Evaluation of Low-Cycle-Fatigue Life of Solder Joints in Surface Mounting Power Devices by Finite Element Modeling

Nicola Delmonte[1], Francesco Giuliani[1], Mirko Bernardoni[2], Paolo Cova[1]

1. University of Parma, Dipartimento di Ingegneria dell'Informazione, Viale G.P. Usberti 181/A, 43124 Parma, Italy;
2. University of Bristol, H. H. Wills Dept. of Physics, CDTR - Centre for Device Thermography and Reliability, Bristol, United Kingdom.

Introduction: Solder joints reliability [1,2] is one of the key factors in the determination of high power density electronic converters reliability. The main mechanism by which solder joints are damaged is thermal cycling and, in particular, thermo-mechanical stress-strain distribution, which arises from the different thermal expansion coefficients of adjacent materials. As a case study, we developed a FE model which describes the thermo-mechanical behavior of solder joints of a power MOSFET in SO-8 package mounted on a small FR4 board (Fig. 1) .

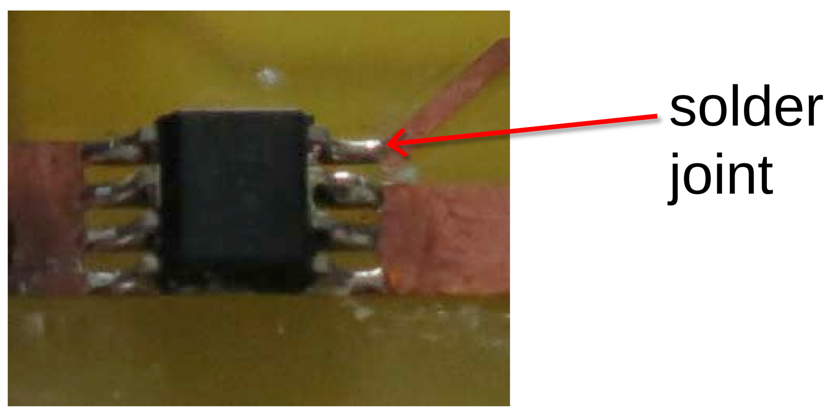

Figure 1. SO-8 packaged device mounted on a small FR4 board.

Computational Method: We built a 3D thermo-mechanical model (Fig. 2) of a power transistor subjected to thermal cycles, by exploiting the Coffin-Manson law to obtain indications about the fatigue life of the solder joints, which depend on material and geometrical parameters, neglecting thermo-mechanical transients. The study is at the stationary conditions and computes the multi-axial stress-strain distribution in the device under test. From the results so obtained we can determine the maximum values of strain once the structures has reached the thermal (and mechanical) steady state. To account for this in terms of life cycles N_f, the Coffin-Manson equation (1) is used [3]:

$$\frac{\Delta\varepsilon_p}{2} = \varepsilon'_f \left(2N_f\right)^c \qquad \textbf{(1)}$$

where $\Delta\varepsilon_p/2$ is the strain to which the sample is subjected (the *maximum* by the simulation), N_f is the number of load reversal (i.e., half of the number of loading cycles), and ε'_f and c are characteristic parameters of the soldering alloy.

Since the probability for a crack to nucleate is higher in high stressed regions, we have focused the study on this areas.

