TECHNISCHE UNIVERSITÄT DRESDEN

ifte

Institute of Electromechanical and Electronic Design

www.ifte.de

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

**Steve Bigalke and Jens Lienig**

## 1 Introduction

Electromigration (EM), stress migration (SM) and thermomigration (TM) have been identified as the main causes of material dislocation within interconnects. To fully understand the migration process, one must investigate all these three phenomena for a given circuit condition. They can compensate or amplify each other, differ in their orders of magnitude and depend on mutual parameters. Our goal is to identify predominate migrations for common circuit conditions in order to simplify the simulation of interconnects with migration problems.

## 2 Motivation

The impact of material transport on interconnect structures rises with their downscaling. To ensure future reliability of Integrated Circuits (ICs), a migration estimation of each interconnect becomes important. The dependencies in the interaction of EM, SM and TM complicate this step (Fig. 1).

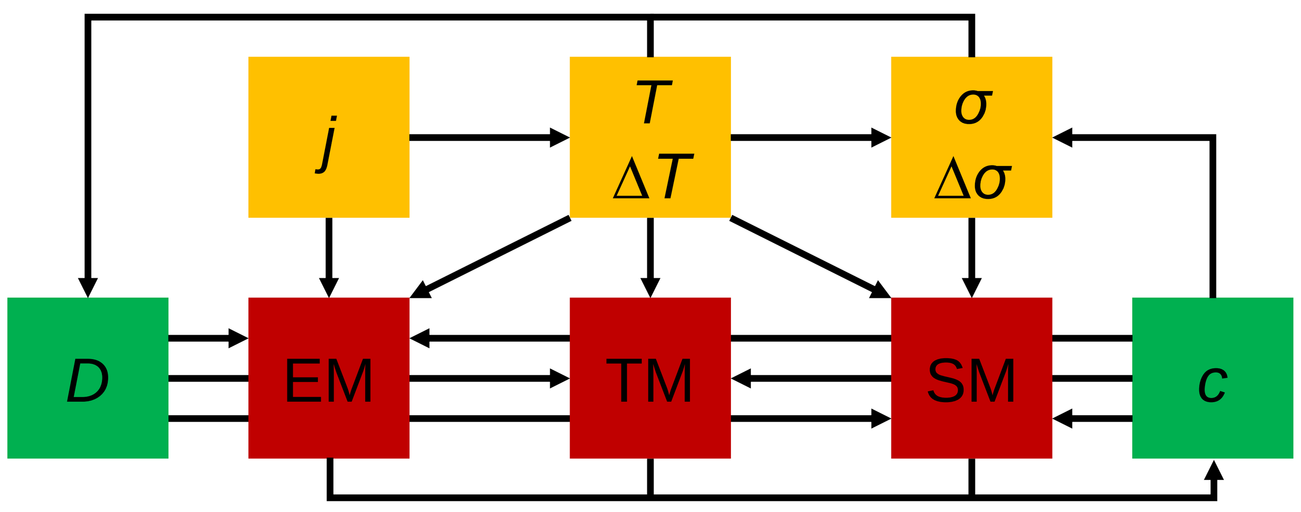


***Fig. 1.*** *Mutual dependencies between EM, SM and TM (red), their driving forces (yellow: j … current density, σ … mechanical stress and T … Temperature) and equation parameters (green).*

## 3 Material Migration

### *A. Electromigration*

The atomic flux *($J_{EM}$) of* EM depends on the concentration (c), diffusivity *(D)*, Boltzmann's constant *(k)*, temperature *(T)*, charge of an electron *(e)*, effective charge number *(Z*)*, resistivity *(ρ)* and current density *(j)* :

$$\overrightarrow{J_{EM}} = {}^{cD}/_{kT}\, eZ^* \rho \vec{j}\,.$$

The main driving force of EM is the current density. Special interconnect geometries can cause peaks in the current density distribution (Fig. 2(b)).

