Miniaturized Shape Memory (SMA) Bimorph Actuators with Polymer Layers

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Shape-memory alloy (SMA) actuators based on nickel-titanium (NiTi, or NITINOL) are promising candidates for miniaturized sensors and actuators in MEMS applications [1]. Thermal processing constraints currently limit monolithic SMA actuator integration for example in soft body micro robotics or onto soft polymer substrates. Other electronic materials can also degrade when exposed to typical NiTi crystallization temperatures in excess of 450 °C. Historically, NiTi crystallization requires sputter or anneal temperatures of 450 °C or more so there is a desire to obtain shape memory effects at lower processing temperatures.

To motivate the mating of polymer and crystallized NiTi SMA layers, we developed and carried out the microfabrication of a simple, yet novel, shape memory (SMA) bimorph actuator, outlined in Figure 1, and based on previous deposition and micromachining processes of NiTi on platinum [2, 3]. By following crystallized 270 nm NiTi SMA with a 1 micron photosensitive polymer layer, we created a bimorph with a large coefficient of thermal expansion (CTE) mismatch (>40 ppm/°C) allowing significant yet predictable curvature upon release. An analytical strain/curvature model [4] predicted the radius of curvature to within 10% as shown in Figure 2, and resulted in a measured radius of curvature down to 50 µm for an actuator that folded flat upon actuation.

The full benefits of combining SMA materials with polymers can only be realized without the constraint of high temperature crystallization coming before polymer deposition. To this end, we carried out experiments to investigate the crystallization of amorphous NiTi using a Novacentrix pulse forge additive manufacturing tool. This tool is used to sinter metal powders on standard polymer substrates, and our goal was to assess whether the as-deposited amorphous NiTi could be crystallized using intense (>10,000 W/cm^2) microsecond bursts of light. We tested experimental stacks of sputtered, amorphous submicron thick films of NiTi on Si and on 1.2 micron films of polyimide. We developed thermal models used to predict transient temperature profiles in the NiTi film/substrate stacks, using differential scanning calorimetry (DSC) scans on substrate-released NiTi films to determine specific heat values. Using these values, models and preliminary experiments using x-ray diffraction analysis indicate that the pulse forge method may be a novel technique to crystallize shape memory materials while limiting thermal exposure of adjacent polymer layers or other electronic materials.

[1] Kahn H, Huff MA, Heuer AH. The TiNi shape-memory alloy and its applications for MEMS. J. Micromech. Microeng. 1998; 8 213–221.

[2] C. Knick, M. Srour, and C. Morris, “Characterization of sputtered nickel-titanium shape memory alloy and micro fabricated thermal actuators,” in *Micro Electro Mechanical Systems, 2016. MEMS ’16, Proceedings, IEEE., 29th Annual International Workshop on*, pp. 256–261, Jan 2016.

[3] C. Knick, M. Srour, G. Smith, C. Morris, “Reduced radius of curvature NiTi-on-Pt bimorph actuators based on reversible shape memory effect,” in *ASME Conference on Smart Materials, Adaptive Structures, and Intelligent Systems (SMASIS 2016)*, September 2016.

[4] C. A. Klein and R. P. Miller, “Strains and stresses in multilayered elastic structures: The case of chemically vapor-deposited ZnS/ZnSe laminates,” *Journal of Applied Physics*, vol. 87, no. 5, pp. 2265–2272, 2000.

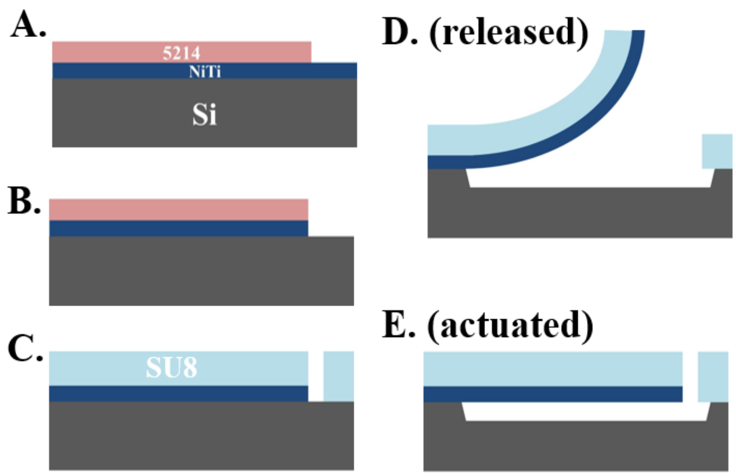

Figure 1 microfabrication process for SU8 on NiTi devices

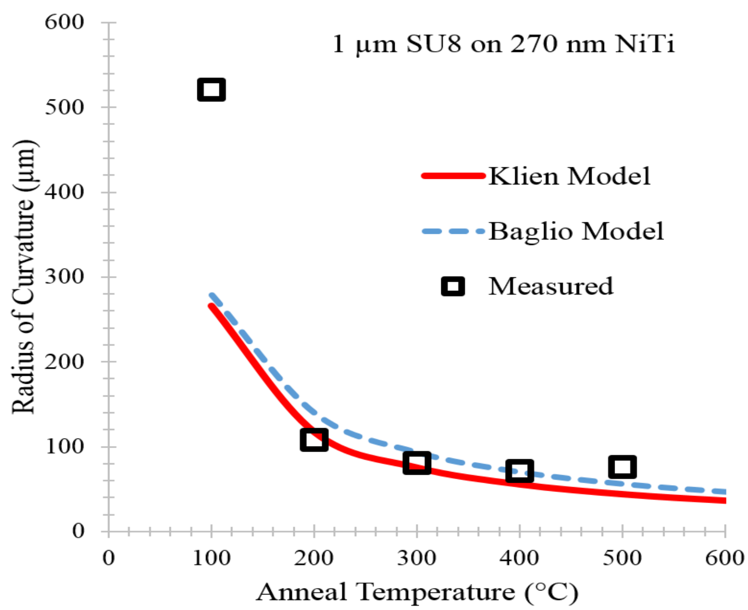

Figure 2 measured and modeled curvature radius for SU8 on NiTi devices vs. SU8 cure temperature