Resistance of advanced interconnects with anisotropic conductors: finite element simulations

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The continued decrease in feature sizes in integrated circuits result in strong increasing resistivity in copper interconnect due to additional charge carrier scattering at small dimension due to interfaces and grain boundaries. This is now considered as a severe limitation for the further downscaling of Cu interconnects [1,2]. Among potential alternative metals to replace Cu metallization in future technology nodes, several considered materials possess two-dimensional anisotropic resistivities. Examples are MAX materials [3] or delafossite oxides. In particular the latter are interesting since they possess in-plane resistivity around 2 μΩcm, comparable to Al [4]. However, delafossite oxides are characterized by a strong resistivity anisotropy with a much higher resistivity along the hexagonal axis [5]. In this work, we study the effect of resistivity anisotropy in 2D metals for advanced interconnects by finite element simulation to understand its impact on interconnect performance and materials characterization.

To address the impact of strong resistivity anisotropy of a two-dimensional interconnect, a "top contact" model is built by COMSOL Multiphysics, as shown in Fig. 1a. The line consists of an metal with varying degree of anisotropy, including isotropic transport as a limit. Simulated results for out-of-plane/in-plane resistivity anisotropies of 100 and 1 (isotropic) in Figs. 1b and 1c, respectively. The simulations show that the simulated line resistance of the anisotropic metals is 6 times larger than that of an isotropic metal for the same resistivity along the line direction. This can be explained by a large spreading resistance and surface current crowding for anisotropic metals with large out-of-plane resistivities. This can be mitigated by a side contact model with (isotropic metal) vias inside the anisotropic metal line, as shown in Fig. 1d. The simulations show that the side contacts strongly reduce the impact of the resistivity anisotropy on the line resistance, although further design optimization is needed to fully recover isotropic metal values.

This indicates that the full characterization of the anisotropic resistivity in thin films is critical for materials benchmarking. Macroscopic Four-Point-Probe (4PP) measurement have thus also been modelled in by COMSOL, as shown in Fig. 2a. Two types of metal films are compared, both isotropic as well as two-dimensional anisotropic films. Fig. 2b shows that the simulated resistivities for both cases correspond to the in-plane resistivity, here 2 μΩcm. Hence, 4PP measurements can assess accurately the in-plane resistivity but are not sensitive to the out-of-plane resistivity. Therefore, an alternative transmission line method (TLM) test structure is proposed to access out of plane resistivity of two-dimensional metals.

Commonly used to characterize contact the contact resistance of semiconductor/metal interfaces, TLM can also be used to extract the spreading resistance increase due to the resistivity anisotropy, independent of the sheet resistance. The simulations in Fig. 3a indicate that µm distances between contacts is necessary for the TLM model to be sensitive (Fig 3b). For very short distances, however, the overlap of the spreading resistance areas modifies the behavior qualitatively. Moreover, as shown in Fig 3c, sub-µm contact sizes are needed for the spreading resistance to be measurable. This demonstrates that simulations can further drive the study of two-dimensional metals for advanced interconnect metallization.

References

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Figure 1: Simulation of isotropic and anisotropic metals on top contact and side contact interconnect

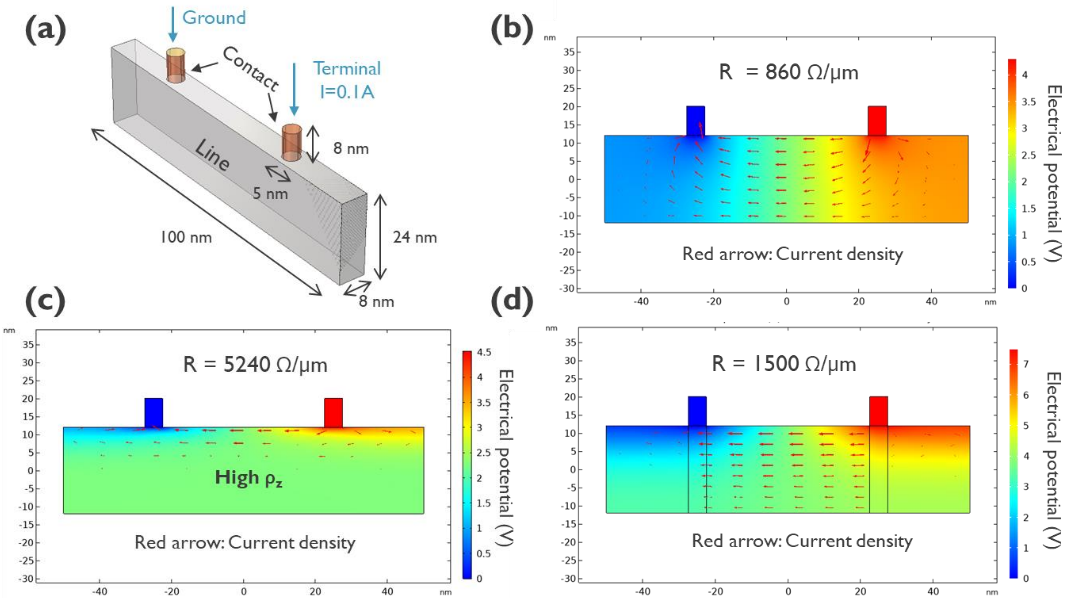

Figure 2: Simulation of macroscopic Four-Point-Probe (4PP) measurement on isotropic and anisotropic metal films

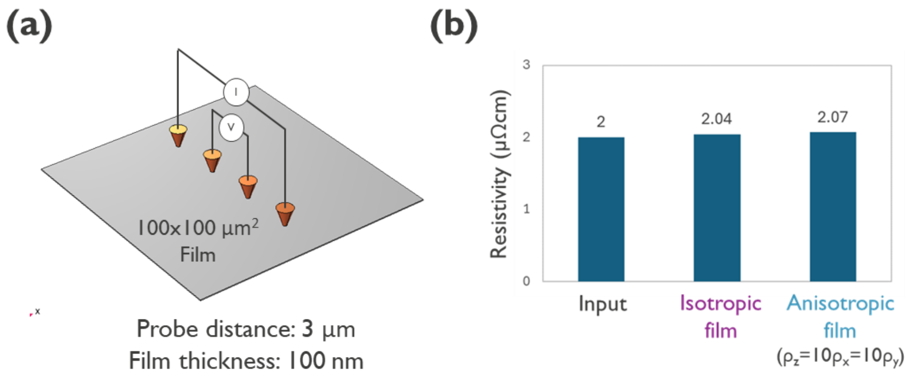

Figure 3: Simulation of Transmission Line Model (TLM) on anisotropic thin metal films