TETRA – Thermal Environment by Transient Response Analysis: Auto-calorimetry toward material and structure evolution studies in concentrator photovoltaic cells

John P.D. Cook, Robert Li, Joan E. Haysom, Karin Hinzer and Henry Schriemer

SUNLAB, University of Ottawa, Canada

Corresponding author: john.cook@uottawa.ca

1. Introduction

Eutectic Sn-Pb solder joints have been widely studied in the microelectronics industry. On cooling after reflow and with cyclic thermo-mechanical fatigue, solder joints are known to undergo **spinodal decomposition**, **intermetallic grain growth**, **Kirkendall void growth**, **micro-crack** and **macro-crack** formation, and other processes [1].

Our **objective** is to demonstrate whether these processes affect the **thermal and reliability properties of a 3JPV solder joint**, and whether this can be detected in a **simple, non-destructive, thermal test during stress cycling**.

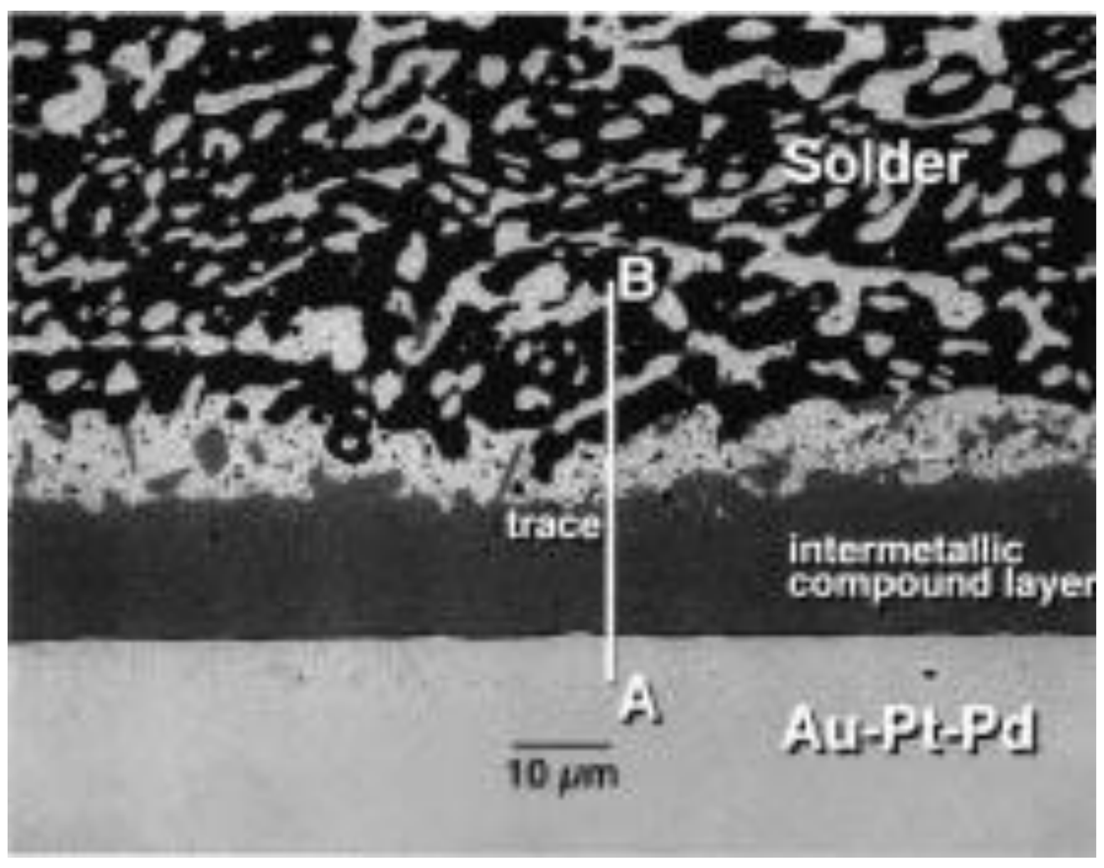


Fig. 1: Microstructure of aged Sn-Pb solder on AuPtPd metal. [1]

Previous work in this program [2] used a high-concentration solar simulator to develop cyclic thermal transients of approximately 65K for 8 seconds in 3JPV cells, but device failure was not seen after 7,000 cycles.

