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6. AUTHORS

A. Maximenko
E. Olevsky
SDSU

R. R. Kline
R. L. Waters
M. E. Aklufi
SSC San Diego

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SSC San Diego
San Diego, CA 92152-5001

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14. ABSTRACT

The present investigation is devoted to the finite element modeling of stress buildup during processing of multi-layered micro-dynamical devices. Modeling is performed with the commercial software package Mark-Mentat. Mechanical properties of materials during modeling are assumed to be elastic. In the current modeling, only the final composite structure is considered. However, to imitate the thermal cycling that occurs during deposition or etching of layers, elastic time-dependent material parameters are used. Development of this model gives a means to predict the distortion of multi-layered devices due to residual stresses.

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Modeling of Thermal Stress Build-up During Processing of Multi-layer Micro-dynamical Systems

A.Maximenko[1], E. Olevsky[1], R.Kline[1], R. L. Waters[2], M. E. Aklufi[2]
[1]San Diego Center for Materials Research, SDSU, 5500 Campanile Drive, San Diego, CA 92182-1323
[2]SPAWAR Systems Center, San Diego, 53560 Hull St., San Diego, CA 91252-5001

In recent years, rapid progress has been realized in the development of micro-dynamical systems. Micro-dynamical systems are moving micro-mechanical devices that provide a wide range of possibilities for the design of novel integrated sensors and actuators when combined with on-chip interface circuitry. Micro-dynamical systems are based on science and technologies developed for the integrated circuits industry and are considered a subclass of Micro-Electro-Mechanical Systems (MEMS). The ability to take advantage of the existing microelectronics infrastructure has enabled the rapid development and evolution of MEMS devices and sensors. In particular, this approach offers the possibility of a small, low-cost alternative to many macro-scale systems currently in production. Furthermore it creates new functionality and system capabilities in the area of sensing, biology, environmental instrumentation, robotics, engine control, and guidance to name a few [1]. From a fundamental point of view, non-ideal process induced variations introduced during the fabrication of MEMS devices have a significant impact on experimental and theoretical analysis of thermo-mechanical material properties. Theoretical modeling of these devices is further complicated by the fact that the physical properties of thin layers can vary markedly from their bulk crystalline counterparts and can further vary based on any one of a number of deposition parameters. While much progress has been made in the development and fabrication of MEMS-based devices, the ability to accurately model and predict their properties has not been as rapid.

The current work deals with the analysis of multi-layered MEMS structures deposited using standard micro-machining techniques on single crystal silicon substrates. This is followed by the subsequent use of wet / dry etch technologies. The ability to accurately model and control both the depositions and subsequent etches is a serious challenge for the application of fundamental theory. One of the most daunting tasks, from both a theoretical as well as processing point of view, is the ability to accurately measure residual stress in deposited layers and predict their effect on mechanical systems. If these residual stresses are not taken into account this can cause an increased loss in tolerance, alter geometry-dependant design parameters such as stiffness and vibrational modes, and can adversely affect the operation of micro-optical devices. In order to maximize performance of many MEMS-based devices including micro-photonics, optically flat surfaces are required. Distortion or warping of these devices, due to residual stress, must be mitigated. High residual stresses can also lead to premature breakdown of MEMS devices. It is desired to understand the nature of this stress, the role geometry plays in the manifestation of the stress, and the relationship between stress and the deposition parameters in order to allow tailoring of the residual stress field.

In general, micro-dynamical systems are multi-layered structures consisting of materials that can have markedly different physical properties. In the analysis and characterization of residual stress between layers, the mismatch in thermal expansion coefficient plays a dominant role. The residual stresses may be caused by thermal expansion mismatch between dissimilar materials or non-equilibrium conditions introduced during the deposition on a substrate. The finite element method has been widely used by engineers to build models to estimate the stresses of structures. The use of the method for multi-layered structures traditionally come up against the problem of changing geometry of the structure from one processing step to another as material layers are added or removed. Furthermore, in structures subjected to thermal cycling, a common assumption involves existence of a certain temperature when the structure is in a stress-free state and then estimating the stresses generated when the temperature is decreased to room value. The assumption is obviously not correct if each layer of material is deposited at a different temperature [2,3] Different numerical approaches have been put forward to overcome modeling difficulties. However, this problem needs further consideration, especially from the point of view of development of algorithms with simplicity and flexibility needed by today engineers.

