Metallization of Through-Silicon-Via in 2.5D Interposers by Cold Plasma Jet

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Abstract. We proposed a cold capacitively-coupled-plasma jet method to deposit the seed layer in the inner wall of Through-silicon-vias (TSVs) directly. Comparison experiments were carried out to optimize the process parameters. The testing results were discussed and proved the potential application of this technique in the metallization of TSVs in 2.5D integration technology.

1. Introduction
There is an increasing necessity to integrate multiple dice into a single package to achieve high performance in smaller integration size. 2.5D integration technology is a promising solution that enables the vertical connection between active and passive chips [1] by the interposers technique [2]. Through-silicon-vias (TSVs) technology plays a key role in interposer technique, providing the shortest Z-directional interconnect through the substrate [3]. Hence, a faster running speed and a high-power efficiency can be achieved. The typical formation process of TSVs includes the fabrication of deep vias by BOSCH etching [4], the growth of barrier layer and seed layer by magnetron sputtering [5], and the filling of vias by electroplating [6]. However, it requires a vacuum environment and also a long deposition time [7]. To address this issue, the metallization of the seed layer of TSVs can be optimized by adopting a new method of cold plasma jet.

In our work, we propose a cold capacitively-coupled-plasma method to deposit seed layer in TSVs efficiently with less cost. The device setup is simple with the low requirements for the environment. After several experiments, we select a set of parameters and optimize the deposition process according to the morphology and the resistivity. The testing results of the final product are analysed to verify the feasibility of this technique.

2. Materials and Methods
The schematic diagram of the cold plasma jet metallization platform is illustrated in Figure 1. The discharge chamber is between a metal wire electrode with 50 μm diameter and a quartz tube of 1 mm inner diameter. A 6-turn tesla coil winds around the outside of the glass tube. The gas passes through the glass tube. One end of the tungsten coil is connected to the ground electrode; copper wire, as an electrode, is connected to a matching box that tunes the reflective resistance to 0.

For copper particles generation and deposition, a 13.56 MHz radio-frequency (RF) generator is used [8]. The diameters of the TSVs used in our study are 80 μm. The thickness of the silicon substrate
is 300 μm. The TSVs silicon substrate is set on the holder plate with a precisely controlled X-Y-Z mechanical manipulator.

![Figure 1. Schematic diagram of setup for the metallization of TSVs](image)

When the RF power is added to some extent, the metal electrode surface especially the tip clusters enough electrons and generates a strong electrical field to point discharge, thus the plasma is ignited [9]. Then the Joule heating and the heat transfer from plasma to the metal electrode evaporate the atoms. Collided with each other and with Helium atoms, metal atoms crystallize and nucleate.

In order to optimize the deposition process, a series of comparison experiments supplied with various gas flow rate and RF power are carried out. The forwarded RF power is 75-95 W and the controlled gas (Helium) is 200-400 sccm. A scanning electron microscopy (SEM) (FEI Nano SEM 450) is utilized for observing the morphology of the deposits. The nanoparticles’ size distribution is obtained by using a software called Nano measurer. The resistivity and deposition rate of the thin film are measured to evaluate this technique.

3. Results and Discussion
The objective of our study is to explore the feasibility of depositing copper seed layer of TSVs for 2.5D interposers by cold plasma jet. For this purpose, the testing results of different process parameters are carefully analysed. Figure 2 presents the SEM images and particles’ distributions under 75 W, 85 W and 95 W with Helium flow rate setting as 300 sccm. As can be seen from the figures, particles have a denser arrangement and larger diameters as RF power increases. Overall, particles synthesized at 85 W show a satisfactory configuration.
Figure 2. SEM images and particles distributions with the different RF powers of 75 W, 85 W and 95 W.

Resistivity measured under different combinations of gas flow rate and RF power is demonstrated in figure 3. It is shown that the resistivity of copper seed layer is less than twice the bulk copper (1.78x10^{-8} \, \Omega/m) under the conditions of 85 W and 300 sccm. As listed in Table 1, then the average deposition rate of depositing cooper seed layer is compared with that by magnetron sputtering [10]. The proposed technique in this paper shows a slightly higher depositing rate than that of magnetron sputtering.

Figure 3. Resistivity of deposits under different conditions.

| Technique               | Depositing rate (nm s^{-1}) |
|-------------------------|-----------------------------|
| Magnetron sputtering    | 0.36                        |
| Cold plasma jet         | 0.51                        |

Table 1. Comparison of the depositing rate by Magnetron sputtering and cold plasma jet.
4. Conclusions
A cold capacitively-coupled-plasma method is proposed to deposit the seed layer of TSVs in 2.5D interposers. Comparison experiments are carried out to optimize the process parameters in terms of the morphology and the resistivity. The copper seed layer obtained under 85W and 300sccm Helium flow rate presents better performance. Depositing rate by the proposed method is proved to surpass the magnetron sputtering, and can be considered as a potential method to fabricate the seed layer of the TSVs in 2.5D interposers with higher efficiency and fewer cost.

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