Solder joint failure has been induced using conventional oven cycled stress [3], where 1,000–2,000 cycles at ramp rates of 7.5 to 140K/min were used.

2. Method

Multi-junction photovoltaic cells (MJPV) convert concentrated sunlight to electrical power with efficiencies approaching 50%. MJPV cells can also be operated as a **self-thermometer** and a **self-heater**, without added structure or componentry, which enables **auto-calorimetry** using only a programmable source-monitor unit (SMU).

Thermal transients can be introduced into the cell using the self-heater, and the device response can be followed using **junction temperature T_j**. **Thermal transient response** is informative regarding the state and evolution of materials and structures in the cell [4,5]. Transient response is found to change in different ways, after **hot and cold thermal shocks**.

<ins>**Auto-calorimetry**</ins>:

Segment 1: low-current monitor (10mA) for ambient temperature

Segment 2: known energy dose (400mA, 1s) injected into junctions

Segment 3: low-current monitor transient response

<ins>**Proxy for cyclic thermo-mechanical fatigue**</ins>:

Hot shock: 115°C hot plate, 10 seconds

Cold shock: –196°C liquid nitrogen dip, 10 seconds

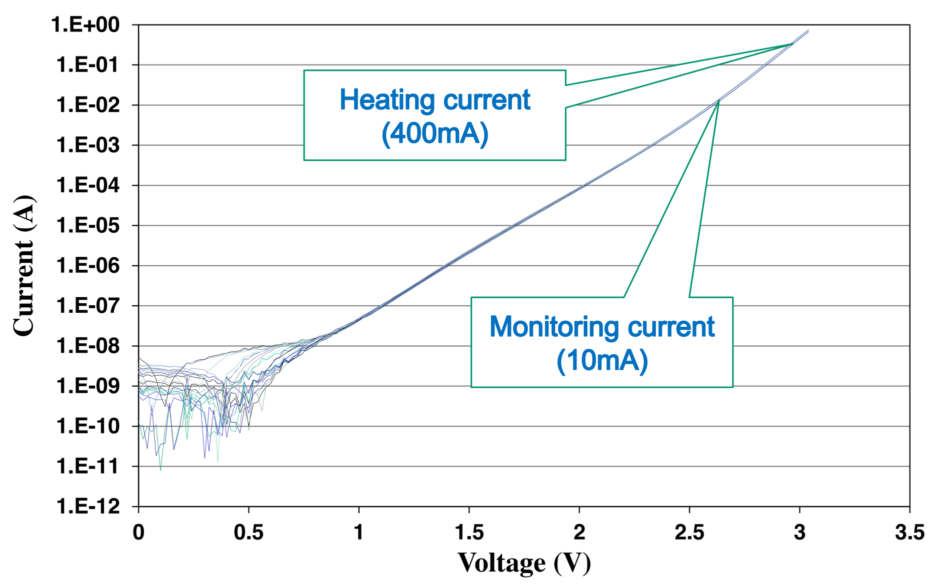


Fig. 3: Dark forward I-V curves of some 3JPV cells at room temperature.