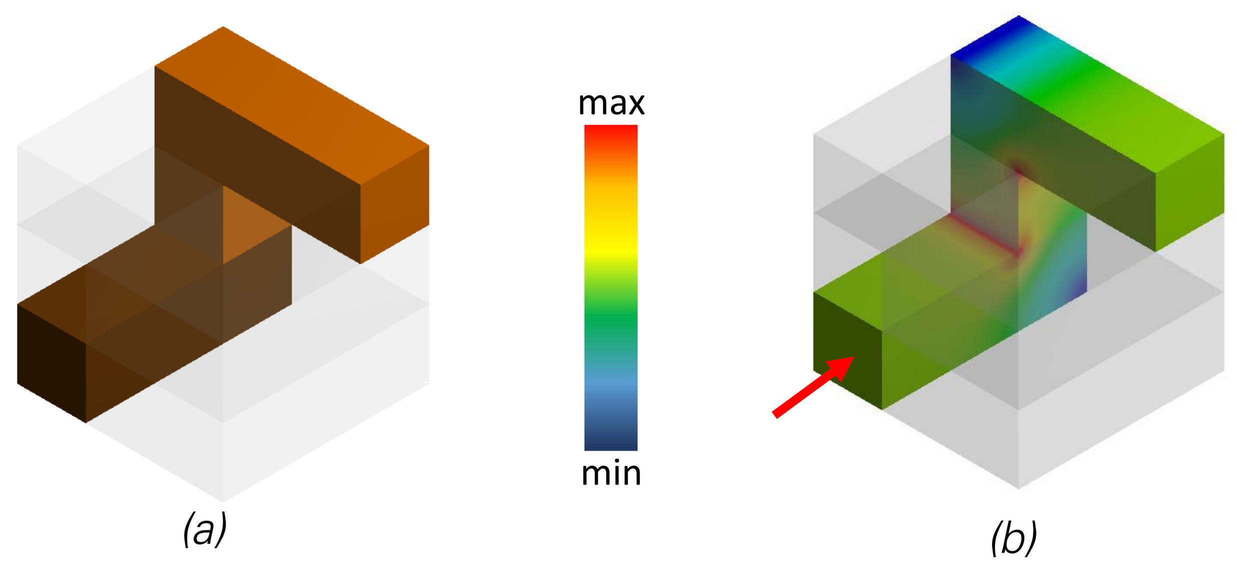


***Fig. 2.*** *(a) Two via-connected segments on different metal layers (brown and orange). (b) Resulting distribution of the current density.*

### *B. Stress migration*

Ancillary to the prior mentioned parameters, the atomic flux *($J_{SM}$)* of SM depends on the atomic volume *(Ω)* and the gradient of hydrostatic stress *($\vec{\nabla}\sigma_H$)* :

$$\overrightarrow{J_{SM}} = {}^{cD}/_{kT}\, \Omega \vec{\nabla}\sigma_H.$$

The main driving force of SM is the stress gradient. This gradient can be caused by unbalanced layer growth, external bending, different coefficients of thermal expansion and accumulation or depletion of atoms.

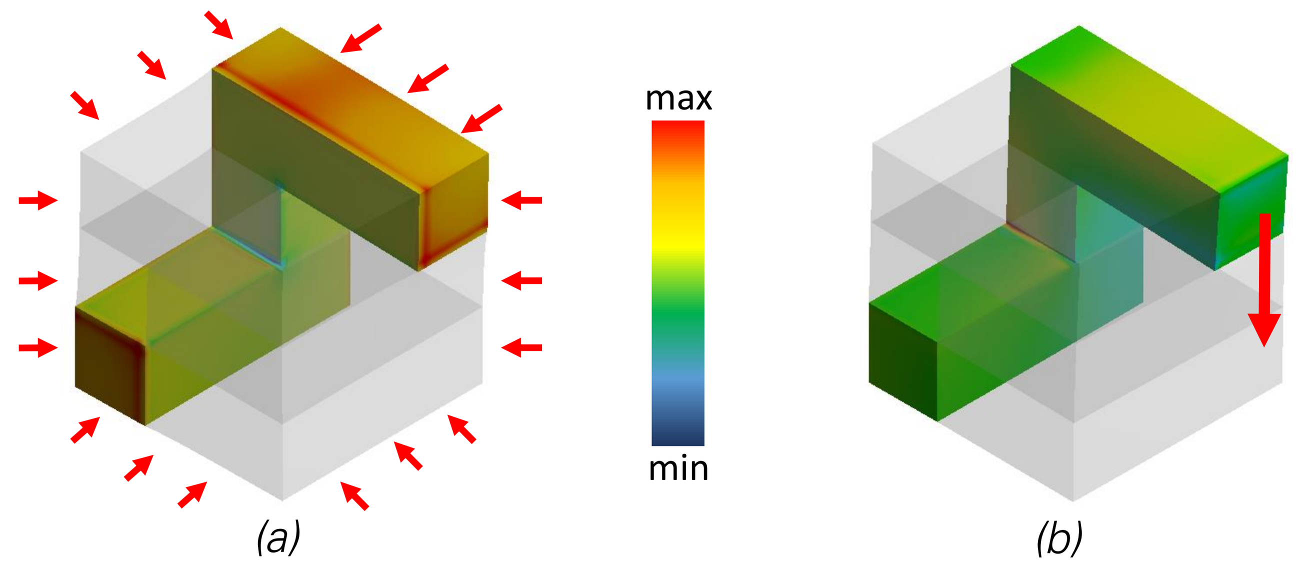


***Fig. 3.*** *(a) Stress creation in the interconnect and surrounding material due to different thermal expansion coefficients and an external force (b).*

### *C. Thermomigration*

In addition to the already defined parameters, the atomic flux *($J_{TM}$)* of TM depends on the heat of transport *(Q*)* and the gradient of temperature *($\vec{\nabla}T$)* :

$$\overrightarrow{J_{TM}} = {}^{cD}/_{kT^2}\, Q^* \vec{\nabla} T.$$

It can be seen that a temperature gradient is the main driving force of TM. Active self-heating or passive heat sources can be reasons for this.

