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Diffusion-based deformation in elevated temperature micropillar compression of Mg-Nb multilayers

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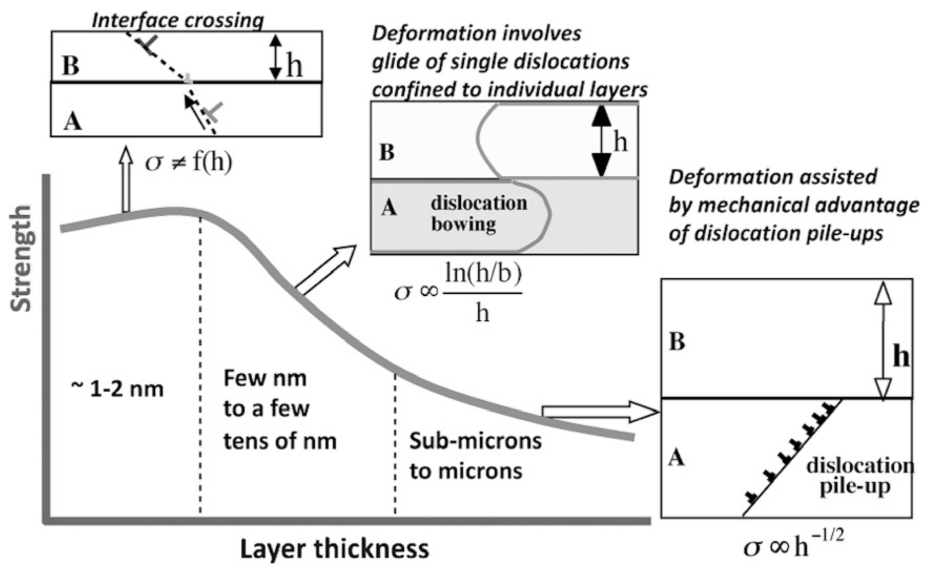
Background and Motivation

The mechanics of metallic multilayer thin films are regularly studied using periodic bilayers. While FCC and BCC material combinations have been studied extensively at room temperature, data at elevated temperatures and for HCP metals is scarce. In-situ micropillar compression at various temperatures and strain rates can be used to calculate both an activation energy and volume to gain insight into the dominant deformation mechanisms at work.



