Abstract:

Through Silicon Via (TSV) enabled by copper electrodeposition is the key technology of 3DIC packaging, which allow high packaging density, high speed signal transmission, and reduce power consumption. TSV technology has a bright future, with TSV packaging revenues estimated to increase to about $ 4.5 billion in 2023 (Source: 2.5D / 3D TSV & wafer-level stacking technology & market updates 2019 report by Yole Development). However, TSV technology still has challenges including production cost and reliability problems to solve for mass volume production. These challenges are addressed in detail and the solutions for these challenges are investigated this research.

Copper electrodeposition accounts for 41% of the total production cost of TSV and is the most expensive step in the TSV production process. Thus, reduction of the copper electrodeposition cost is necessary. There are several ways to reduce the cost of copper electrodeposition, including using latest electrodeposition tools and reducing the time required for electrodeposition. However, the latest electrodeposition tools are expensive. Furthermore, large clean room areas need to accommodate a large amount of electrodeposition tools. Increasing current density, which means shorten the electrodeposition time, is a promising solution to reduce electrodeposition time. However, if the current density is too high, constriction occurs at the TSV opening and voids will be formed. Over the last decade, there are many studies looking at void-free fast TSV filling solutions, such as using pulsed reverse currents, designing different TSV structures, investigating new additives, and optimizing additives concentration. There are thousands of additives, each with different effects on TSV filling. Therefore, there is still room for reducing TSV filling times with new novel additives. In this research, a new leveler additive has been introduced for copper electrodeposition. The new leveler additive shows a strong inhibition effect during copper electrodeposition and the optimal concentration of the new leveler enables fast bottom-up TSV filling.

Copper is commonly used for TSV filling due to its low resistivity. However, copper TSV poses reliability problems due to thermal expansion coefficient (TEC) mismatch between copper and surrounding silicon. During SiO_2 formation step in via middle process, copper TSV is exposed to high annealing temperature ranging from 400ºC to 600ºC. Due to the large TEC mismatch between the copper and silicon substrate, copper expands much more than silicon during the annealing process, causing high thermal stresses inside copper TSV and in the surrounding silicon. The thermal stress inside copper TSV causes some reliability problems such as copper pumping, voiding, cracking, and delamination. The thermal stress also causes the degradation in silicon surrounding the copper TSV. Keep Out Zone (KOZ) is defined as the area around the TSV where transistors cannot be located to prevent device failure. Multiples long time pre-annealing followed by chemical mechanical polishing (CMP), using copper alloys, or using polymers as TSV insulator liner layer have been proposed to solve copper pumping and KOZ problems. However, these methods are expensive, or result high copper resistivity, and may require special methods for electrodeposition. In order to overcome copper pumping and KOZ challenges, this research establishes a simply method to save costs while maintaining the resistivity of the electrodeposited copper. Low thermal expansion of electrodeposited copper has been developed using the additives in copper electrodeposition. After that, low thermal expansion copper is applied to fill TSVs with SiO_2 liner layers formed by atmospheric pressure chemical vapor deposition (APCVD) and plasma enhance chemical vapor deposition (PECVD). The results showed that low thermal expansion electrodeposited copper effectively reduced copper pumping and KOZ in TSV. In addition, low thermal expansion electrodeposited copper has lower resistivity value than conventional copper.