# Thermo-Mechanical Analysis and Fatigue Life Prediction for an Electronic Surface-Mount Device (SMD)

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## Introduction

Overheating and thermo-mechanical stress are the main causes of failure for electronic equipments. In fact, exceeding in maximum safe operating temperature means a strong reduction of semiconductors efficiency, reliability and lifetime [1]. Combined with the thermal expansion mismatch between the different materials of the assembly, cyclic thermal loading results in stress reversals and potential accumulation of inelastic strain in the solder joint. This inelastic strain accumulates with repeated cycling and ultimately causes solder joint cracking and interconnect failure [2]. In general, the solder layers are the weakest part of the electronic devices.

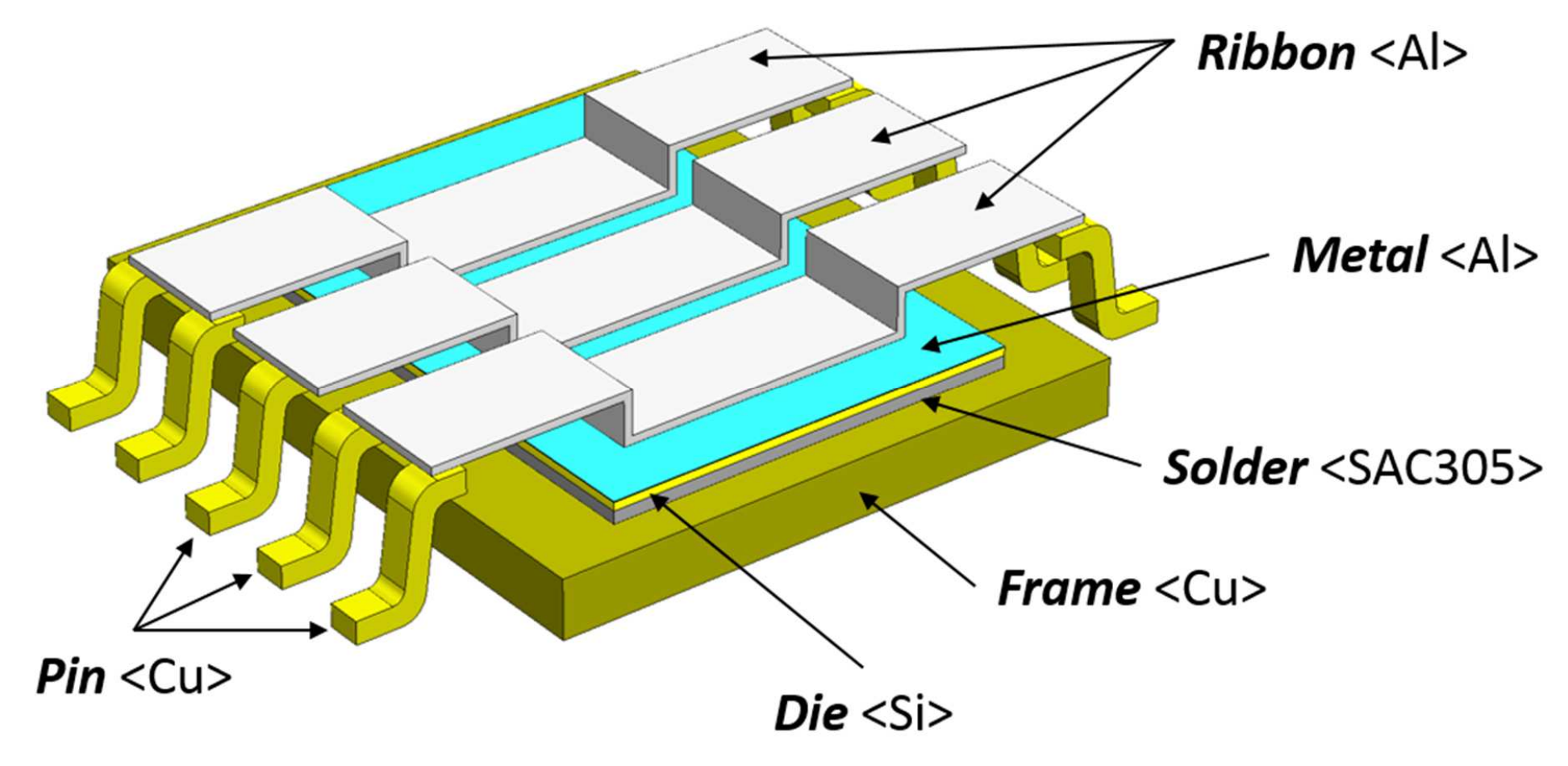

***Figure 1.*** *Geometry of the numerical model.*

Because of the demand for very high power density electronic devices, coupled thermo-mechanical analyses oriented to the solder joint fatigue life prediction are becoming a topic of very high interest.

In this framework, a numerical analysis on thermo-mechanical behavior and fatigue life prediction for an electronic Surface-Mount Device (SMD) is proposed.

## Computational methods

| | $\rho$ | k | $C_p$ | $\alpha$ | E | $\nu$ | $\sigma_Y$ |
|---|---|---|---|---|---|---|---|
| **Material** | [kg/m$^3$] | [W/(m·K)] | [J/(kg·K)] | [K$^{-1}$] | [MPa] | [-] | [MPa] |
| *Copper* | 8700 | 400 | 385 | 1.7E-5 | 1.1E5 | 0.35 | 48 |
| *Solder* | 7370 | 75 | 220 | 2.2E-5 | 5.0E4 | 0.36 | 34 |
| *Silicon* | 2329 | 130 | 700 | 2.6E-6 | 1.7E5 | 0.27 | 40 |
| *Aluminium* | 2700 | 238 | 900 | 2.3E-5 | 7.0E4 | 0.33 | 11 |