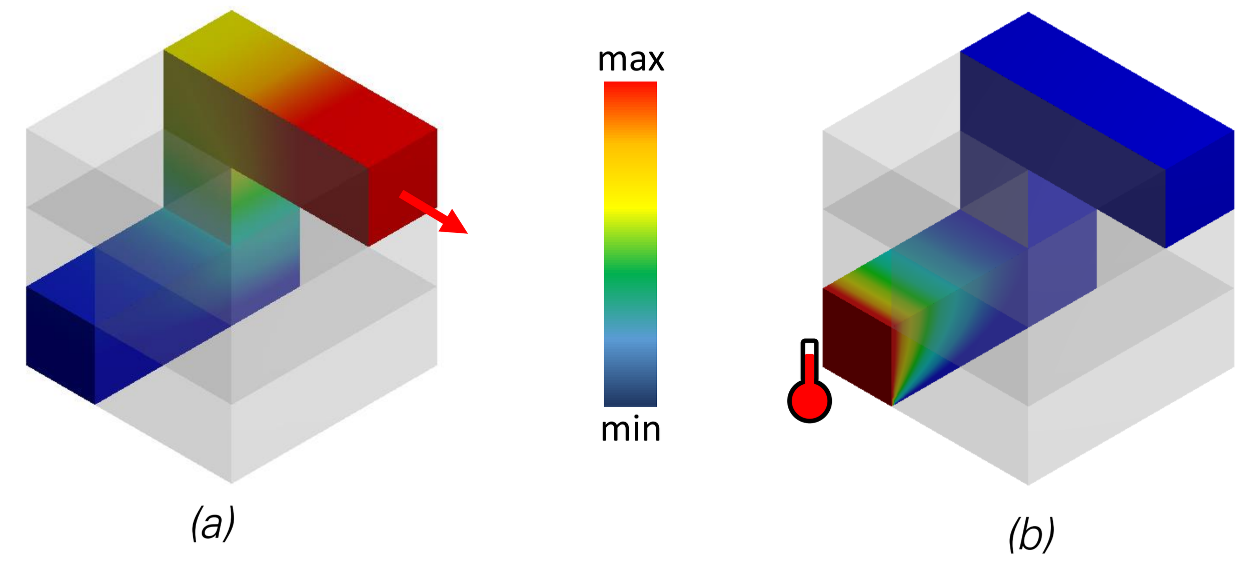


***Fig. 4.*** *Unbalanced temperature profile due to active self-heating (a) and passive heating because of an adjacent heat source (b).*

### *D. Total Atomic Flux and Divergence*

The total atomic flux in an interconnect is the sum of $J_{EM}$, $J_{SM}$ and $J_{TM}$. A negative or positive divergence of the total atomic flux indicates void or hillock creation, respectively.

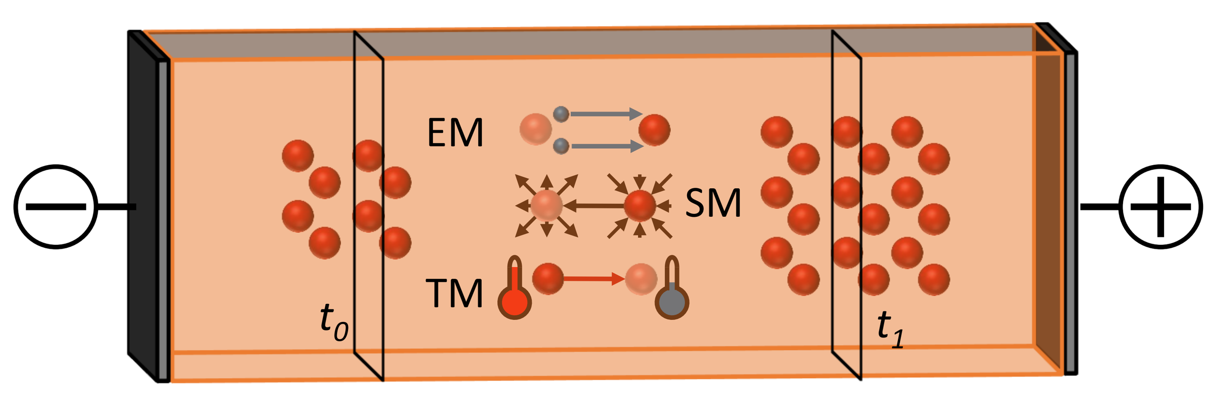


***Fig. 4.*** *EM, SM and TM including their driving forces define the total atomic flux. The divergence of the total atomic flux indicates void or hillock building.*

## 4 Conclusion

The impacts of EM, SM and TM are mainly linked to their driving forces. Circuit condition can scale these forces. The total atomic flux in an interconnect is an interaction of all three migrations, whereby one migration can dominate the others. Dependencies in mutual parameters complicate the simulation of migration.

Dresden University of Technology
Institute of Electromechanical and Electronic Design
01062 Dresden, Germany

steve.bigalke@tu-dresden.de
www.ifte.de