Assessing Reliability of Embedded Resistor Designs in Integrated Circuit

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INTRODUCTION:

Electromigration, or biased metal ion diffusion in interconnecting wires under electrical loading, is one of the major reliability concerns in integrated circuit (IC) [1,2,3]. Driven by temperature and electrical current, electromigration causes metal depletion at flux divergence site and eventually leads to voiding and open circuit failure. We present an example of using FEA to evaluate the temperature and current density distribution in order to study electromigration reliability of on-chip embedded resistor designs for IC. The Black equation is used to translate the modeled temperature and current values to resistor lifetime, or mean-time-to-failure (MTTF)

$$MTTF \propto j^{-n} \exp\left(\frac{Q}{k_B T}\right)$$

where j is the current density, n is the current exponent, Q is the activation of electromigration process, k_B is Boltzmann's constant and T is the temperature in °K [4].

COMPUTATIONAL METHODS:

Two models of embedded resistor designs are studied using COMSOL Multiphysics 5.4. The Electric Currents module is coupled with Heat Transfer in Solids module via Electromagnetic Heating Multiphysics interface.

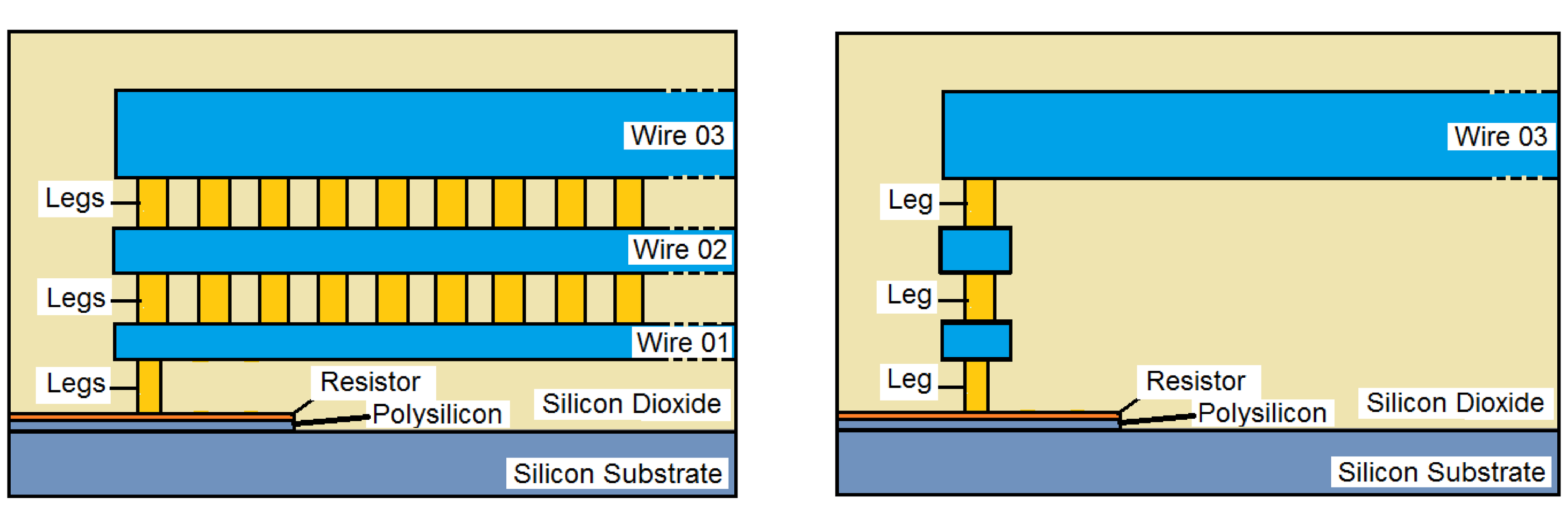

Figure 1. Diagrams of Structures A (left) and B (right) used as models in this simulation. Only half of the structure are shown in these diagrams. The structure B lacks of Wires 01 and 02.