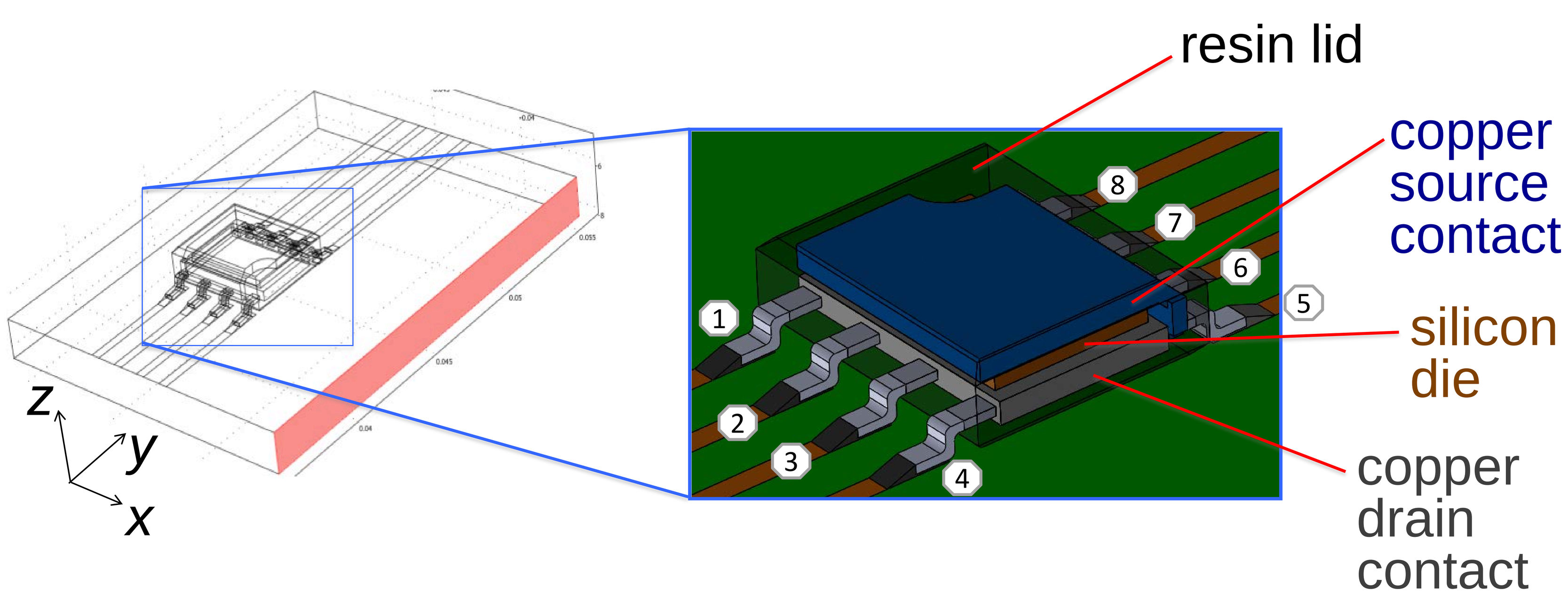

Figure 2. 3D model implemented in COMSOL. The board is fixed by the corresponding mechanical constraint at the highlighted border.

Results: We run the model at four different power levels (power dissipated in the silicon die): 0.3 W, 0.4 W, 0.5 W and 0.6 W.

The maximum temperature reached by the solder joints were 67 ° C, 81° C, 95 ° C and 110 ° C, respectively; clearly, these are representatives of an accelerated life test. The von Mises stress has been evaluated at all power levels for each joint (Fig. 3).