***Table 1.*** Physical properties of materials.

$$\rho C_p \frac{\partial T}{\partial t} = \nabla \cdot (k \nabla T) + Q$$

$$\sigma - \sigma_0 = C : (\varepsilon - \varepsilon_0 - \alpha\theta)$$

$$\varepsilon = \frac{1}{2}(\nabla s + (\nabla s)^T)$$

$$\frac{\Delta\varepsilon_p}{2} = \varepsilon'_f \, (2N_f)^c$$

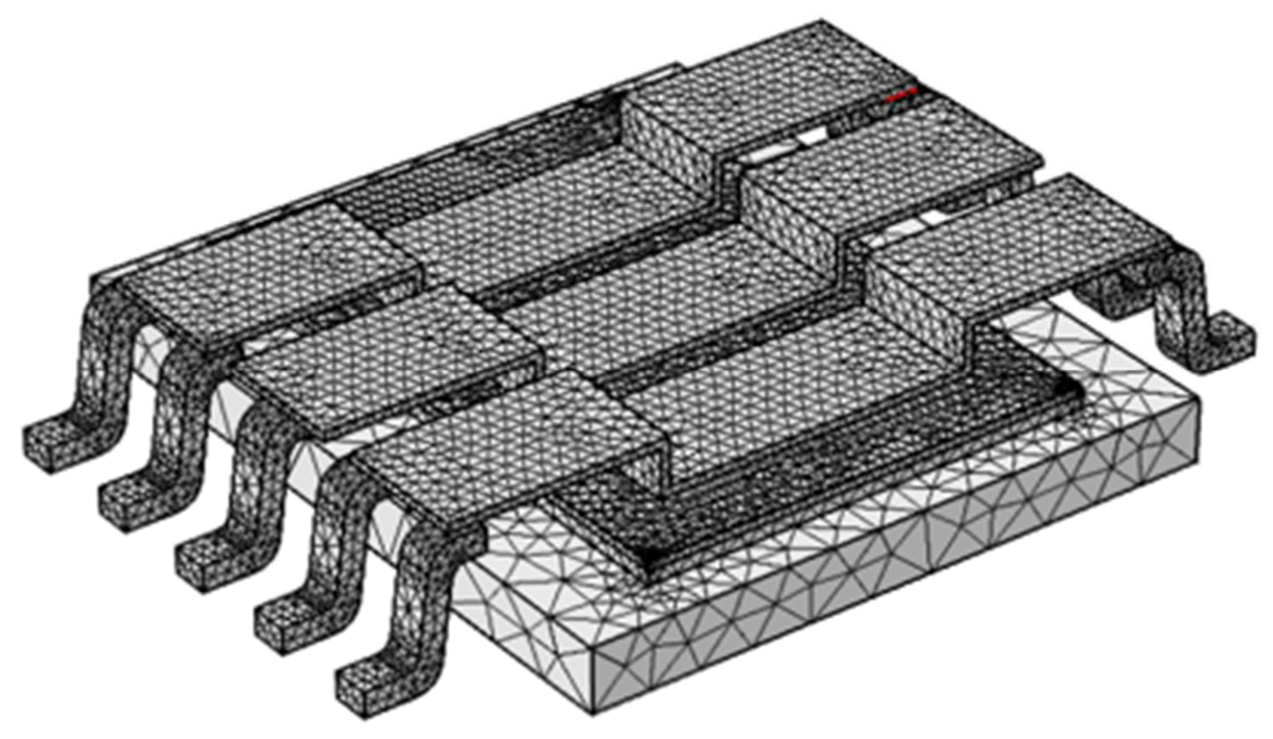

***Figure 2.*** *Computational mesh.*

- Equations discretized by a FE method;
- Non-uniform and non-structured grids (tetrahedral Lagrange elements, order 2);
- Newton-Raphson scheme for steady solution;
- Algebraic systems solved by a direct solver;
- Implicit Differential-Algebraic (IDA) solver for time-marching simulations.

## Results

Two kinds of investigation were carried-out. The first analysis, labelled as (Case A), was performed considering the worst working conditions in order to compute the maximum temperature and related stress-strain during the module functioning. To this goal, the bottom surface of the frame was held at constant temperature ($T_{ref}$) and a volumetric heat source was applied to the device. Values of thermal heat source correspond to the maximum power supplied to the device during its functioning. The structural load was related to the thermal computed state only.