Materials	$k\ (\frac{W}{mK})$	$\sigma\ (10^5\ \frac{S}{m})$	Purposes
Aluminum	235	350	Wires
Tungsten	175	179	Legs
Polysilicon	130	~0	Insulators
Silicon Dioxide	1.4	~0	Insulators
Silicon Substrate	130	~ 0	Insulators
Resistive Material	50	30	Resistor

Table 1. The thermal conductivity k and electric conductivity σ of the materials used in this study.

Name	$h\ (\mu)$	$w\ (\mu)$	$L\ (\mu)$
Resistor	0.1	6.0	38.0
Wire 01	0.65	6.0	32.2
Wire 02	0.80	6.0	32.2
Wire 03	3.00	6.0	32.2
Long Leg	0.40	6.0	0.95
Short Leg	0.55	6.0	0.90

Table 2. The dimension of the model components used in the simulation.

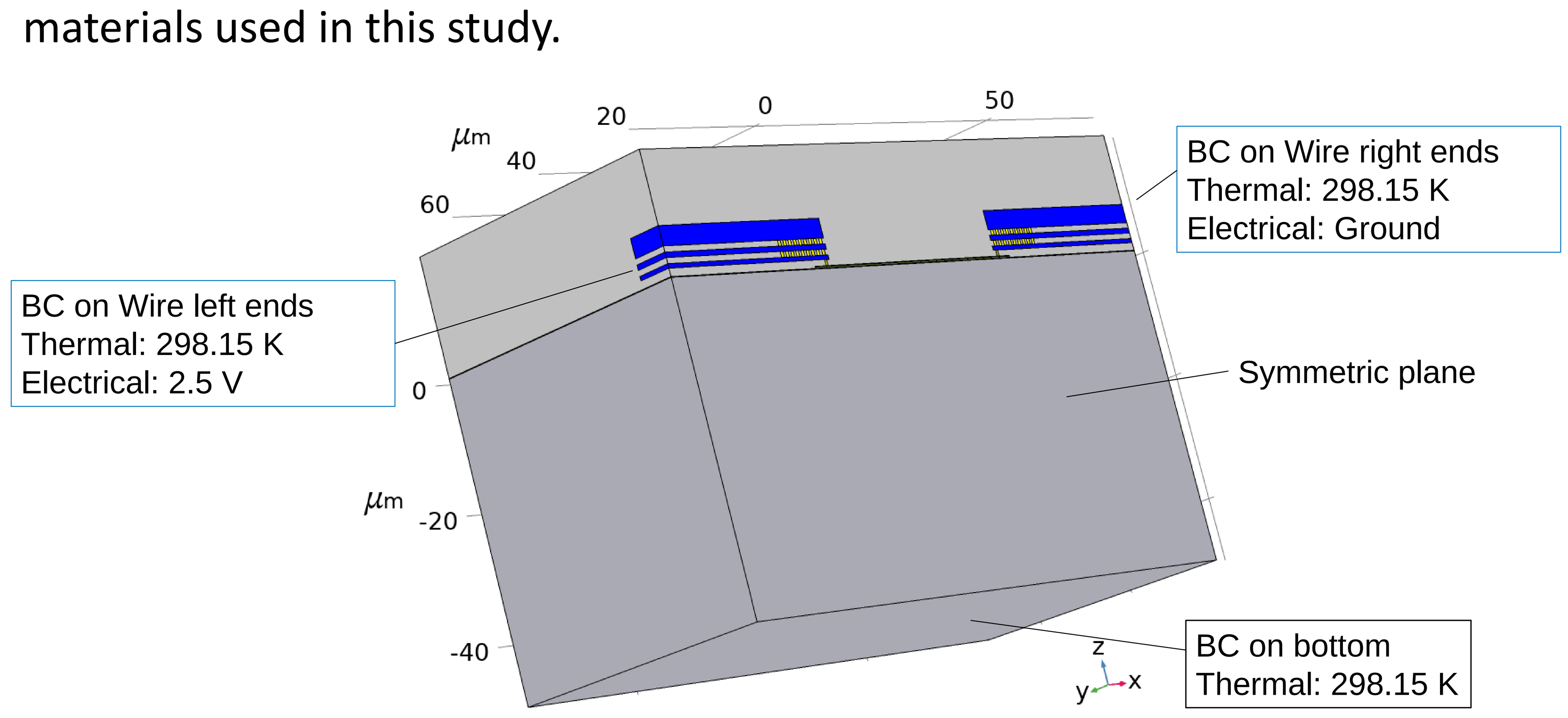

