Investigation Of Electromigration In Fine-Pitch Copper Interconnects Through Simulation And Analysis

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Abstract

The scaling down of Copper interconnects is an effective approach to increasing the number of signal I/O lines and performance in advanced fine-pitch packaging. However, as dimensions are reduced, the risk of electromigration-induced failures in the copper interconnects becomes increasingly critical, degrading the reliability and performance of modern microelectronics. High current densities play a crucial role in electromigration, causing the migration of metal atoms in the interconnects, leading to the formation of voids or hillocks and eventual device failure. To reduce the risk of failure and enhance overall performance, Joule heating and current crowding, two significant factors contributing to this problem, must be effectively addressed through design optimization approaches.
Originally, thermal oxide (SiO2), has been used for dielectric layers. However, the two main challenges for thermal oxide are electrical performance and cost. In such cases, polymer-based dielectrics have advantage due to their ability to lower trace capacitance and enhance power efficiency while being compatible with low-cost panel-scalable methods.
But polymers have lower thermal conductivity. By using a thinner polymer, the problem of lower thermal conductivity and consequent Joule heating in the copper interconnects produced by electric current flow across them can be reduced. Therefore, it reduces the risk of localized temperature rise that can cause damage due to thermomigration and electromigration (Figure 3).
Current crowding, on the other hand, occurs when there is an increase of the local current density. It raises the local temperature as Joule heating is proportional to the square of current. The conductor's resistance, form, thickness and width have an impact in the current crowding phenomena. This can be managed through optimization of the interconnect geometry, such as having straight lines and using rounded corners (Figure 2 and 4). As a result, the potential current crowding hotspots and subsequent electromigration risks can be decreased.
The AC/DC Module in COMSOL Multiphyiscs® was used to study the effects of Joule heating and current crowding on interconnect reliability. The simulations included the boundary conditions to corelated experimental values ensuring accurate representation of electromigration. The results thus can be compared to the experimental data to determine accuracy and validity.
Through the simulation of current and temperature distribution across the 3D model build in COMSOL Multiphyiscs®, first an improved geometry of the test structure was derived iteratively (Figure 1). The effect of current crowding was reduced with approximately 42% from the standard test layout (STANDARD ASTM-F1259M, US National Institute of Standards and Technology (NIST) test structure) (Figure 2) to the optimized structure. Following was a conformation of the effect of polymer thickness. The effect of Blech length on electromigration immortality of the interconnect can also be simulated. Therefore, the use of COMSOL® simulation provides a powerful means to investigate the effects of different design factors as well as material flux density on interconnect reliability. By understanding the comprehensive knowledge gained from these simulations, it is possible to optimize the design and reduce the risk of interconnect failure.

Figures used in the abstract

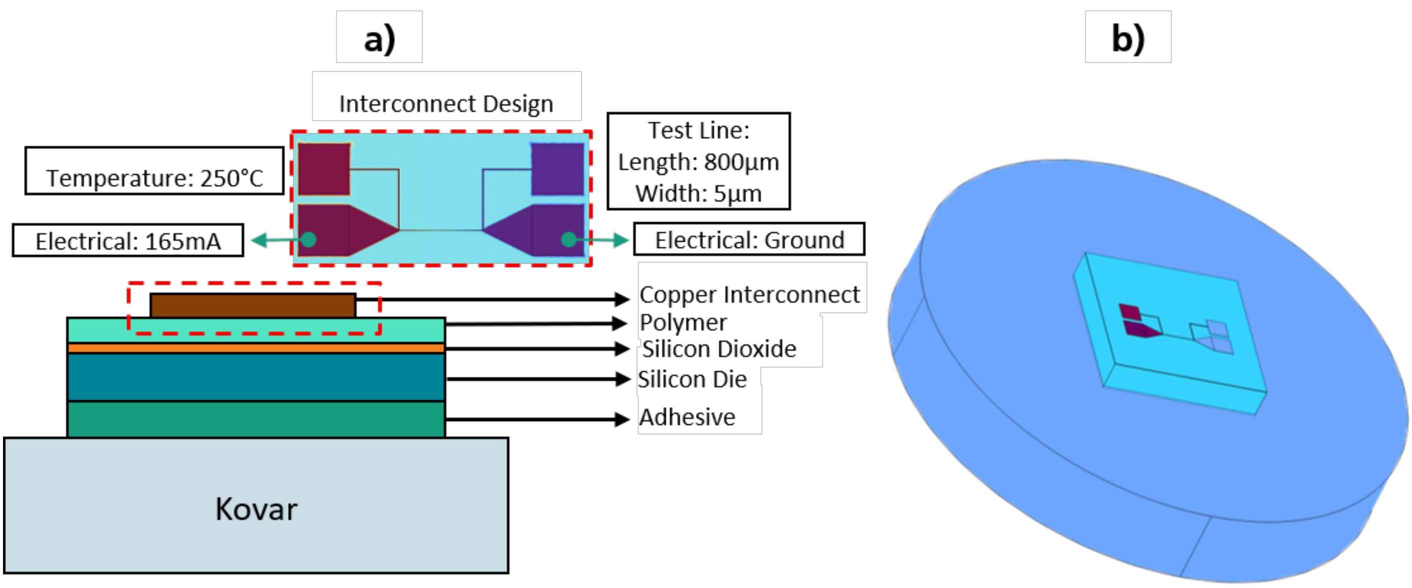

Figure 1 : a) Stack-up and boundary conditions of the test vehicle for electromigration, b) 3D model build in COMSOL.