Mechanical Behavior of Metallic Nanolaminates - Amit Misra

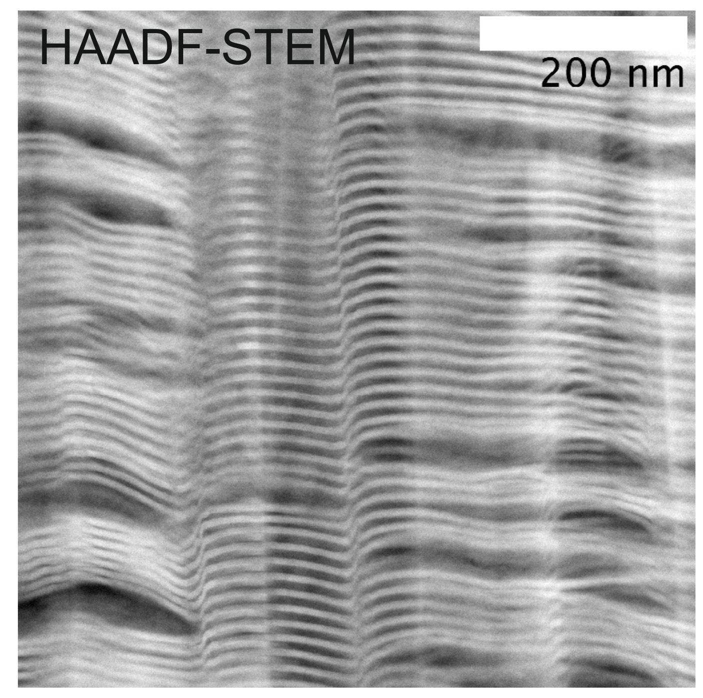
Experiment and Results

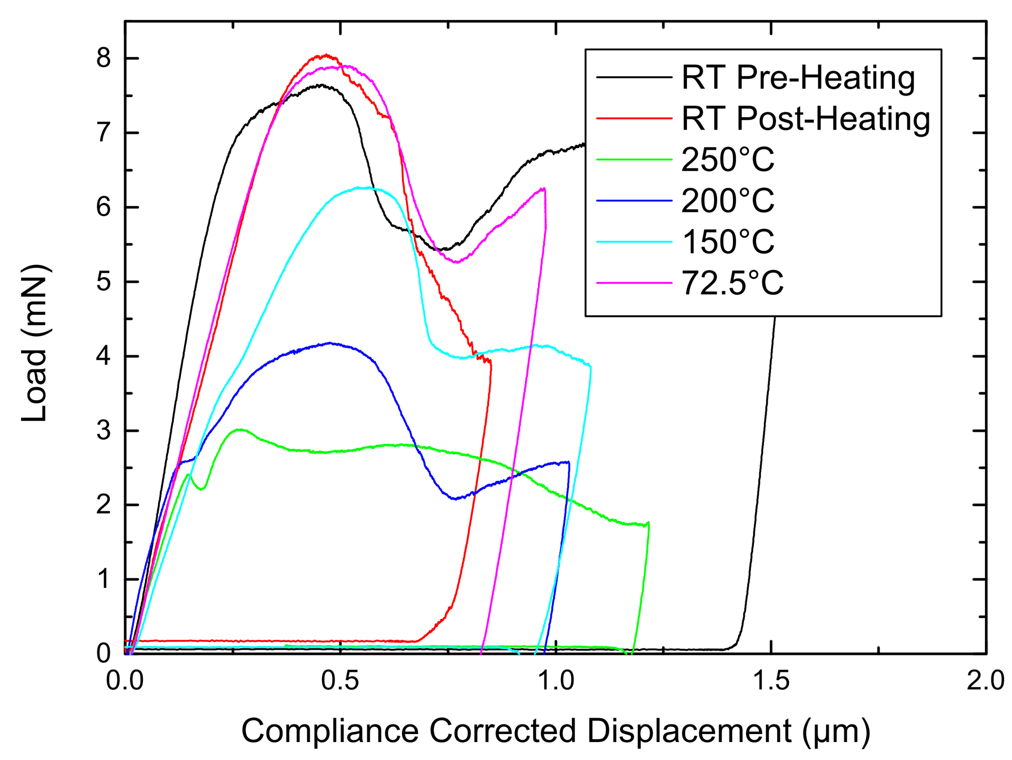
Multilayers of magnesium and niobium with periodicities of 10 and 100 nm were deposited on silicon substrates using magnetron sputtering. Micropillars were prepared in the films using a focused ion beam and compressed at five different temperatures and three different strain rates. At lower temperatures plastic deformation is isolated to the upper region of the micropillars due to higher stresses there from the pillar taper. At higher temperatures the magnesium layers throughout the pillar account for the vast majority of plastic deformation. Magnesium protuberances form on the surface of the micropillars and sometimes coalesce. At the highest temperatures whiskers with a hexagonal cross-section and up to several micrometers in length extend laterally from the micropillars.

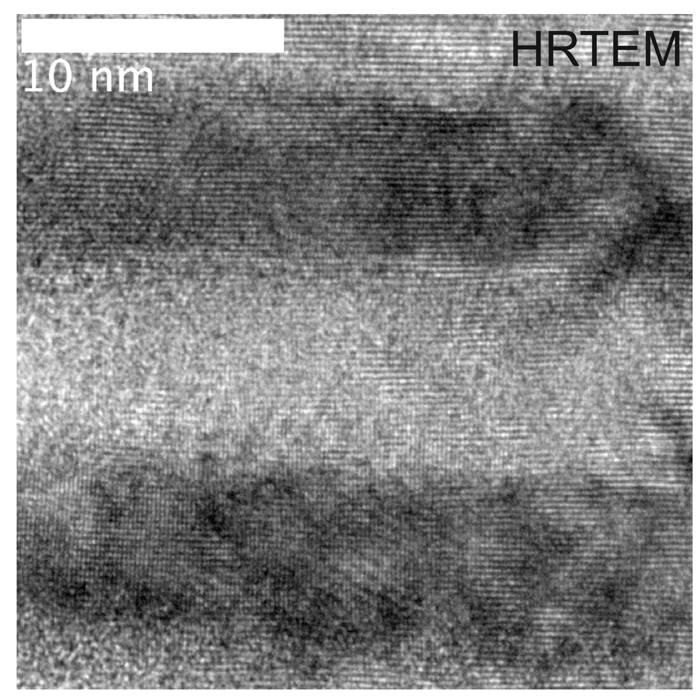
$$\log\sigma = \log\left\{\frac{1}{A^{(m)}}\right\} + m\log\dot{\varepsilon} + \left(\frac{mQ}{RT}\right)$$

