Principles for Forming and Characterizing Thin film Nanostructures for MEMS/NEMS

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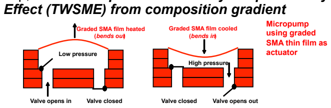
Graded SMA Thin Films

(NSF-DMR 0407517, PhD Student: Dr. Dan Cole)

Compositionally-graded Shape Memory Alloy (SMA) thin films are being developed and characterized to understand the relationship between:

Processing (•DC magnetron sputtering •Diffusion Modification) → **Structure** (•Composition •Crystal structure) → **Properties/Performance** (•Elastic modulus, Hardness •Recovery mechanisms)

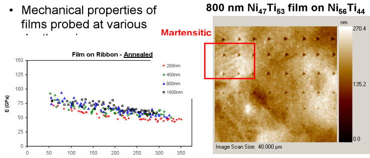
Application example: Graded SMA thin films can act as thermal actuators in MicroElectroMechanical Systems (MEMS), such as a micropump, due to the ***equivalent Two-way Shape Memory Effect (TWSME) from composition gradient***



Results: *Nanoindentation*

- Mechanical properties of films probed at various

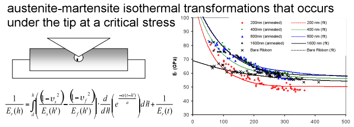
800 nm $Ni_{47}Ti_{53}$ film on $Ni_{56}Ti_{44}$



- Indentation response of graded SMA films also **predicted** using the following approach:

Classic diffusion solution for bi-material interface predicts initial composition gradient ⇨ Composition gradient used to predict the initial distribution of the Austenite-Martensite volume fraction throughout the film's thickness ⇨ Using Austenite/Martensite volume fraction and associated elastic properties, the initial elastic modulus predicted as a function of depth using a Rule-of-Mixtures assumption

- The model accounts for initial elastic distributions and austenite-martensite isothermal transformations that occurs under the tip at a critical stress

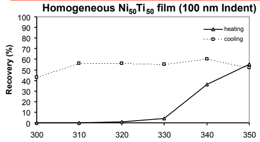


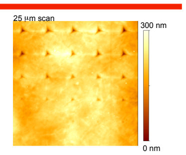
$$\frac{1}{E_r(h)} = \int_0^\infty \left[\frac{(1-\nu_i^2)}{E_i(h')} - \frac{(1-\nu_f^2)}{E_f(h')} \right] \frac{d}{dh'} \left(e^{-\frac{\alpha(t)h'}{a}} \right) dh' + \frac{1}{E_s(t)}$$

D. Cole, A. Roytburd, H. Bruck, *Journal of Applied Physics* (2008) and *Strain* (2009)

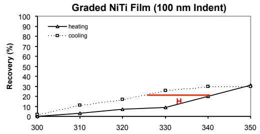
Results: *Characterizing Shape Memory Effect*

Homogeneous $Ni_{50}Ti_{50}$ film (100 nm Indent)





Graded NiTi Film (100 nm Indent)



$$R = \frac{h_i - h}{h_i}$$

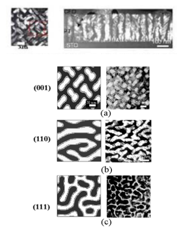
- Heights of nanoindents measured using AFM with *in situ* heating/cooling
- **Homogeneous films:** Abrupt transformations and **one-way effect**
- **Graded films:** Gradual transformations, reduced hysteresis (~15 K) and **two-way effect**

D. Cole, H. Jin, W. Lu, A. Roytburd, H. Bruck, *Applied Physics Letters* (2009)

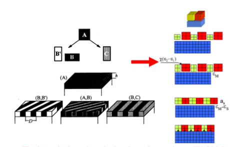
Principles for Formation of Transversely Modulated Heterophase Nanostructures

(NSF-DMR 0907122, PhD Student: Brad Boyerinas)

To impact the development of nanostructured devices, such as optoelectronics to modulate electrical or optical signals to increase bandwidth for information processing and storage capacity, we are creating *transversely modulated nanostructures* (TMNS) along heterophase interfaces.



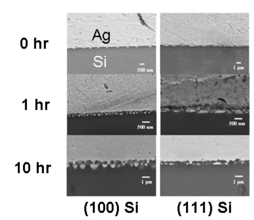
Experimental (right side and top) and Phase Field Modeling (left side) of Epitaxial formation of TMNS in $0.33CoFe_2O_4$-$0.67PbTiO_3$

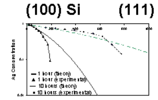


Epitaxial principle for forming TMNS

TMNS are formed epitaxially from elastic strain accommodation between two or more phases in a film on a single crystal substrate. Elastic domains in an epitaxial film can be: (1) differently oriented domain of the same phase (twins), (2) domains of the parent and product phases, and (3) domains of structurally different product phases

Epitaxial Control of TMNS in Ag-SI





(top) SEM cross-section of epitaxial TMNS in Ag/Si showing control of size, spacing, and morphology of nanostructures along heterophase interfaces through substrate orientation and time of heat treatment, (bottom) measured and predicted concentration distributions

B. Boyerinas, J. Balsam, A.L. Roytburd, and H.A. Bruck, *to be submitted* (2010)

Fabrication and Detection Principles for Lab-on-a-Chip Biosensors

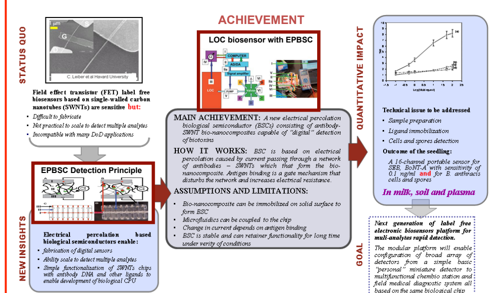
(FDA-CDRH, PhD Student: Josh Balsam)

Motivation:
In order to make biodetection portable, it is necessary to scale-down detection to fit on a Lab-on-a-Chip (LOC) platform. This is a challenge, since many existing components in detection systems systems do not scale (e.g., lenses in optical detection systems). Therefore, new detection principles and methods for fabricating them that are compatible with LOC biosensors are necessary.

Approach:
We have two different approaches we are pursuing to overcome this challenge:

1. New detection principles: *Electrical Percolation Biological Semiconductors for Label-free Detection*
2. New detection components: *Lens-free Optical Sensing*

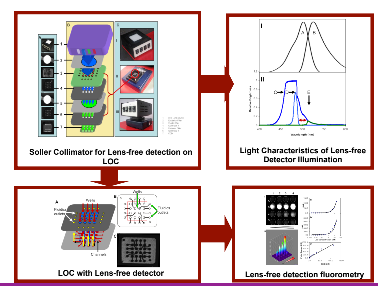
Electrical Percolation Biological Semiconductors for Label-free Detection



Creating the next generation of label free biosensors based on electronic biological semiconductor

M.H. Yang, H.A. Bruck, Y Kostov, A. Rasooly, *Analytical Chemistry* (2009) and *Lab on a Chip* (2010)

Lens-free Optical Sensing



Can achieve similar level of detection on LOC as in conventional plate reader