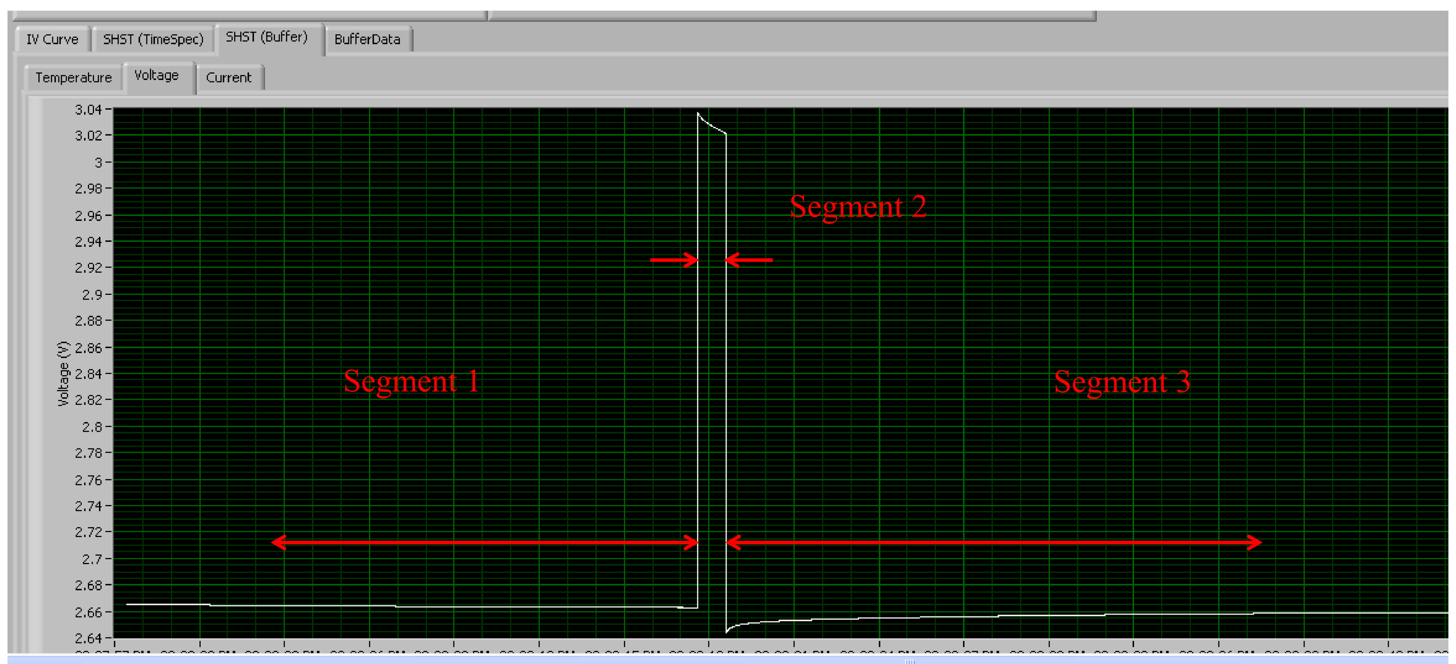
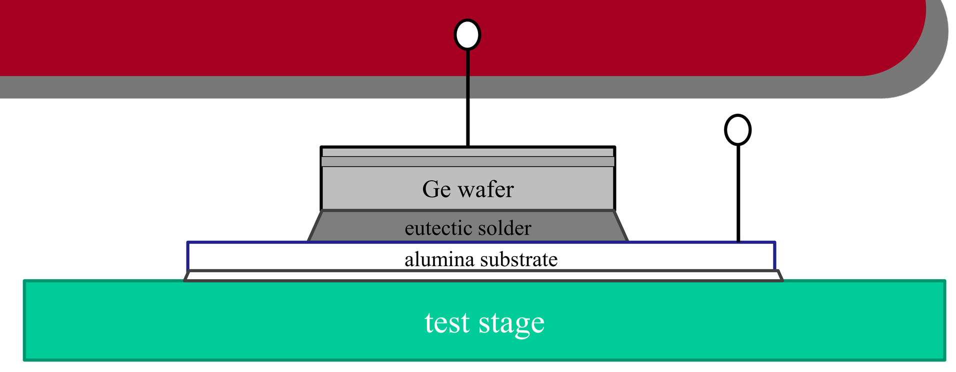


Fig. 2: TETRA three-segment scan.



