Inelastic deformation of bilayer microcantilevers with nanoscale coating

I.-Kuan Lin, Xin Zhang, Yanhang Zhang

Abstract

The application and commercialization of microelectromechanical system (MEMS) devices suffer from reliability problems due to the structural inelastic deformation during device operation. Nano coatings have been demonstrated to be promising solutions for suppressing creep and stress relaxation in bilayer MEMS devices. However, the micro/nano-mechanics within and/or between microcantilevers and coatings are not fully understood, especially when temperature, time, and geometric and material nonlinearities play significant roles in the thermomechanical responses. In this study, the thermomechanical behavior of alumina-coated/uncoated Au/SiN$_x$ bilayer microcantilevers was characterized by using thermal cycling and isothermal holding tests. Finite element analysis with power-law creep was used to simulate the mechanical behavior of microcantilevers during isothermal holding. To better understand the stress evolution and the mechanism of inelastic deformation, scanning electron microscopy and atomic force microscopy was employed to explore the grain growth and grain boundary grooving after isothermal holding at various temperatures of 100°C, 150°C, and 200°C. The methods and results presented in this paper are useful for the fundamental understanding of many similar bilayer microcantilever-based MEMS devices.

Keywords: Inelastic deformation, Bilayer microcantilever, Nanocoating, Thermomechanical deformation, Isothermal holding, Finite element analysis

1. Introduction

Bending of bilayer microcantilevers is widely employed in MEMS for a variety of sensor and actuator applications. The bilayer microcantilever sensors including infrared (IR) detectors [1], thermal detectors [2] and calorimetric high frequency detectors [3] rely on the thermal expansion mismatch induced deformation upon energy absorption. Subsequently, the deformation can be readily determined by means of piezoresistive, optical or capacitive methods [4–6]. On the other hand, the bending of bilayer microcantilever-based actuators can be controlled by applying a temperature change. Such actuators have been commonly used in DC electrical relays and contacts [7], radio frequency (RF) switches [8], and tunable split ring resonators (SRRs) [9]. In order to meet sensitivity and movement requirements, as well as maintaining MEMS and IC process compatibility, the bilayer microcantilever-based sensors and actuators must: (1) have a large thermal expansion mismatch between two layers; (2) be able to operate in wide temperature range; and (3) have good MEMS and IC process compatibility, so that bilayer microcantilever-based sensors and actuators have the potential of commercialization. To satisfy these requirements, one layer is typically made of metal (Au, Ni, Al… etc.) and the other layer is made of ceramic (Si$_N$$_x$, SiO$_x$, poly Si… etc.) which has a much lower thermal expansion coefficient than metal [10].

From the design viewpoint, the ideal bilayer microcantilevers will deform proportionally to temperature change and do not exhibit inelastic deformation over the operation period. However, the metal layers are typically not stable after deposition [11–13]. When subjected to thermal loading, the microstructural evolution in metal layers can be triggered, such as extinction of excess vacancies, subgrain coalescence and grooving [14–18]. The microstructural evolution results in inelastic strain behavior in metal layers and thus highly inelastic deformation in bilayer microcantilevers. Neglecting the inelastic deformation can result in misinterpretations of the measurement data from bilayer microcantilever-based sensors and can compromise control precision of actuators. Hence, it is of vital importance to perform accurate thermomechanical behavioral characterization on bilayer microcantilevers and to develop an appropriate model for the description of its time-dependent inelastic deformation.
Fig. 1. Fabrication process of the Au/SiNx bilayer microcantilever beams with nanocoating: (a) deposition of 1.5 μm thick SiOx and etching of SiOx by RIE with SF6, (b) deposition of a 1.15 μm thick PECVD SiNx layer and a 0.5 μm thick e-beam evaporated Au layer, and patterning of Au and SiNx layers using KI and RIE with SF6 and He, respectively, (c) releasing of the microcantilever beams by isotropic etching of SiOx with BOE and then drying by supercritical CO2 release system and (d) nanocoating of alumina by ALD.