The present investigation is devoted to the finite element modeling of stress build up during processing of multi-layered micro-dynamical devices. Modeling is performed with the commercial software package Mark-Mentat. Mechanical properties of materials during modeling are assumed to be elastic. In the current modeling, only the final composite structure is considered. However, in order to imitate the thermal cycling that occurs during deposition or etching of layers, elastic time-dependant material parameters are utilized. Development of this model gives a means to predict the distortion of multi-layered devices due to residual stresses.

Particular attention has been given to optimization of the structure to prevent considerable accumulation of residual stresses. Wide ranges of membrane structures with different ratios of flexural rigidity and in-plane stiffness have been considered. Structures with minimum thermal distortion have been selected.

As an illustration, results of an initial thermal distortion calculation for a particular multi-layered MEMS structure are given in Fig.1. The two pictures of Fig.1 demonstrate undistorted and thermally distorted shapes of the structure respectively. The analyzed structure consists of alternate layers of Si_3N_4 and silica glass. Due to the difference in thermal expansion coefficients between the silicon nitride and silica glass [4], considerable distortion of the structure is predicted. In the modeling, two different temperature-dependant depositions, one each for the Si_3N_4 and silica glass, were incorporated.

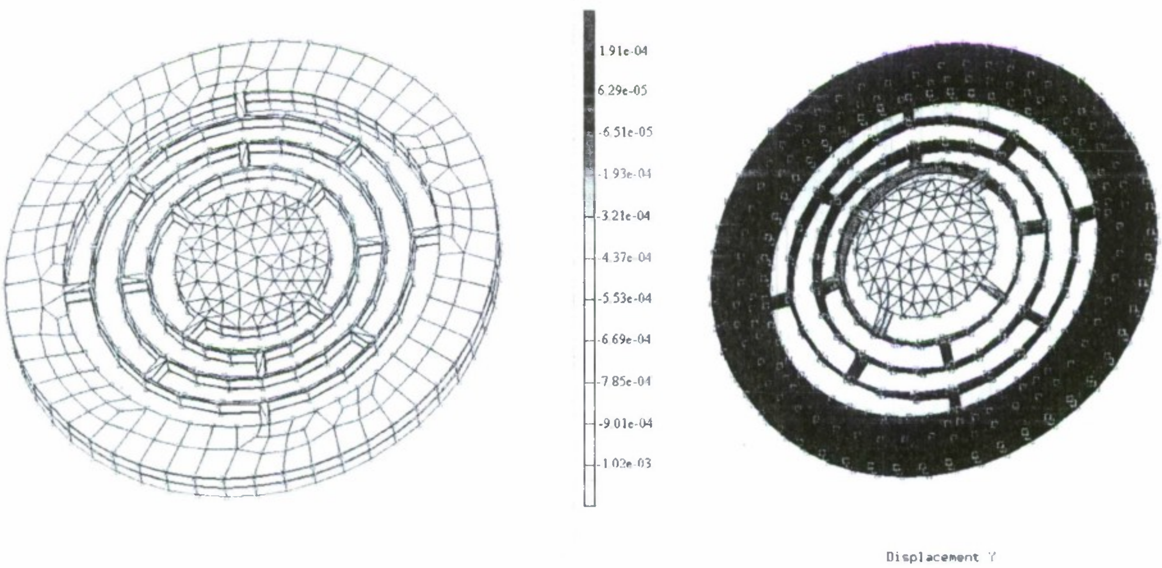

Fig.1 Undistorted and distorted shapes of multi-layer structure

References

1. R.S. Muller, MEMS: Quo Vadis in Century XXI, Microelectronic engineering, 53 (2000), 47-54.
2. A.O. Cifuentes, I.A. Shareef, Modeling of multivel structures: a general method for analyzing stress evolution during processing, IEEE Transaction on Semiconductor Manufacturing 5 (1992), 128-138.
3. P. M. Igic, P. A. Mawby, An advanced finite element strategy for thermal stress field investigation in aluminium interconnections during processing of very large scale integration multilevel structures, Microelectronic Journal 30 (1999), 1207-1212.
4. A. Kwatera, A. Sawka, Preparation of amorphous composites of silicon nitride and carbon layers on silica glass by chemical vapor deposition method, J. Non-Cryst.Solids 265 (2000), 120-124.