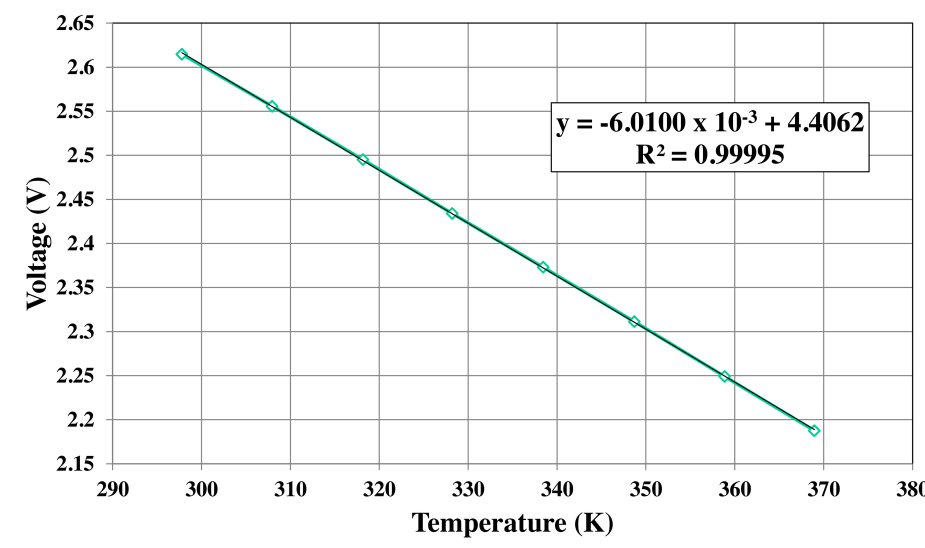


Fig. 4: Junction temperature calibration curve.

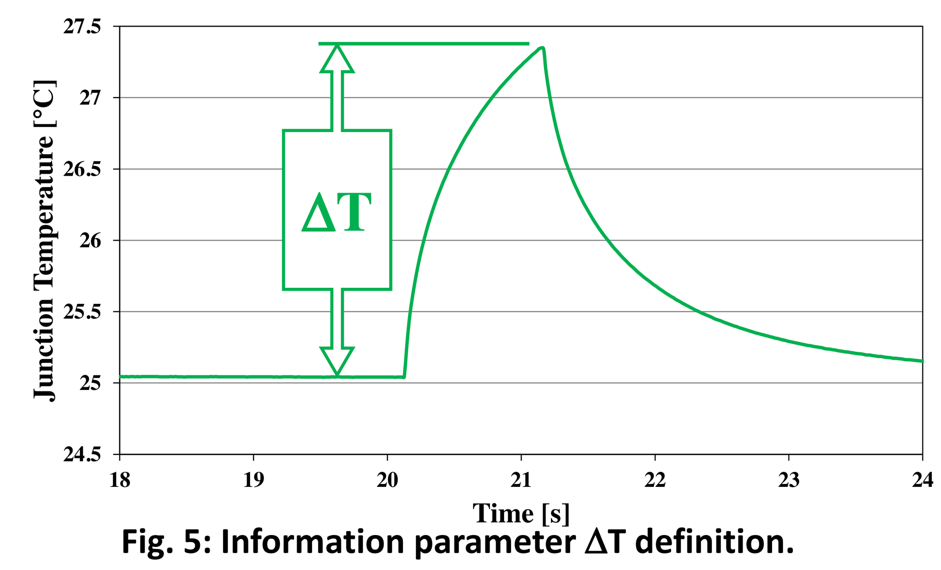


Fig. 5: Information parameter ΔT definition.

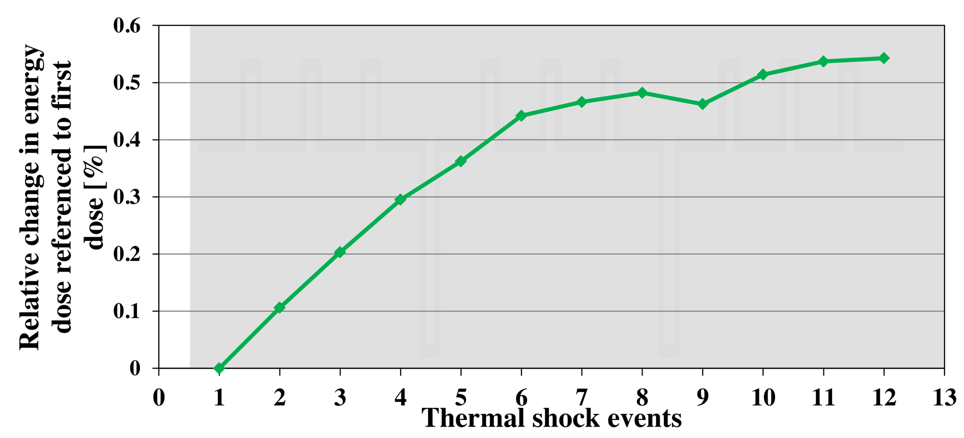


Fig. 6: Energy dose uniformity.