In order to address the aforementioned needs, we studied the thermomechanical deformation of Au/SiNx microcantilever beams with combined effects of geometric and material nonlinearities. These behaviors need to be fully understood in order to properly design, characterize and manufacture reliable MEMS structures and devices. Previous studies indicate that not only geometric nonlinearity (large deformation) can be of importance when multilayer thin film microstructures are subjected to thermal loading, but the material nonlinearity (creep, stress relaxation...) and the interaction between these two are also of equal importance in MEMS applications [11–14,17,18]. Following the same scope, we used Au/SiNx microcantilever beams to explore the combined effect of geometric and material nonlinearity which resulted in more complex behaviors. We demonstrated that the time-dependent inelastic deformation can be suppressed by the use of nano-coatings realized by atomic layer deposition (ALD). Our study suggested that the nanoscale coating causes alternation of the stress state in the metal layer and a change in the fundamental inelastic deformation mechanisms.

In this present work, we performed a rational analysis/characterization of thermomechanical deformation on coated Au/SiNx microcantilevers, and used finite element analysis (FEA) with power-law creep to describe the inelastic deformation of the microcantilevers over a significant period of time. Section 2 describes the fabrication of the bilayer and alumina coated microcantilever beams. Interferometric microscopy was employed to in situ measure the deformation of microcantilever beam subjected to thermal loading. Finite element analysis procedure is presented in Section 3. Section 4 describes the thermomechanical evolution and the modeling results of the deformation of microcantilever beams during thermal cycling and isothermal holding. Finally Section 5 discusses and correlates the microstructural evolution from scanning electron microscopy (SEM) and atomic force microscopy (AFM) studies to the observed thermomechanical deformation during isothermal holding on both uncoated and coated microcantilever beams.

2. Sample preparation and measurements

The bilayer and alumina coated Au/SiNx bilayer microcantilever beams were fabricated following the process flow in Fig. 1. The testing structures consisted of 6 Au/SiNx bilayer microcantilever beams with a 40 μm width and lengths ranging from 60 μm to 360 μm with 60 μm increments. In this study, results from the beam with a 180 μm length were presented. Fig. 2 shows one of the beam arrays, where a 0.5 μm gold layer was grown on top of a 1.15 μm SiNx layer using surface micromachining techniques with SiOx as the sacrificial layer.

Before fabrication, Piranha solution (H2SO4:H2O2 = 3:1) and 40% hydrofluoric acid solution were used to clean the native oxides and organic residues from the (100) silicon wafer, respectively. The first step of the fabrication was to deposit a 1.5 μm thick SiOx film as a sacrificial layer using plasma enhanced chemical vapor deposition (PECVD) (PECVD Multiplex, STS Inc.). The SiOx layer was then patterned using reactive ion etching (RIE) (790, Plasma-Therm LLC.) with SF6 gasses to create anchors for the micro-

Fig. 2. SEM image of an array of Au (0.5 μm thick)/SiNx (1.15 μm thick) microcantilever beams suspended over a silicon substrate.
cantilever beams, as shown in Fig. 1(a). Following the etching processes, a 1.15 μm-thick SiN\textsubscript{x} layer and 0.5 μm-thick Au layer with a 5 nm Cr adhesion layer were deposited on top of the SiO\textsubscript{2} layer in series using PECVD and an E-beam thermal evaporator (Auto 306 R&D, BOC Edwards Limited). To make the bilayer cantilevers, the Au/SiN\textsubscript{x} bilayer was patterned using potassium iodide solution (KI) and RIE with SF\textsubscript{6} and He, respectively, as shown in Fig. 1(b). Subsequently, the specimen containing sets of Au/SiN\textsubscript{x} bilayer microcantilevers was immersed in the buffered oxide etcher (BOE) for 30 min to remove the sacrificial SiO\textsubscript{2} layer. In order to prevent the microcantilever beams from sticking to the substrate, the specimen was immersed in methanol after BOE etching and then dried with a supercritical CO\textsubscript{2} release system, as shown in Fig. 1(c). One group of the Au/SiN\textsubscript{x} bilayer microcantilever beams were used to investigate their thermal mechanical characteristics including temperature and time-dependent deformation. Another group of the specimens were coated with alumina (Al\textsubscript{2}O\textsubscript{3}) using ALD technique (Savannah S100, Cambridge NanoTech Inc.), as shown in Fig. 1(d). The trimethyl aluminum (Al(CH\textsubscript{3})\textsubscript{3}; TMA) and water (H\textsubscript{2}O) were used in ALD as two reactants under a pressure of 0.93 Torr at 100 °C [19,20]. By repeating this bilayer reaction sequence cycle, a linear, atomic-layer-controlled alumina growth was produced. The microcantilever beams were coated with 5 nm, 10 nm, 20 nm, and 40 nm alumina layers resulting from 6, 12, 23, and 45 cycles, respectively.

