Assessment of Electromigration in Nano-Interconnects

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The drastic reduction of nano-interconnects linewitdh towards 10nm and below has a tremendous impact on the electromigration failure behavior. This development has brought to the fore two crucial questions regarding the future of interconnect technology: The first one is how far we can go with copper as an interconnect metal without reaching a point, where the increase in interconnect resistivity and the reduction in electromigration reliability become unacceptable, and the second, which metal can optimally replace copper in the future. In the pioneering work by Sarychev *et al.,* https://doi.org/10.1063/1.371169, the general framework for electromigration degradation modeling of metallic interconnects in micro-scaled regions is provided. Since then, the original model has been extended and refined to include the treatment of various microstructural properties of metal and interfaces, crystal anisotropy, stress-dependent diffusivities, and more, e.g., Ceric and Selberherr, https://doi.org/10.1016/j.mser.2010.09.001. As the interconnect technology moves to the nano-scale, changes in the basic technology demand enhanced electromigration models. With reducing linewidth of interconnects, the importance of electromigration-induced material transport along grain boundaries and interfaces increases. The lifetime of interconnects thus becomes more sensitive to the values of the parameters which determine this transport, such as effective valences and diffusivities. The interconnect linewidth has also an impact on the interconnect resistivity and the effective valence, which must be considered. There are three principal challenges in modeling of nano-scaled interconnects. The first challenge involves the complexity of the layout of the studied interconnect structure. In order to reproduce realistic mechanical conditions, all materials in the layout and their corresponding properties must be included in the overall modeling framework. Only with this comprehensive approach, the mechanical effects of low-*k* materials can be considered. The second challenge is the physics of grain boundaries and interfaces, which can be modeled with different levels of complexity, either by applying dedicated local sub-models or by using cumulative and average values. The third challenge is the appropriately accurate modeling of void growth which leads to an increase in interconnect resistance and to its final failure. In down-scaled interconnects, smaller voids can produce a fatal failure and the dynamics of void growth strongly depends on the local microstructural features.

First, a short overview of the most promising modeling approach to these three challenges will be given and an overall modeling and simulation methodology will be presented. The goal is a modeling concept which is not unnecessarily complex and which can be optimally combined with experimental methods in order to assess the relative impact of different factors on interconnect reliability. Thereafter, the difference in physics of degradation processes for copper and the two most promising copper-replacement metals, cobalt and ruthenium, will be discussed. Finally, several application examples for an assessment of electromigration in nano-interconnects utilizing the presented modeling concepts will be given. Three aspects of the electromigration assessment in nano-interconnects will be addressed: understanding of the degradation process for a particular interconnect structure under investigation, estimation of the relative impact of different factors on electromigration for a particular technology, and estimation of the lifetime of a given interconnect structure.