Electronic Composites :Overview with two case studies, thermal interface materials and active composites.

Minoru Taya, University of Washington, Box 352600,Seattle, WA 98195, USA
Email: tayam@u.washington.edu

Key words: electronic composites, CNT, thermal interface material, active composites, Eshelby model, resistor network model

Abstract

The subject of electronic composites has attracted stronger attention among the researchers on composites and composite structures which require multi-functionality such as electromagnetic and optical properties. My talk is aimed at recent advances on modeling and processing of selected electronic composites: (1) thermal interface materials(TIM) a key interconnect material for thermal management of electronic packaging in both chips and pumped laser diodes, (2) active composites that can sense and actuate under themo-mechano-electromagnetic loading. Both materials, use of accurate modeling that can bridge the nano-micro-structure and macroproperties of the composite is a key design step in identifying the optimum their nanostructure and microstructure before proceeding their processing.

Thermal interface materials (TIM) are thin film material that can bond between heat emitting source such as chip or laser diode, and the heat spreader and/or heat sink which promote quick heat removal emitted from the heat source. Thermal resistance, R=ρL/A is the key engineering constant used by packing engineers where ρ, L and A are the intrinsic thermal conductivity , thickness and area of a TIM, respectively. RA is also key parameter, called thermal impedance ,θ in units of [Kcm^2/W]. The microstructure of commercial TIMs is conductive metal fillers such as silver frakes and phase changeable polymer such as olefine. In order to reduce the themal resistance R, one can reduce thermal resistivity, ρ by using highly conductive fillers such as silver and also reduce the TIM thickness, L. It is noted that the TIM thickness , L is limited by the size of Ag flakes. Therefore, it would be better for designer to search for thinner or smaller sized conductive fillers. In this respect, we recently propose to use carbon nanotubes which form as interconnected network. If this CNTs net work is inserted in phase changeable polymer, one can design the TIM with lower R value, which is realized during the installation of TIM into a packaging with heat emitting chip. It is noted that during the installation of TIM, compressive force is applied through compressive spring , and upon switching of chip, heat is generated to make the polymer phase-changed so that the initially solid polymer becomes softened like liquid form but would not flow out of the interface area. This results in a large thickness change, typically 500 micron to 20 micron, thus reducing themal resistance. Fig. 1 shows the experimental data of R-values as a function of TIM thickness. The experimental data of θ-L relation of Fig. 1 supports that the above equation of thermal impedance i.e., θ is linearly proportional to L, but it also reveals that the intersection of θ-L line with the vertical axis is not zero, leaving some positive θ-value, which is called as "Interface thermal impedance", $\theta_{interface}$, thus, the total θ is sum of $\theta_{intrinsic}$ and $\theta_{interface}$. $\theta_{ntrinsic}$ can be reduced by using higher conductive fillers, while the value of $P_{interface}$ depends on the nanostructure of the interface between TIM and the chip, but not the nanostructure of TIM composite. The experimental values of thermal conductivity are obtained from $\theta_{ntrinsic}$ /L, and they are compared with the predictions based on the resistor network model [Taya,2005], resulting in a good agreement between them, Fig. 2.

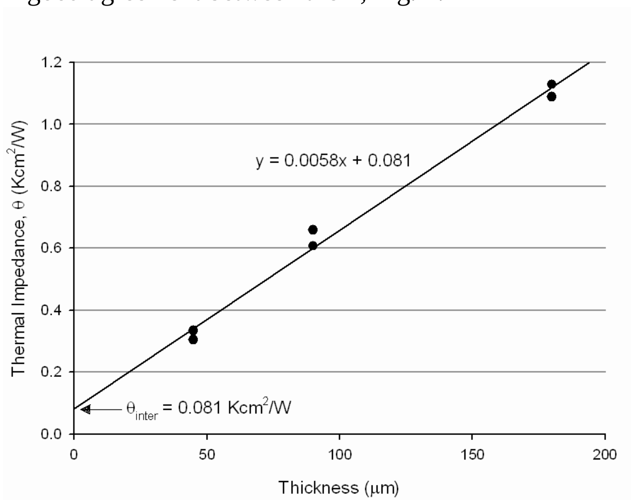

Fig.1 Thermal impdance, θ of CNT network reinforced phase changeable polymer matrix composite for TIM as a function of TIM thickness (Park and Taya, 2006).

