Uncertainty-enabled Thermal Stress Management of Engineered Multilayered Structures

Drs. Jordan E. Massad and Robert J. Kuether
Sandia National Laboratories, New Mexico

Multilayered structures, such as composites, laminates, and bonded and fastened structures are composed of multiple materials with dissimilar thermomechanical properties. The individual materials used are chosen primarily to satisfy functional requirements, but differences among material properties can manifest elevated stress and deformation during fabrication, assembly, and post-assembly thermal environments. For example, if one layer in a multilayer structure expands more during a temperature change than does an adjoining layer, thermal stresses develop and structural bending can ensue. For many applications, such as microelectronics, the increased stress and deformation associated with this bending are deleterious. The amount of bending depends on many factors, including the number and position of layers, layer geometries, temperature-dependent mechanical properties, and bonding and attachment temperatures. In principal, if these and other process variables can be controlled, then the potential thermal stresses can be managed *a priori*. A sufficient level of control is becoming achievable with advanced manufacturing techniques. Nevertheless, particularly for thin multilayered structures, variations and uncertainties in these factors can lead to uncertain behavior of the resulting structure. Therefore, a multilayered structure design capability that manages thermal stress in the presence of uncertainty is sought. This project aims to develop a computationally-efficient, model-based tool that estimates multilayer configurations optimized under uncertainty given manufacturing, design, and performance constraints and requirements. This tool is intended to provide supporting information that addresses design feasibility and that facilitates further evaluation using higher-order modeling techniques.

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Project Team References:

- P.M. Hall, “Thermal Expansivity and Thermal Stress in Multilayered Structures,” Thermal Stress and Strain in Microelectronics Packaging, Ed. J.H. Lau, pp. 78-94, 1993.
- C.A. Klein and R.P. Miller, “Strains and stresses in multilayered elastic structures: The case of chemically vapor-deposited ZnS/ZnSe laminates,” *J. Applied Physics*, **87**(5), pp. 2265-2272, 2000.
- T.W. Clyne, “Residual Stresses in Coated and Layered Systems,” Encyclopedia of Materials: Science and Technology (2nd Edition), Eds. K.H.J. Buschow, et al., pp. 8126-8134, 2001.
- X.C. Zhang, B.S. Xu, et al., “Modeling of thermal residual stresses in multilayer coatings with graded properties and compositions,” *Thin Solid Films*, **497**(1-2), pp. 223-231, 2006.