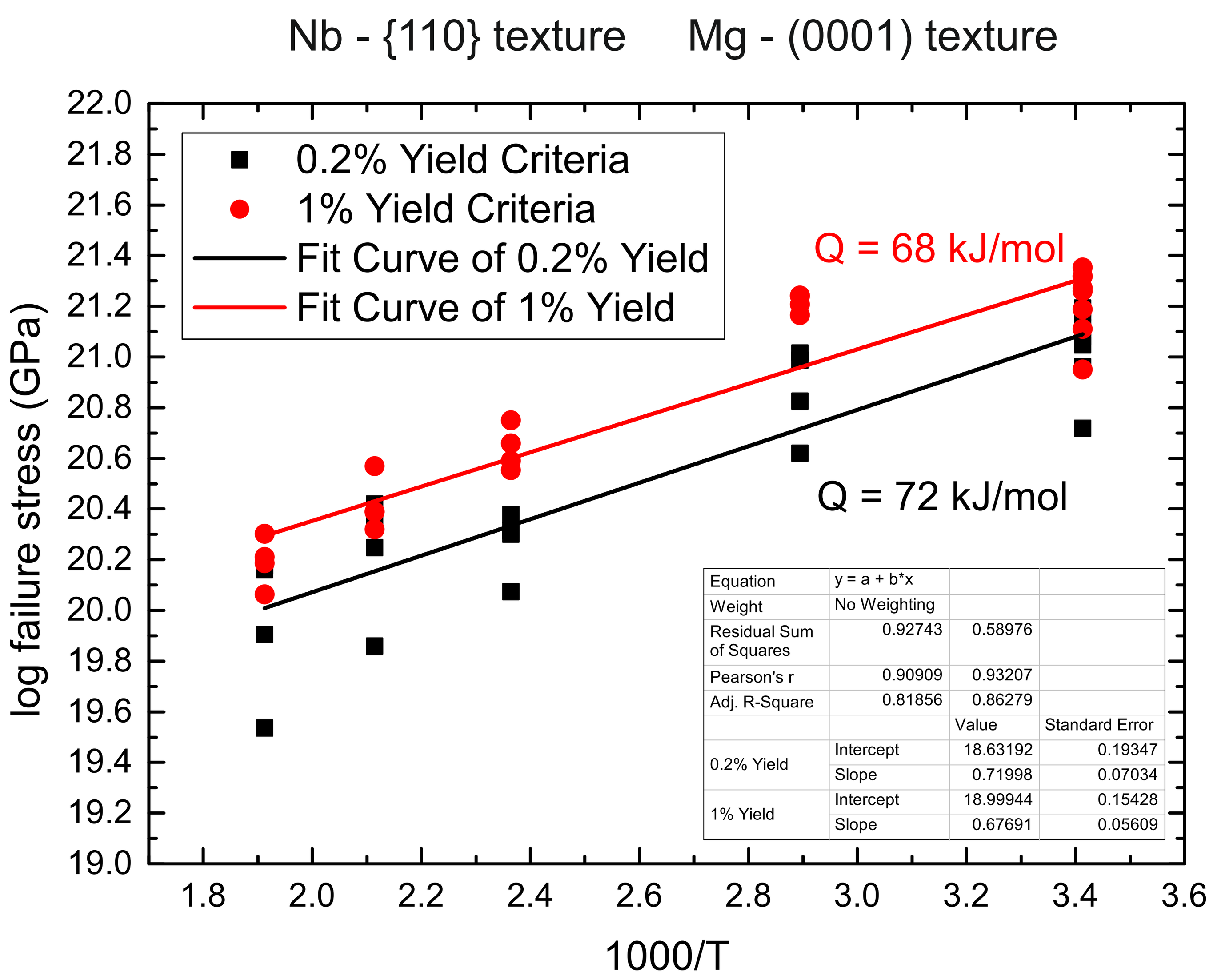
$$\sigma = \frac{1}{A^{(m)}}\dot{\varepsilon}^{(m)}\exp^{\left(\frac{mQ}{RT}\right)} \qquad \dot{\varepsilon}^{\left(\frac{1}{n}\right)} = A^{\left(\frac{1}{n}\right)}\sigma\exp^{\left(\frac{-Q}{nRT}\right)}$$

boundary diffusion: 92 kJ/mol
lattice diffusion: 134 kJ/mol
power-law creep: 230 kJ/mol
http://engineering.dartmouth.edu/defmech/