Figure 2. The 3D model of Structure A (highlighted) embedded in insulator is shown above with the applied boundary conditions (BC). Due to the symmetry, only half of the structure is modeled. The electrical current is induced by applying the electrical potential on the wires.

RESULTS:

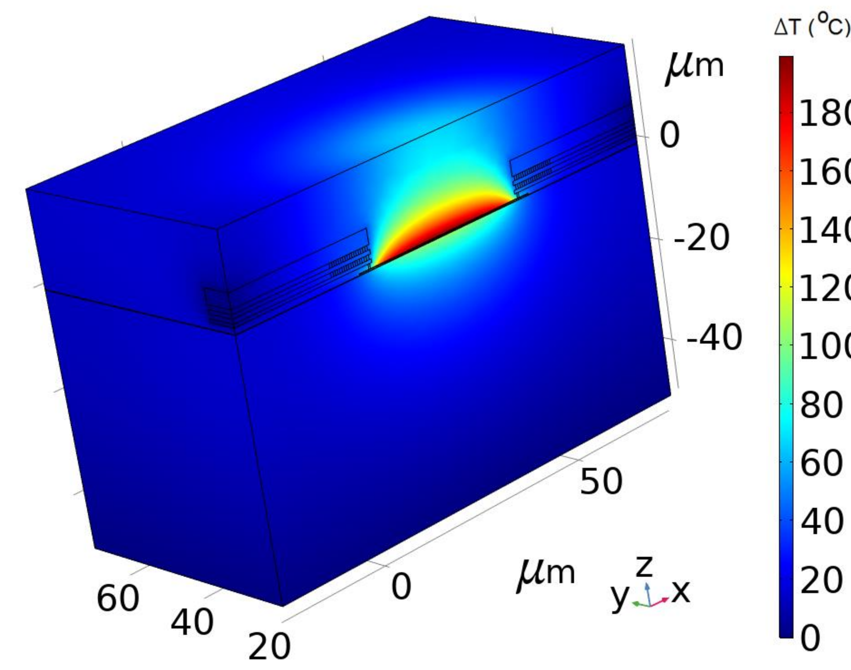

Figure 3. The three-dimensional DT (relative temperature with respect to BC) distribution on the model shows the maximum temperature on the resistor (Structure A)

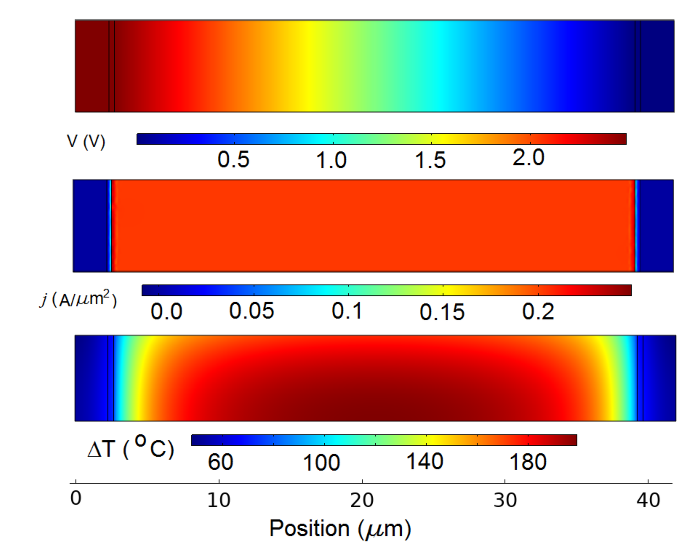

Figure 4. Shown above are the voltage, current density (in x-direction) and temperature distribution on the mid-plane of the resistor of Structure A.