3. Preliminary Results

Preliminary results show **useful sensitivity**, expected test stage material dependence, sample thermal mass effect, transient **time constant structure**, and **substrate curvature change on shocks**.

Future work will explore **piezoelectric** artifacts, **cyclic fatigue monitoring**, differential structure functions, and other transient parameters.

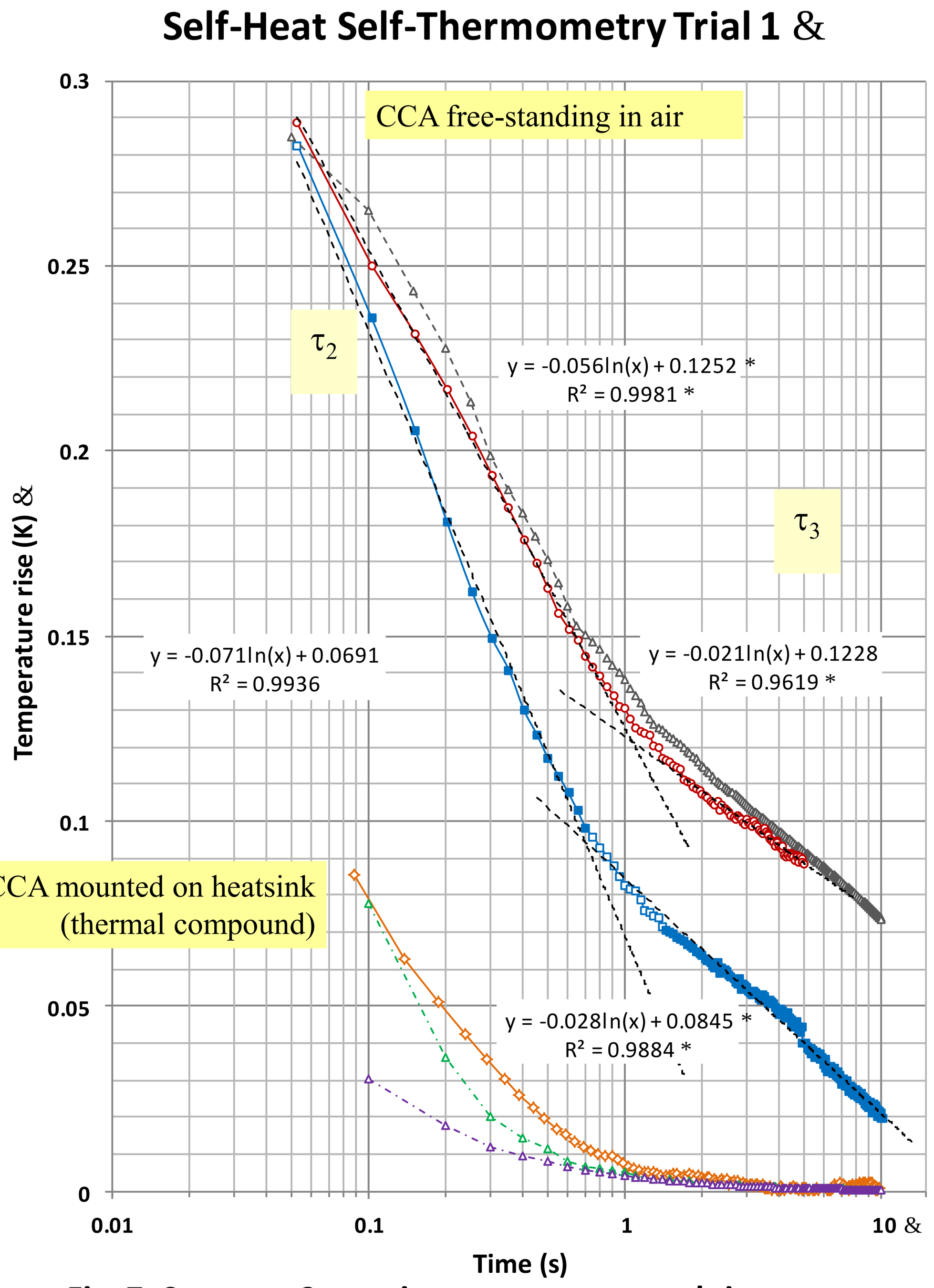


Fig. 7: Segment 3 transient suggests several time constants, and test stage effect.