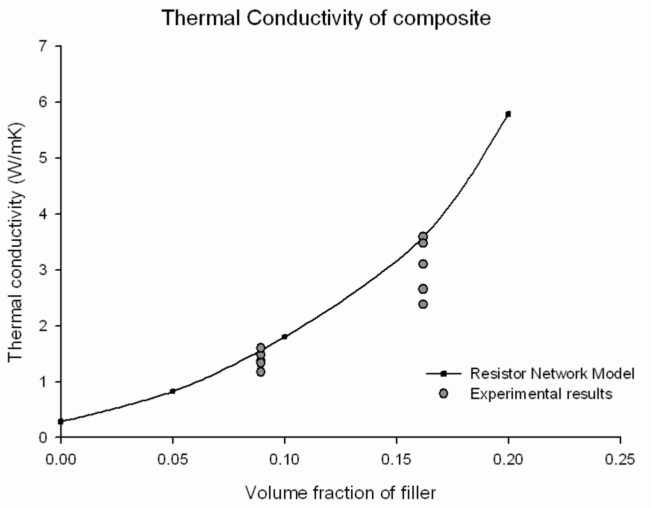

Fig. 2 Thermal conductivity K of TIM as a function of volume fraction of CNT network: experimental data compared with predictions by thermal resistor network model.

Active materials are key materials for sensors and actuators,and they exhibit the coupling among mechano-themo-electromagnetic behavior. Such active materials are shape memory alloy(SMA), ferromagnetic SMA, ferroelectric materials which include piezoelectric materials, and magnetostrictive materials. Although we see rapid improvement of their performance thanks to con tenuous efforts by materials scientists developing the active materials, most of the active materials exhibit now saturated behavior. In order to overcome the above saturated performance, one can use the concept of "active composites" which are composed of two different active materials. For examples, Magnetostrictive composites[McKnight and Carman, 2001; Armstrong and Shanmugham, 2005], Ferromagnetic SMA[Kusaka and Taya, 2004]. In addition to these, we started studying piezo-SMA composite. The aim of this modeling is to see if any merits exist if we combine two active materials, piezo-phase whose response is fast by applied electric field but with small induced strain, while the strain of SMA is large but with slow actuation speed. Here I introduce the modeling of such piezo-SMA composite withing frame work of Eshelby, where SMA fillers are embedded in the piezo-matrix. As a special case , we consider the laminated composite made of two piezo laminae sandwiching one SMA lamina ,which is subjected to applied stress and electric field. Fig. 3 shows the predictions by Eshelby's model of strain induced as a function of applied electric field while the laminated composite is subjected to bias constant stress where the predictions by 1D model are also shown.

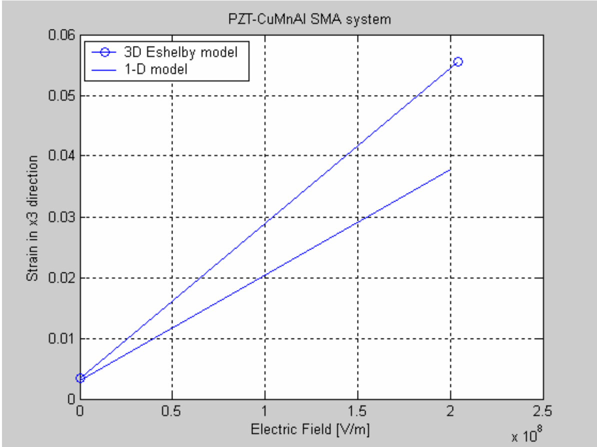

Fig. 3 Strain induced by applied electric field of a laminated piezo-SMA composites predictions by 1D model and 3D Eshelby's model.

References:

Taya, M. 2005, *Electronic Composites*, Cambridge University Press.
Kusaka, H, and Taya, M., 2004, *J. Comp. Mater.*,
McKnight , G.P. and Carman, G. P., 2001, *Smart Structures and Materials: Active Materials: Behavior and Mechanics*, edited by C.S.Lynch, Vol. 4333, pp.178-183.
Armstrong, W.D, and M. Shanmugham, S. 2001, "Degradation of Terfenol-D particle epoxy composites under low frequency cyclic magneto-mechanical loading: comparisions of matrix polymers", *Smart Structures and Materials: Active Materials: Behavior and Mechanics*, edited by W.D. Armstrong, Vol. 5761,pp.148-151.

Park, J. J., and Taya, M. 2006, 2006, "Design of thermal interface material and
measurement apparatus for its thermal conductivity," *ASME Journal of*
Electronic Packaging, Vol. 128, Issue 1, pp 46-52