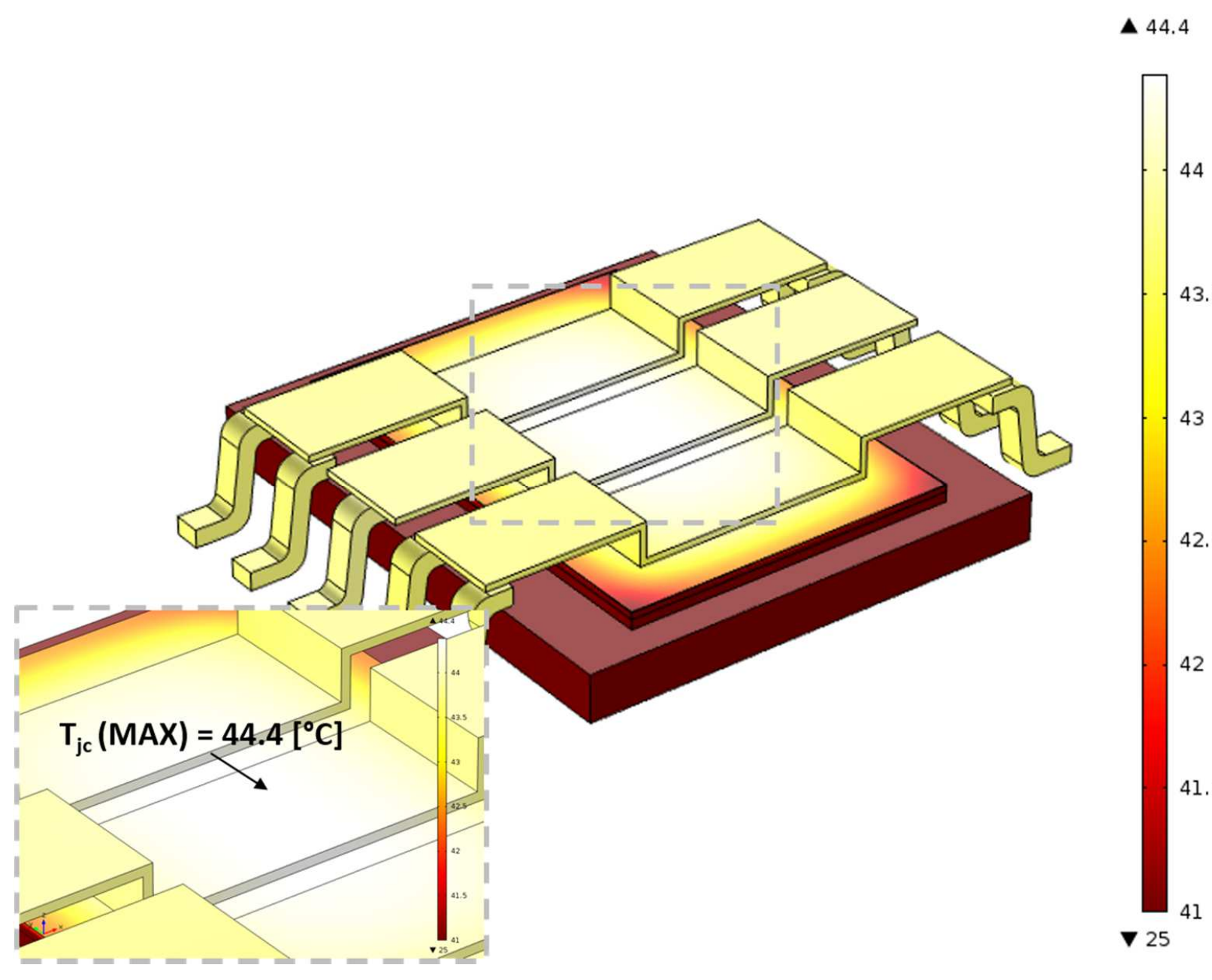

***Figure 3.*** *Thermal map [°C] on the device and enlargement close to device central area (Case A).*

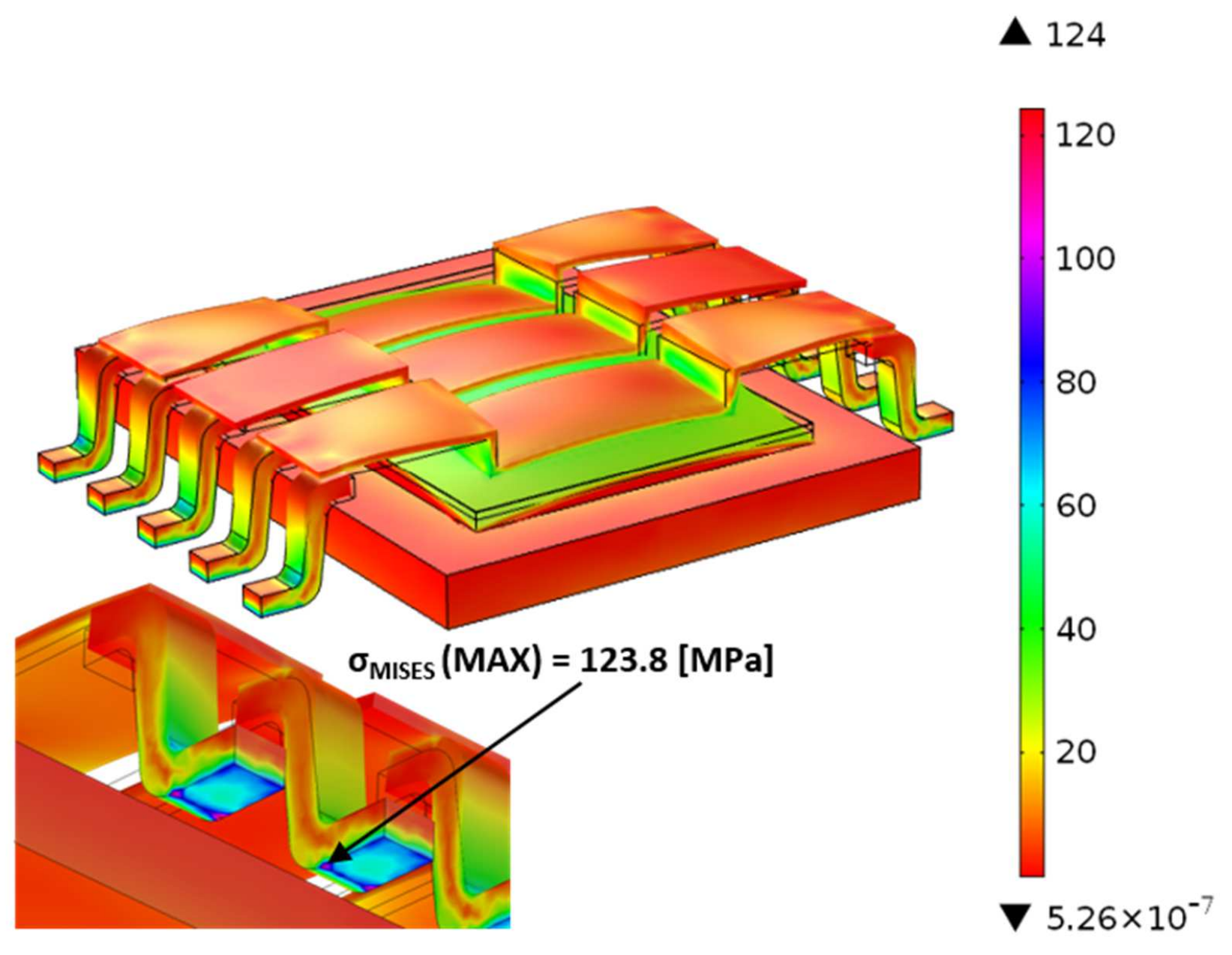

***Figure 4.*** *Von Mises stress distribution [MPa] on the device in deformed configuration (50X) and enlargement close to device pins (Case A).*

In a second step of our investigation, labelled as (Case B), a fatigue life prediction was carried-out for assessing the fatigue life of the solder die when it is subjected to thermal cycles and power cycles. The model proposed for predicting the fatigue life lies on a plastic-strain approach.

The "Thermal cycle model" was built considering two environmental fixed temperatures ($T_c$ = -40 [°C] and $T_h$ = 125 [°C]) applied as thermal load to the entire device external boundaries. No heat source was considered. This procedure simulates the device standing inside a climatic test room, held at the two different temperature values. The "Power cycle model" was built considering the device switched ON/OFF between two power states: (a) the device is switched OFF (P = 0 [W]); (b) the device is switched ON (P = Pmax).