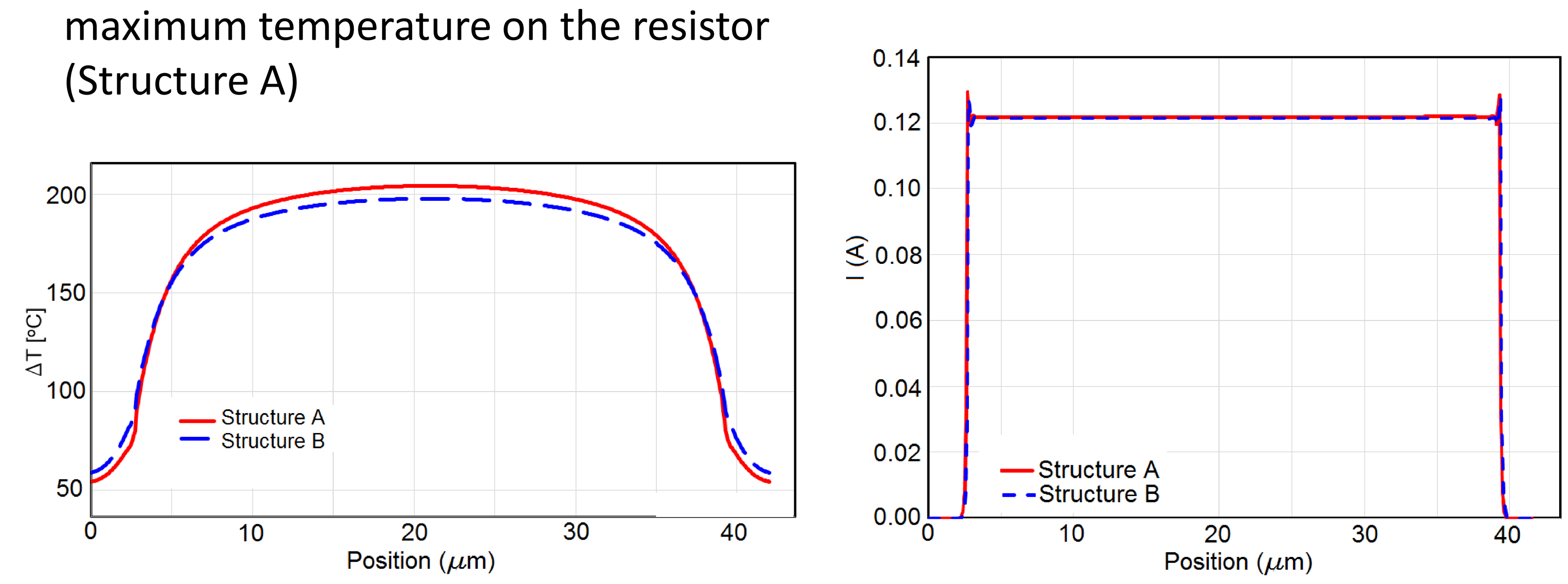

Figure 5. The temperature rise (left) and total current in the x direction (right) along the mid-line of the resistor for Structures A (red line) and B (blue line). The change of wire structure essentially does not affect the resistor.