A scanning white light interferometer (WYKO, Veeco Instruments) equipped with a thermal system (HCP302-STC200, Instec Inc.) was used to measure the thermomechanical deformation of the microcantilever beams. The system consists of a custom-made heating/cooling stage and a close-loop heating/cooling controller with 0.1 °C temperature stability. The full-field out-of-plane deformation of the microcantilever beams was measured in situ using a 10× objective yielding a resolution of about 100 nm [21]. The curvature along the length of the microcantilever beams was determined by fitting the topography profile with a second-order polynomial and taking the second derivative of the polynomial fit. The overall thermomechanical response was represented using calculated curvatures at each temperature.

To understand the mechanisms of microstructural evolution for the observed curvature changes, a series of material characteristics on the thermo-mechanically loaded microcantilever beams were performed. The surface profile of the microcantilever beams before and after isothermal holding was measured using SEM (SUPRA 40VP, Zeiss Inc.) and AFM (Dimension 3100, Digital Instruments Inc.). The SEM operated at a working distance of 6 mm with 10 keV using an in-lens detector for high-resolution top-view imaging. The surface roughness on a 3 μm × 3 μm area of the Au surface was obtained by AFM with a silicon tip (Tap300DLC, Innovative Solutions Bulgaria Ltd.) in tapping mode.

3. Finite element analysis

Finite element analysis with power-law creep in the Au layer was employed to simulate the inelastic deformation during isothermal holding [22–24]. SiN\textsubscript{x} is assumed to be relatively stable due to the relatively higher melting temperature (1900 °C) and creep resistance compared to Au [17,18]. Hence, assuming the SiN\textsubscript{x} deforms elastically and the inelastic deformation mechanism described by power-law creep in the Au layer, the inelastic deformation during isothermal holding was characterized by curvature evolution as a function of time. The power-law can be expressed as [22–24]:

\[ \dot{\epsilon} = A\epsilon^n \]  

where A and n are material parameters. To determine these parameters, results from FEA were fit to the experimental data. Commercial finite element software ABAQUS v.6.7 was used to perform the simulation [25]. Composite shell elements (S4R) were used with a mesh consisting of 18,041 nodes and 3600 elements. Fixed boundary conditions were applied to one end of the beam. Residual stress in each layer was not considered in this model. The model of alumina-coated microcantilever beams consisted of 4 layers, including alumina, SiN\textsubscript{x}, Au and alumina from the bottom to top layer, where the Young’s modulus and Poisson ratio of alumina are 203 GPa and 0.24, respectively [26]. The rest of the input parameters are \( t_{Au} = 500 \text{ nm}, t_{SiN_x} = 1150 \text{ nm}, E_{Au} = 78 \text{ GPa}, E_{SiN_x} = 148 \text{ GPa}, \sigma_{Au} = 14 \times 10^{-6} \text{ K}^{-1}, \sigma_{SiN_x} = 2 \times 10^{-6} \text{ K}^{-1}, v_{Au} = 0.4, v_{SiN_x} = 0.2 \), where t is the thickness of the material; E, \( \sigma \), and \( v \) represent the Young’s modulus, coefficient of thermal expansion, and Poisson’s ratio, respectively [10]. To model the experimental procedure, a uniform temperature change was first applied to simulate the thermomechanical deformation due to temperature change, followed by isothermal holding at temperatures of 100 °C, 150 °C, and 200 °C for 60 h.

4. Results

4.1. Thermal cycling

We first characterized the temperature-dependent deformation of the microcantilever beams during heating and cooling cycles. In each thermal cycle, bilayer microcantilever beams were heated from room temperature (25 °C) to specified maximum temperatures and then cooled back down to room temperature. As shown in Fig. 3(a), the bilayer microcantilever beams have an initial curvature in their as-released state due to the residual stress in Au and SiN\textsubscript{x} layers. During the heating process in the first cycle, the curvature decreases linearly with a constant \( d/C = -0.0081 \text{ mm}^{-1} / °C \) from room temperature to 100 °C. When the temperature continued to rise, the curvature changed at a much smaller \( d/C \). Similar behavior has been observed in other studies and was attributed to the onset of inelastic deformation [12,27,28]. This inelastic deformation continued until the maximum temperature (125 °C) was reached in the first cycle. During this region, the temperature-induced microstructural change in Au occurs as grain boundaries consolidate and other defects are removed, resulting in tensile straining of the Au film [12,17,18]. Upon cooling from the maximum temperature (125 °C) to room temperature in the first cycle, the curvature increased linearly again throughout the whole process. The slopes of curvature change during both heating and cooling were approximately the same. After returning to room temperature, the curvature of the microcantilever beams was found to be larger than that prior to the cycle.