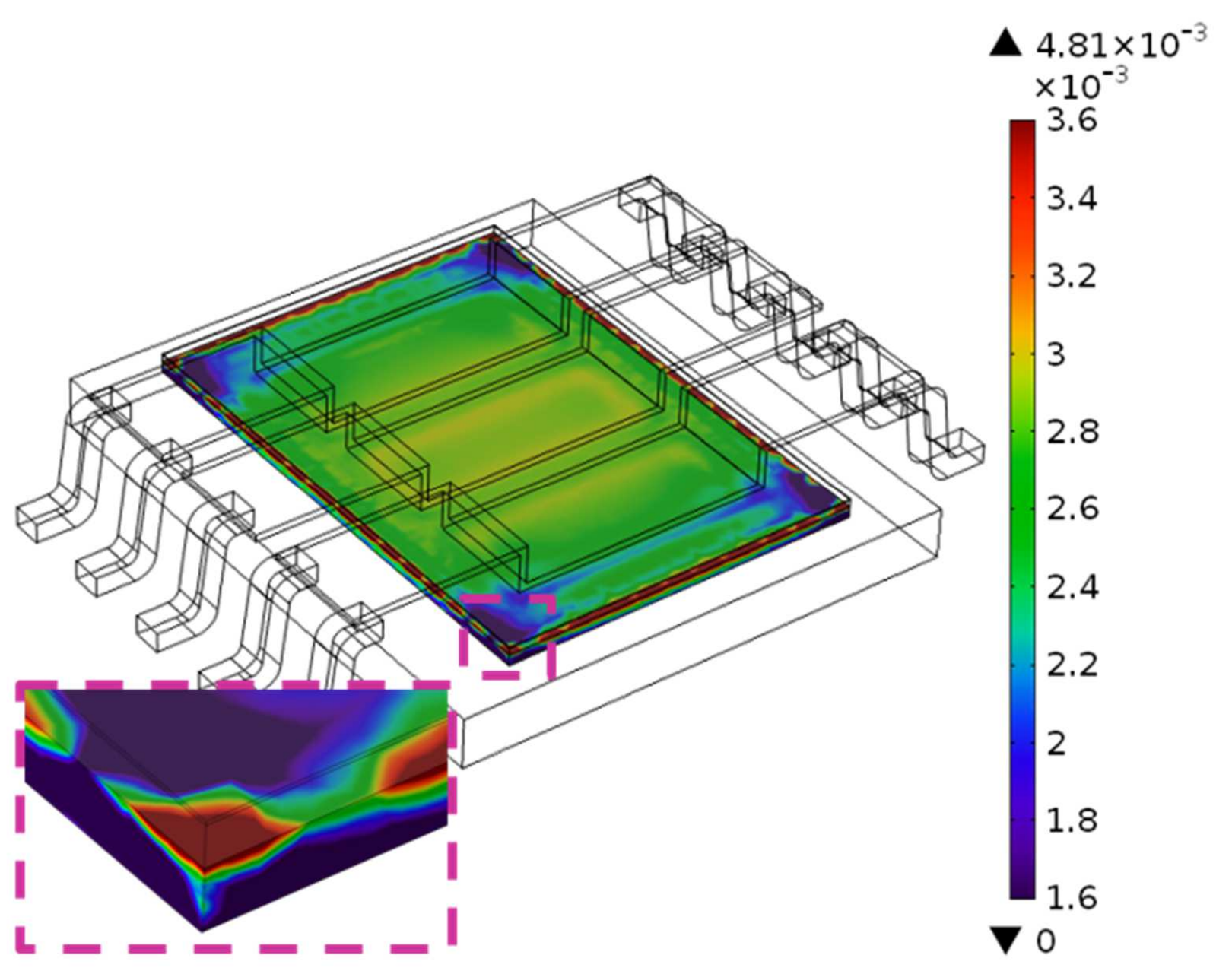

***Figure 5.*** *Effective plastic strain distribution for SAC305 solder, evaluated for $T_h$ = 125 [°C], and enlargement close to solder corner (Case B).*