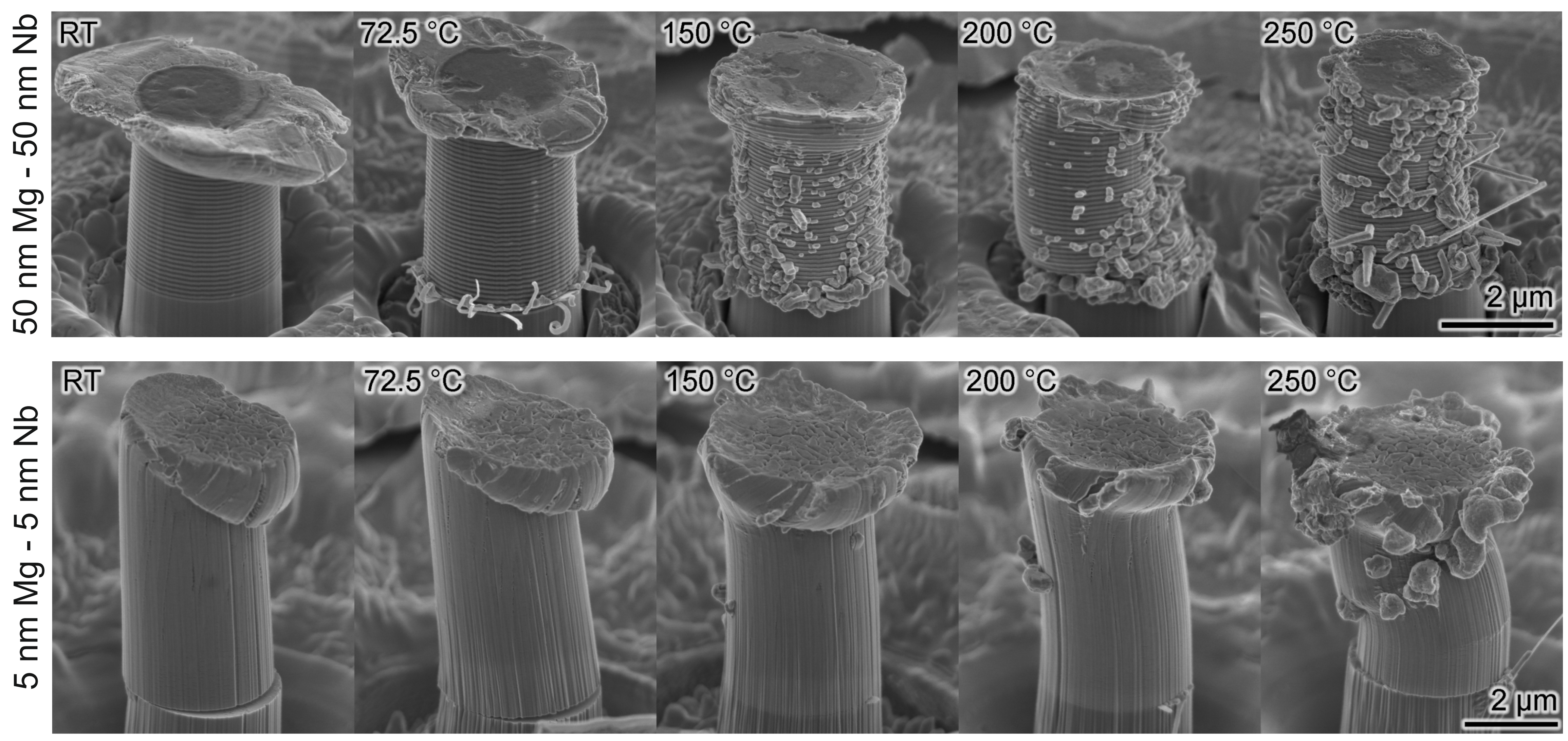








Equation	y = a + b*x		
Weight	No Weighting		
Residual Sum of Squares	0.92743	0.58976	
Pearson's r	0.90909	0.93207	
Adj. R-Square	0.81856	0.86279	
		Value	Standard Error
0.2% Yield	Intercept	18.63192	0.19347
	Slope	0.71998	0.07034
1% Yield	Intercept	18.99944	0.15428
	Slope	0.67691	0.05609



Conclusions and Future Outlook

Whisker and microparticle growth on the surface of pillars compressed at elevated temperatures provide strong evidence for a diffusion-based deformation mechanism. The activation energy of roughly 70 kJ/mol is well above literature values for dislocation-based deformation, but somewhat below that of lattice or grain boundary diffusion. It seems plausible that magnesium diffuses along the interfaces with niobium. Testing across a wider range of temperatures as well as strain rate jump tests are planned to more accurately determine the strain rate sensitivity exponent. More traditional creep testing is also under consideration.

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Swiss Federal Institute of Technology Zurich

SEVENTH FRAMEWORK PROGRAMME

MARIE CURIE ACTIONS

EMPA Materials Science & Technology

Los Alamos NATIONAL LABORATORY EST. 1943