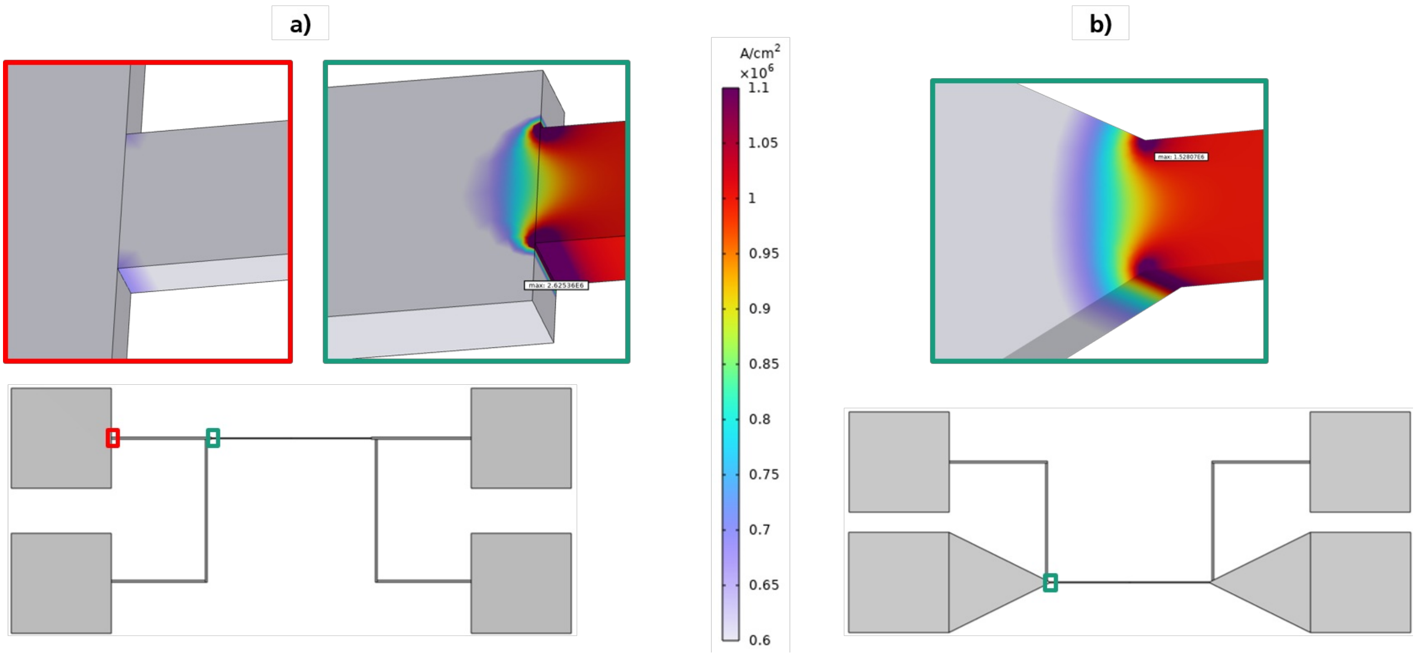

Figure 2 : Comparison of a) NIST with b) optimised design on current crowding.