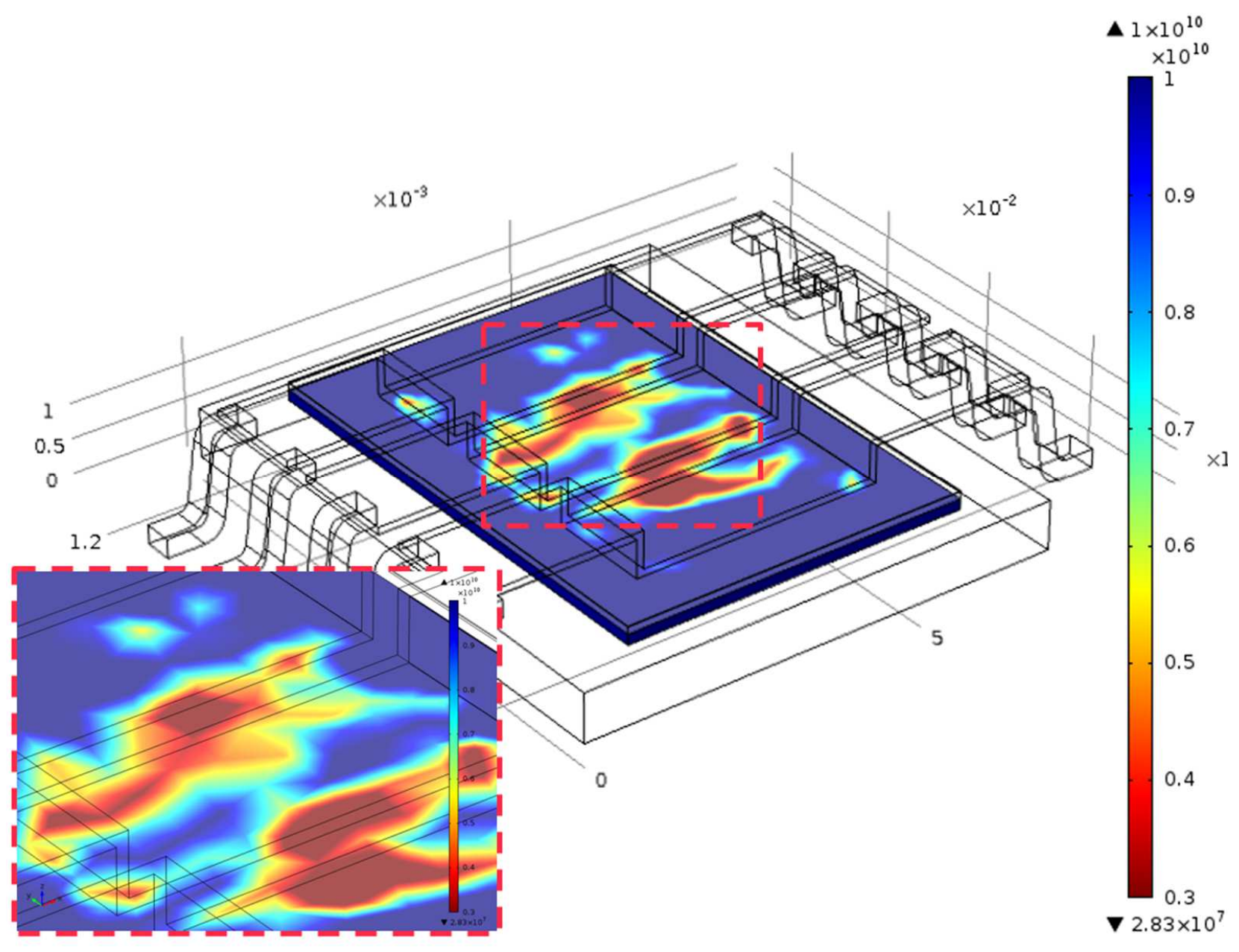

***Figure 6.*** *Number of cycles to failure for SAC305 solder die and enlargement close to solder central area (Case B).*

By means of this approach, the effective plastic strain range ($\Delta\varepsilon_p$) was evaluated by using the achieved thermal states. Then, in analogy to the Basquin equation, we applied the Coffin-Manson equation to compute the number of cycles to failure, in particular for solder layer [3].

## Conclusions

From results, it appears that thermal levels are lower than potential critical values for constitutive materials, even in the worst working conditions. The maximum von Mises stress computed by the thermo-mechanical analysis is lower than the ultimate tensile strength of materials. The fatigue life prediction results in good agreement with literature evidences and experimental findings, both qualitatively (device portion subjected by the highest plastic strain) and quantitatively (number of cycles to failure).

## References

1. G. Petrone et al., *Modelling and Simulation*, 391-417, I-Tech Education and Publishing, Croatia (2008).
2. Z. Sun et al., *Prediction of thermo-mechanical fatigue for solder joints in power electronics modules under passive temperature cycling*, Eng. Fracture Mech., Vol. 107, 48-60 (2013).
3. C. Barbagallo et al., *Thermo-mechanical analysis of a multi-chip power module*, Proc. of the ASME-ATI-UIT Conference, Napoli, Italy (2015).

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