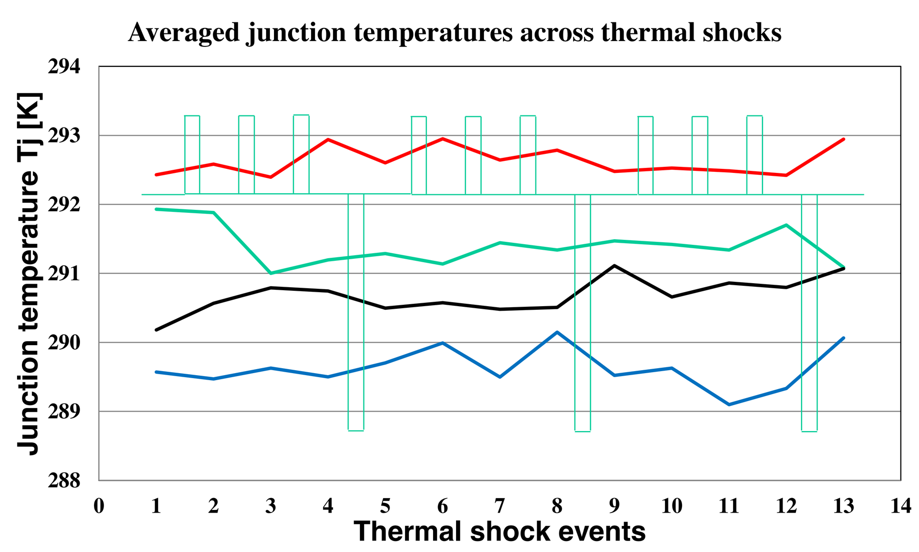


Fig. 8: T_j across thermal shocks. Piezoelectric effect from plastic deformation not obvious.