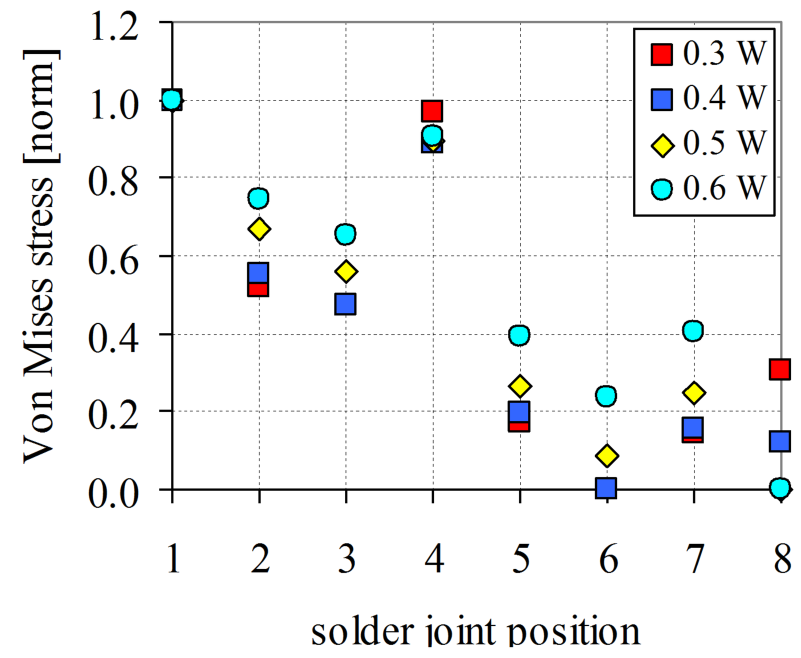

Figure 3. Normalized von Mises stress (integrated over the joint volume) vs pin position, for different power levels. Pins 1 and 4 are always the most stressed pins.

Focusing on the maximum plastic strain components in the solder joint, we found out that two components were always dominant: $\Delta\varepsilon_{pxz}$ and $\Delta\varepsilon_{pz}$; their values are plotted vs the dissipated power in Fig. 4. This means that the solder joint tends to be almost equally lifted up and sheared along the z direction for low powers, with the latter contribution becoming more and more predominant as the dissipated power increases.

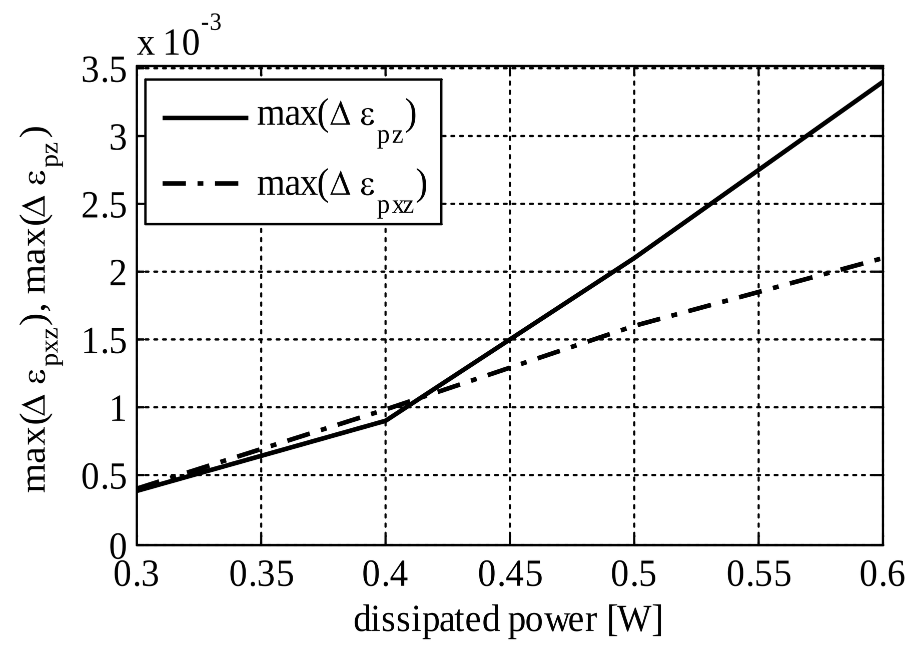

Figure 4. Simulated plastic strain components $\Delta\varepsilon_{pxz}$ and $\Delta\varepsilon_{px}$ vs dissipated power.

Conclusions: This work shows the set up a 3D non-linear thermo-mechanical FE model, to study the fatigue behavior of soldering joints in SO-8 MOSFET on board. A possible method to determine the strain to be used in the Coffin-Manson relationship is shown.

References:

1. Shnawah DA, Sabri MFM, Badruddin IA. A review on thermal cycling and drop impact reliability of SAC solder joint in portable electronic products. Microel. Reliab. 52 (2012) pp. 90-99.
2. Ratchev P, Vandevelde B, De Wolf I. Reliability and failure analysis of Sn-Ag-Cu solder interconnections for PSGA packages on Ni/Au surface finish. IEEE Trans. on Dev. and Mat. Reliab. 4 (2004) pp. 5-10.
3. Cui W. A state-of-the-art review on fatigue life prediction methods for metal structures. J. Mar. Sci. Technol. 7 (2002) pp. 43-56