of analyzer, precipitation of copper sulfate should be prevented during analysis of plating bath. Plating on glass also require special equipment, which is different to traditional plating tools for TSV metallization. Electrochemical and hydrodynamic conditions of these devices cause specific consumption of bath components. The difference in consumption rates dictates more often analysis for some bath components, e.g., brightener.

Analytical methods that are both accurate and reproducible are extremely important to monitor and maintain a healthy plating baths, as the constituents in a plating bath must be controlled in specific concentration ranges to attain desired deposit properties. To develop such analytical techniques, the interactions among organic additives of a commercial copper acid chemistry were investigated in this study. The additives include a strong polarizer (carrier), a depolarizer (brightener), and a leveling agent (leveler) which is not typical for traditional TSV baths. The commercial chemistry is applicable for through hole with both X shape and mechanical drill through hole as well as large size blind via as shown in Figure 1 [6]. The responses of organic constituents under different electrochemical and hydrodynamic conditions were examined, and the results suggest the carrier, brightener and leveler exhibit very prominent polarizing, moderate depolarizing, and weak suppressing effects, respectively in Figure 2A. A comparison between Figure 2B and 2C indicates that these components are more sensitive to mass transfer rate (Figure 2C) than kinetics (Figure 2B). Optimized electrochemical analytical techniques was developed for the commercial chemistry and the analyses were performed with simple and automated fluidics that include a single electrochemical cell and accurate temperature control. The analysis performance was evaluated in terms of accuracy against its expected concentration and repeatability, which is summarized in Table 1.

References

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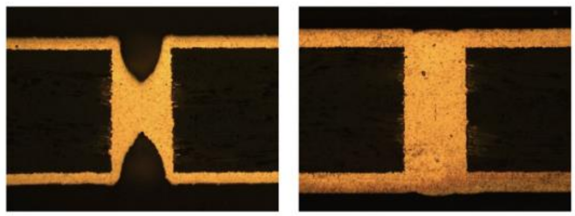

Figure 1 Metallographic images of through hole deposit by the commercial acid copper chemistry [5]

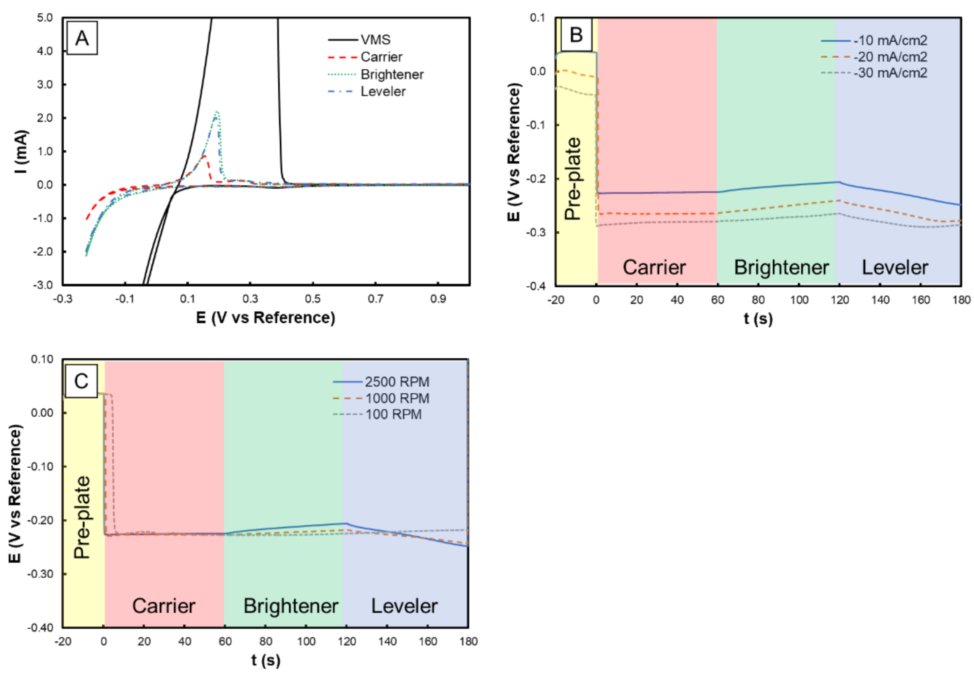

Figure 2 (A) Voltammogram in the commercial chemistry in presence of carrier, brightener, and leveler, (B) effect of organic additives on chronopotentiogram at varying current densities (2500 RPM), and (C) effect of organic additives on chronopotentiogram at varying rotation rates (-10 mA cm^{-2}).

Table 1 Online Performance of analytical techniques of the commercial chemistry for glass substrate plating

Component	Carrier	Brightener	Leveler
Accuracy	<3%	<1%	<0.5%
Repeatability	<1%	<2%	<1%
Analysis Time (min)	<10	<15	<15