The microcantilevers were heated and subsequently cooled for three more cycles with 150 °C, 175 °C and 200 °C as the peak temperatures. The deformation behavior manifested by thermoelastic and inelastic regions exhibit in each thermal cycle are similar and the subsequent room temperature curvature increase after each cycle. The thermomechanical evolution of 10 nm alumina-coated microcantilever beams is similar to the uncoated microcantilever beams, as shown in Fig. 3(b). The presence of alumina layer slightly changes the thermoelastic slope \( d/C \) to \(-0.0072 \text{ mm}^{-1} / °C \). From the design perspective, a desired linear curvature–temperature relation can be achieved by thermal cycling the microcantilever beams to room temperature and a specific maximum temperature. For repeated cycles below this maximum temperature, linear thermoelastic behavior occurs throughout the entire cycle. Linear curvature–temperature relation allows for enhanced reliability during operation and can be predicted analytically. Interested

Fig. 3. Curvature of (a) Au/SiNx microcantilever beams and (b) ALD alumina coated microcantilever beams as a function of temperature during four thermal cycles with peak temperatures of 125 °C, 150 °C, 175 °C, and 200 °C. The triangle and circle symbols are measured curvatures during the heating and cooling process in each cycle, respectively.

Fig. 4. Curvature evolution during the 60 h isothermal holding at 100 °C, 150 °C and 200 °C for Au/SiNx microcantilever beams. The symbols represent experimental data while the solid lines represent simulation results.

Fig. 4 shows that the curvature decreases as time elapsed during isothermal holding at 100 °C, 150 °C, 200 °C. After the isothermal holding at 100 °C, 150 °C and 200 °C for 60 h, the curvature decreased by 2.7%, 14% and 25%, respectively.

The experimental procedure of isothermal holding test on alumina-coated microcantilever beams is the same as uncoated microcantilever beams. These beams were subjected to three pre-thermal cycles between room temperature and 150 °C and then held at 150 °C for 60 h. Fig. 5 depicts the curvature of the microcantilever beams coated with 5 nm, 10 nm, 20 nm and 40 nm alumina decreasing by 11.2%, 6.4%, 5.6% and 4.4%, respectively, from the initial curvature over the holding period of 60 h. Fig. 5 also reveals the suppression capability of alumina nanocoatings as a function of thickness. The magnitude of the curvature evolution during isothermal holding decreases as the thickness of the alumina nanocoating layer increases from 5 to 40 nm. Our results suggest that thicker alumina coating provides higher constraint force that prevents the inelastic deformation in the Au layer. Compared with the uncoated...
beams held at 150 °C, the 40 nm alumina coating significantly reduces the inelastic deformation from 14% to less than 4.4%.

4.3. Finite element analysis

FEA with power-law creep were used to simulate the inelastic deformation behavior of Au/SiN x microcantilever beams during isothermal holding. By using a constant \( n = 5 \) and different \( A \) values \((A = 0.8 \times 10^{-15} \text{ h}^{-1} \text{ MPa}^{-3}, 5.2 \times 10^{-15} \text{ h}^{-1} \text{ MPa}^{-5}, \) and \( 8 \times 10^{-15} \text{ h}^{-1} \text{ MPa}^{-5} \) for 100 °C, 150 °C and 200 °C, respectively), the inelastic deformation behavior during isothermal holding was described well (Fig. 4). An associated finite element model was also constructed to simulate the inelastic deformation of alumina-coated microcantilever beams held at 150 °C for 60 h. The material parameters in the power-law creep model of Au obtained from the isothermal holding on uncoated microcantilever beams (i.e., \( \dot{\varepsilon} = 5.2 \times 10^{-15} \sigma^2 \)) was incorporated into the finite element model. Although not shown here, the FEA simulation shows a decrease in the curvature change with temperature, but nowhere near the magnitude of that observed. This suggests that the presence of the alumina coating layer not only alters the stress state in the Au layer but also the fundamental deformation mechanisms. This phenomenon has also been reported previously [15,16,29]. This implies that the material parameters of the power-law creep obtained from the uncoated microcantilever beams cannot be used to model the inelastic behavior of Au for alumina-coated microcantilever beams. It is possible that the presence of alumina coating layer alters the mechanism of inelastic deformation and the microstructural evolution in the Au layer. Material parameter \( A \) in power-law is highly dependent on activation energy, material type, and the particular creep mechanism. It is usually determined experimentally. Hence, we re-characterized and modified the material parameters in the power-law by fitting FEA results to the experimental data of the alumina-coated microcantilever beams. Again, the appropriate power-law of Au (constant \( n = 5 \); \( A = 3.5 \times 10^{-15} \text{ h}^{-1} \text{ MPa}^{-5}, 1.6 \times 10^{-15} \text{ h}^{-1} \text{ MPa}^{-5}, 1.1 \times 10^{-15} \text{ h}^{-1} \text{ MPa}^{-5}, \) and \( 0.6 \times 10^{-15} \text{ h}^{-1} \text{ MPa}^{-5} \) for 5 nm, 10 nm, 20 nm and 40 nm alumina-coated microcantilever beams, respectively) for alumina-coated microcantilever beams was obtained. Fig. 5 shows the comparison between the FEA simulation with a modified power-law and the experimental results. It can be seen that reasonable agreement was obtained between the experimental data and simulation results.