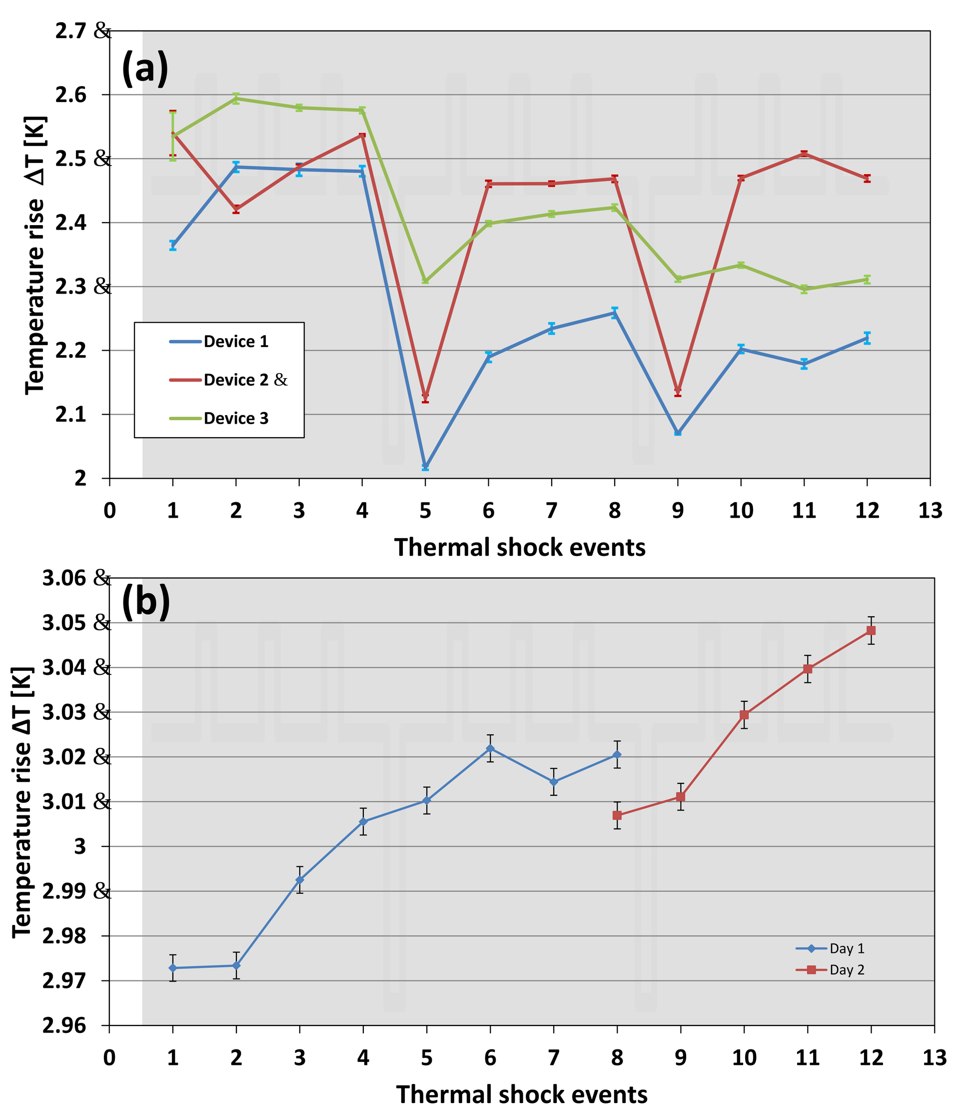


Fig. 9: Substrate curvature and test stage effects – (a) metal stage; (b) polymer foam stage.