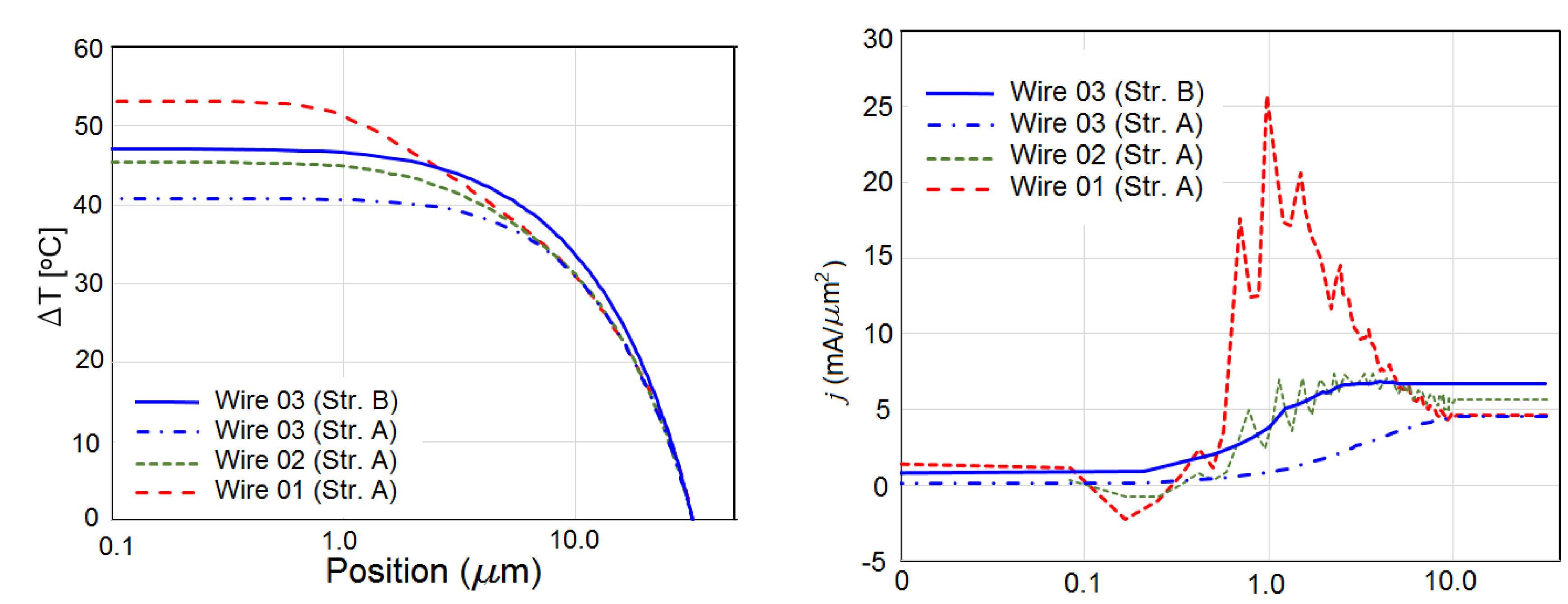

Figure 6. The temperature rise (left) and current density in the x direction (right) along Wires 01, 02, and 03 for Structures A and B. The lifetime of Structure A depends on Wire 01, which in this case has low *MTTF*. On the other hand, the lifetime of Structure B depends on Wire 03 that has higher *MTTF*.

Str.	Wire	T_{max} (°C)	j_{max} (mA/µm²)	Relative *MTTF*
A	01	78.1	18.20	1.00
	02	70.3	5.40	14.3
	03	65.8	1.22	259
B	03	72.1	5.42	12.4

Table 3. Maximum modeled temperature and current density near end of each wire, and the corresponding relative *MTTF*'s estimated from Black's Equation.

CONCLUSIONS:

- Improved lifetime and better resistor functionality can be achieved by structural modification
- FEA offers valuable insight to study functionality and reliability of IC devices and structures
- Future work remains to experimentally validate the simulation results

REFERENCES:

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