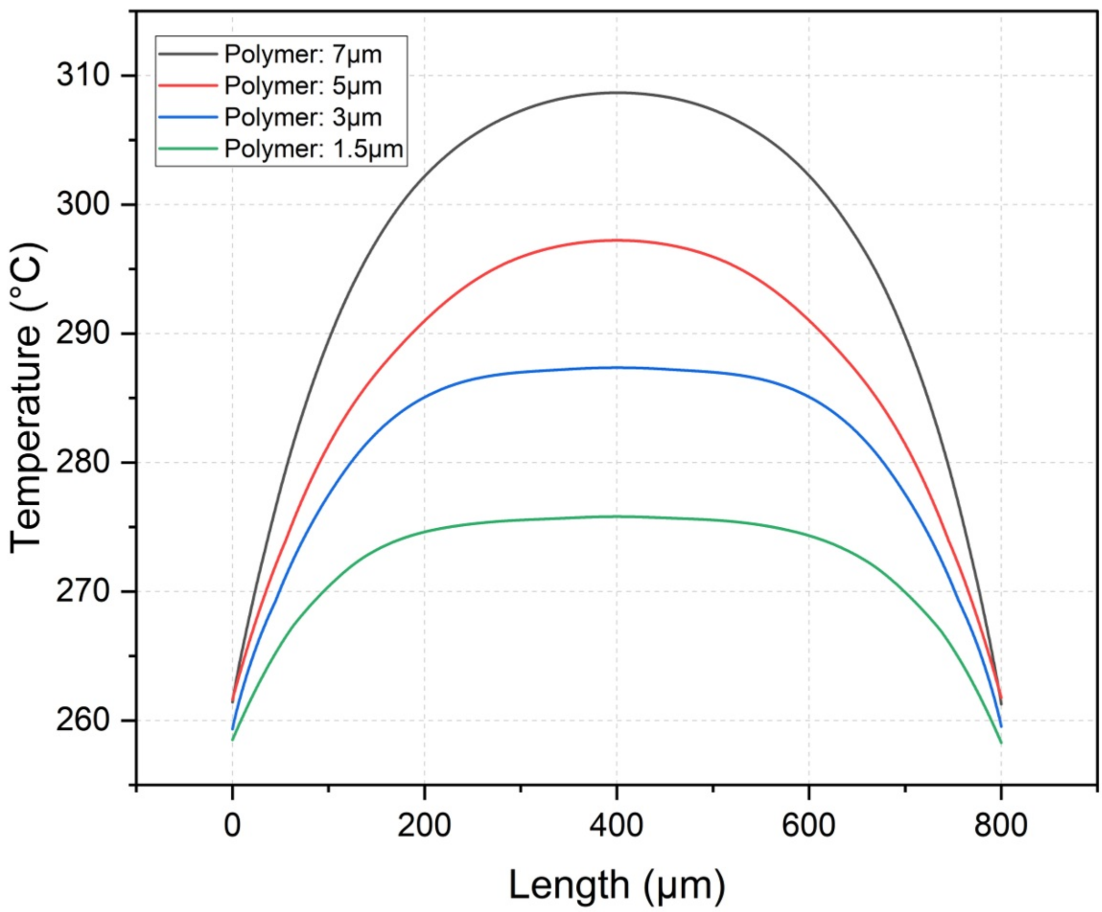

Figure 3 : Influence of polymer thickness in temperature distribution.

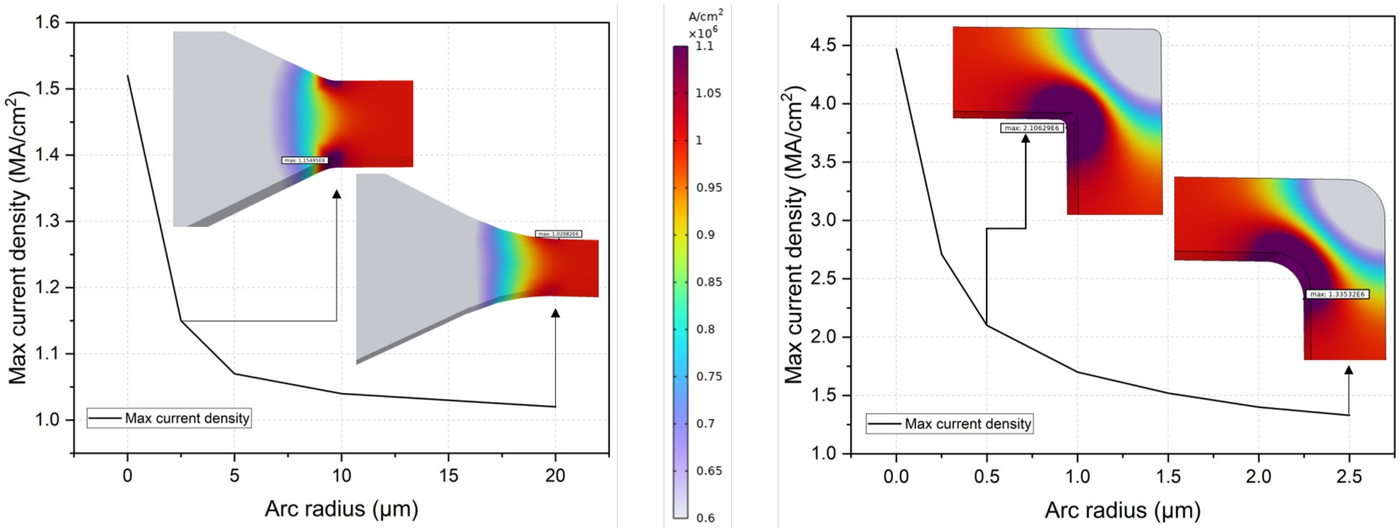

Figure 4 : Influence of arc radius in the a) transition area and b) 90° angled line, on current density.