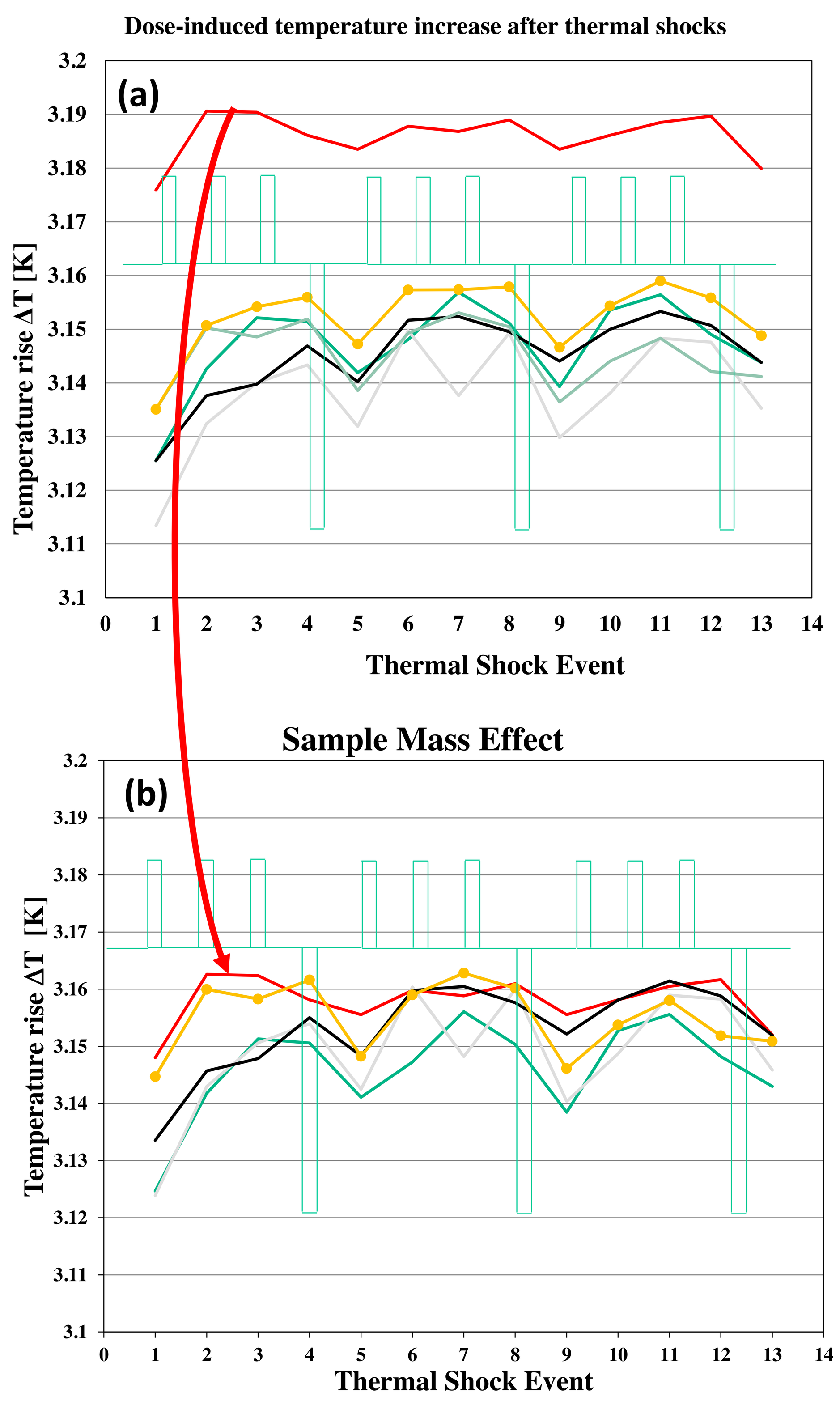


Fig. 10: Mass sensitivity (5 samples) – (a) raw data; (b) normalized to sample mass.

References

1. P.T. Vianco et al., "Intermetallic Compound Layer Development During the Solid State Thermal Aging of 63Sn-37Pb Solder/Au-Pt-Pd Thick Film Couples" IEEE Trans. Comp. Packag. Man. Tech. A, 20(4)(1997)478
2. R.M. Beal, K. Hinzer, et al., "High-intensity light-cycling of HCPV assemblies using the XT-30 solar simulator" Proc. NREL PVMRW 2012
3. N.S. Bosco et al., "On the effect of ramp rate in damage accumulation of the CPV die-attach" 37th IEEE PVSC, 2012
4. V. Szekely "A new evaluation method of thermal transient measurement results" Microelectronics Journal 28 (1997) 277-292
5. A. Vass-Varnai, M. Rencz et al., "Application of Thermal Transient Testing for Solar Cell Characterization" Proc. 28th IEEE SEMI-THERM Symposium

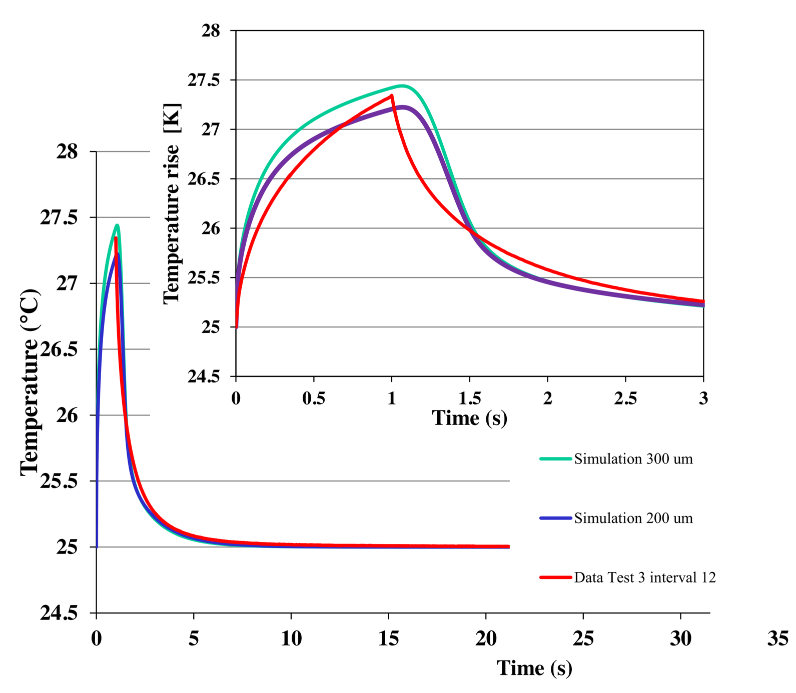


Fig. 11: Finite–element modeling Segments 2 & 3, on metal stage (COMSOL).