# Electro-, Stress- and Thermomigration: Three Forces, One Problem

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***Abstract*—It is well-known that the downscaling of microelectronic structures (“Moores Law”) reduces the reliability due to an increase in potential material migration. Electro-, stress- and thermomigration have been identified as the main causes of materiel dislocation in integrated circuits (ICs). They are driven by current densities, stress and temperature gradients, respectively, but they also depend on common parameters like material constants. While each of these three driving forces causes migration, they can compensate or amplify each other, resulting in various overall material dislocations. These interactions are poorly understood which complicates the prevention of migration processes in ICs. Our software demonstrator presents a basic approach to identify the predominate migration within various circuit conditions including the interaction of all three forces. Our approach can also be adjusted to three-dimensional circuits (3D ICs) and alternating conditions.**

## I. Introduction

The impact of material transport on interconnect structures rises with their downscaling. Electromigration (EM), stress migration (SM) and thermomigration (TM) have been identified as the main causes of material dislocation within those structures. To fully understand the migration process of interconnects, one must investigate these three phenomenons for a given circuit condition. This is crucial, because they can compensate or amplify each other, differ in their orders of magnitude and depend on mutual factors of influence.

## II. Material Migration

### *A. Electromigration*

The atomic flux due to EM ($J_{\text{EM}}$) depends on the concentration of atoms ($C$), diffusion coefficient or diffusivity ($D$), Boltzmann's constant ($k$), average temperature ($\overline{T}$), charge of an electron ($e$), effective charge number ($Z^*$), resistivity ($\rho$) and current density ($j$) [1]:

$$\overrightarrow{J_{\text{EM}}} = {}^{CD}/_{k\overline{T}} \cdot eZ^*\rho\,\vec{j}\,. \tag{1}$$

This equation clearly shows that the driving force of EM is current density, however, it also depends on other factors such as temperature.

### *B. Stress migration*

In addition to the parameters from Eq. (1), the atomic flux of SM ($J_{\text{SM}}$) depends on atomic volume ($\Omega$) and hydrostatic stress ($\sigma_{\text{H}}$) [1]:

$$\overrightarrow{J_{\text{SM}}} = {}^{CD}/_{k\overline{T}} \cdot \Omega\vec{\nabla}\sigma_{\text{H}}. \tag{2}$$

The main driving force of $J_{\text{SM}}$ is the stress gradient. This gradient can be caused by unbalanced layer growth, external bending, different coefficients of thermal expansion (CTE) and accumulation or depletion of atoms in a encapsulated interconnect.

### *C. Thermomigration*

Ancillary to the parameters from Eq. (1) and (2), the atomic flux of TM ($J_{\text{TM}}$) depends on heat of transport ($Q^*$) and local temperature ($T$) [1]:

$$\overrightarrow{J_{\text{TM}}} = {}^{CD}/_{k\overline{T}^2} \cdot Q^*\vec{\nabla}T. \tag{3}$$

It can be seen that a local temperature gradient within an interconnect is the main driving force. An active self-heating process or a passive heat source can be reason for this.

### *D. Interaction*

The total atomic flux ($J_{\text{total}}$) in interconnects is defined as [2]:

$$\overrightarrow{J_{\text{total}}} = \overrightarrow{J_{\text{EM}}} + \overrightarrow{J_{\text{SM}}} + \overrightarrow{J_{\text{TM}}}, \tag{4}$$

whereby only a negative or positive divergence of the total atomic flux ($\nabla J_{\text{total}}$) indicates void or hillock creation, respectively. Figure 1 shows one possible interaction of EM, SM and TM and their individual driving forces [3].

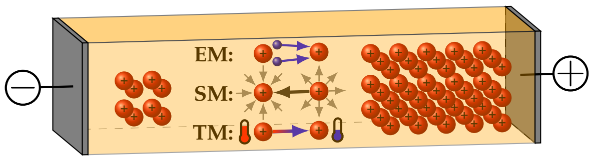


Fig. 1. Atom migration within an interconnect due to EM, SM and TM and their individual driving forces.

## III. Software Demonstrator

Our software demonstrator is tailored to determine the impact of EM, SM and TM for a given range of circuit conditions. We can identify the predominate migration with respect to the interaction with other migrations. It is also possible to investigate the impact change of EM, SM and TM, individually, due to increasing or decreasing driving forces.

## IV. Conclusion

The mutual compensation or amplification of EM, SM and TM must be considered to fully understand (and prevent) the migration process of interconnects. Negligence of one of them is only reasonable if it is orders of magnitude smaller than the others.

## References

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