Fig. 6 shows the stress distribution through the thickness of the uncoated microcantilever beam at 0, 10, 20, 40 and 60 h of the isothermal holding period with holding temperatures of 100, 150, and 200 °C. At \( t = 0 \), the stress gradient exists across both the Au and SiN x layer. During isothermal holding, majority of the tensile stress relieves in the Au layer. After 40 h of isothermal holding, stress is almost uniform through the thickness of the gold layer and stress change in both layers are very small afterwards. Fig. 7 shows the stress distribution through the thickness of the 10 nm alumina coated microcantilever beam at 150 °C holding temperature. Compared with Fig. 6(b), the tensile stress in the Au layer does not change significantly due to the presence of the nanocoating layer. FEA results of stress evolution allow us to further understand the inelastic deformation suppression of alumina-coated microcantilever beams (Fig. 5).

Although the results showed the feasibility of current FEA approach, further material characterization and sophisticated modeling are necessary to improve the power-law and the prediction of inelastic deformation. For example, Eq. (1) could be further extended as: \( \dot{\varepsilon} = C \varepsilon^n \frac{Q}{kT} \sigma^p \), where \( C \) is the creep constant dependent on the material and the particular creep mechanism, \( k \) is the Boltzmann constant, \( n \) is the stress exponent, \( Q \) is the activation energy for creep, and \( T \) is the absolute temperature [24,30]. With the extended power-law model above, the temperature effects on the curvature evolution of microcantilevers might be predicted. However, we suspect that the extended power law developed from the uncoated beam structures still cannot be applied directly to the coated beam structures as the activation energy might be different for the coated and uncoated beams. Re-characterization will still be a necessary step for the coated microcantilevers.
5. Discussion

The inelastic deformation of uncoated and coated microcantilever beams during isothermal holding may be due to the volumetric change in the Au layer [14,16,31]. It is commonly accepted that the tensile stress in the metal layer is generated by volumetric reduction such as recovery, grain growth, recrystallization [32], surface texture consolidation [33], and hillocking [34]. On the other hand, the compressive stress in the metal layer is generated by volumetric addition such as grain boundary grooving [35], grain boundary separation [36], diffusion of a foreign chemical species, precipitation, and chemical reaction [37].

Table 1

<table>
<thead>
<tr>
<th>Temperature</th>
<th>RMS roughness (nm)</th>
<th>Average roughness (nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>As-released</td>
<td>4.92</td>
<td>4.01</td>
</tr>
<tr>
<td>100 °C</td>
<td>4.95</td>
<td>4.02</td>
</tr>
<tr>
<td>150 °C</td>
<td>5.896</td>
<td>4.64</td>
</tr>
<tr>
<td>200 °C</td>
<td>6.159</td>
<td>4.84</td>
</tr>
</tbody>
</table>

The inelastic deformation occurred at high temperature regions of the three pre-thermal cycles may due to recovery and grain growth. The microstructure of the evaporated Au layer was not stable in the as-deposited condition and the increased temperature promoted Au subgrains to coalesce [12,32]. This temperature-induced microstructural evolution is typically a volumetric reduction process which will result in an increased tensile stress in the Au layer. The generated tensile stress competes with the compressive stress due to thermoelastic deformation and thus results in a much smaller $d/dT$ in the inelastic regime than in the thermoelastic regime (Fig. 3).

After isothermal holding, both grain growth and growth of grooves were found on Au layer. SEM was employed to measure the surface morphology of Au layer as shown in Fig. 8. Initially, the Au surface is relatively smooth in the as-released beams at room temperature as shown in Fig. 8(a). For the microcantilever beam held at an isothermal holding temperature of 100 °C in Fig. 8(b), the grain size and grain grooving of Au surfaces were slightly increased compared with the as-released microcantilever beams. After 150 °C and 200 °C isothermal holdings, the grain size and groove size were significantly increased and morphology was rougher as shown in Fig. 8(c) and (d). The grooving process usually companions with diffusion and oxidation of Si [14,16]. The grain grooving, diffusion and oxidation are typically volumetrically addition processes, which result in increased compressive stresses in the Au layer [16].

![Fig. 7. Stress distribution through nanocoating layer, Au and SiN layers of 10 nm alumina coated microcantilever beams for 0, 10, 20, 40 and 60 h duration in isothermal holding at 150 °C.](image1)

![Fig. 8. SEM images of surface morphology of microcantilever beams (a) before and after 60 h isothermal holding at (b) 100 °C, (c) 150 °C and (d) 200 °C.](image2)
mean roughness ($R_a$) and mean square roughness ($R_q$) of the Au layer from AFM measurements are shown in Table 1. The roughness of the Au surface is 0.2%, 15.7%, and 20.7% at holding temperatures of 100 °C, 150 °C, and 200 °C, respectively. The grain growth process results in tensile stress generation in Au layer [38,39]. The net stress from both grain growth and grooving alters the stress distribution through the bilayer beam. In our study, we found the curvature decreased during isothermal holding. This indicates that the net effect from grain growth and grooving results in compressive stresses. Furthermore, the degree of both the grain growth and grain grooving processes are highly dependent on holding temperature.

SEM was also employed to measure the morphology on the alumina-coated microcantilevers, as shown in Fig. 9. Although covered by alumina nanocoatings, the grain size and grain boundary in the Au layer can still be observed. After 60 h of isothermal holding at 150 °C, the morphology images do not show any significant difference between the 20 nm, and 40 nm alumina-coated microcantilever beams in Fig. 9(c) and (d), and the grain size are close to the Au layer on the as-released beams as shown in Fig. 8(a). For the 5 nm and 10 nm alumina-coated microcantilevers in Fig. 9(a) and (b), the grain size and grooving seem slightly increased, but nowhere near the magnitude of that observed on the uncoated microcantilever beams in Fig. 8(c). This suggests that the alumina nanocoating constrains the Au surface and suppresses the grain growth and grain grooving during the isothermal holding. Previous studies also found that diffusion and oxidation were suppressed by nanocoating of thick oxide layer [23,40]. In addition, thicker alumina coating layers are more effective in suppressing inelastic deformation during isothermal holding. Fig. 10 shows that the stress decrease in Au layer is inversely proportional to the thickness of alumina. The 5 nm, 10 nm, 20 nm and 40 nm alumina nanocoatings suppress the stress decrease in Au layer from 18% to 12%, 6.8%, 5.9%, and 3.9%, respectively, after 60-h isothermal holding at 150 °C. This further proves that the thicker alumina layer provides more constraint stress on the Au surface and more effectively suppresses the net volumetric change in Au from grain growth, grooving, diffusion and oxidation.

6. Conclusion

Understanding of the thermomechanical behavior of coated and uncoated microcantilevers, including temperature and time-dependent deformation, is critical to the achievement of robust and reliable MEMS structures and devices for the next generation. The present study forms a comprehensive methodology for the thermomechanical characterization of coated/uncoated bilayer microcantilevers to meet the performance and reliability requirements of MEMS devices, as well as a FEA model to
describe the inelastic deformation and stress evolution in such structures. Moreover, to better understand the stress evolution and alumina suppression mechanism, SEM and AFM were employed to explore the grain growth and grain boundary grooving after isothermal holding. Results from our study demonstrate that alumina nanocoating layer provides constraint forces on the Au surface and effectively suppresses the volumetric change in Au from grain growth and grain grooving during the isothermal holding. Such evidences are not reported in our previous study.

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References


Biographies

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a clear trajectory toward exemplary leadership career in all dimensions of science and engineering.

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