REDUCED RADIUS OF CURVATURE AND OPTICAL ACTUATION OF NITINOL SHAPE MEMORY ALLOY MEMS ACTUATORS

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NOVELTY / PROGRESS CLAIMS

Through the use of a thinner platinum (Pt) and NiTi, we have achieved a 5.45 X reduction in radius of curvature (R_C) for thin film NiTi on Pt actuators that fold flat when heated beyond 60 °C. The radius of curvature reduced from 1.2 mm [1] to 220 μm , enabling devices with an overall smaller size. We have also optically actuated devices at 1.44-24.0 W/cm², demonstrating actuation times from 4 ms to 240 ms.

BACKGROUND / STATE OF THE ART

Sputter-deposited NiTi shape memory alloys are well characterized on a material basis, and several demonstrations of NiTi MEMS cantilevers or actuators have been reported [2]. These devices are variations of sputtered NiTi films on released silicon or other micro machined substrates, where both layers are typically several micrometers or more in thickness [3] ultimately putting a limit on bending radius and range of motion. Cantilever tip deflections in the range of 100's of micrometers for cantilevers several millimeters in length are typical [4].

One reason for the limited selection of substrate materials for MEMS applications is the need to carry out a crystallization step at temperatures of 450°C or higher. This anneal step is critical to realizing any shape memory effect, but the fact that significant interdiffusion occurs between NiTi and any substrate material can limit how thin the initial NiTi film may be. Consequently, thicker films are typically used to insure that any interdiffusion layer is an insignificant part of the overall device.

DESCRIPTION OF NEW METHOD / SYSTEM

Here, we report on the characterization of NiTi films on Si and Pt layers, with NiTi deposited at 600 °C at an in-situ crystallization process. We focused on equiatomic NiTi, which thermally transforms between martensite and austenite phases near room temperature, corresponding to significant changes in residual stress, Young's modulus, and other properties that translate into large force and deflection.

Figure 1 shows the process flow used to fabricate the devices which was accomplished via a blanket Pt evaporation and NiTi co-sputter deposition (Figure 1a) and subsequent lithographic device patterning with a dilute HF wet etch and ion mill for NiTi and Pt films, respectively (Figure 1b). An optional Au electroplate step is possible to help stabilize wider cantilevers and restrict bending to 1 dimension (Figure 1c). We have shown that this step is not necessary when the cantilever width is ~20 μm or less. A

xenon difluoride (XeF₂) dry release was performed to release devices from the Si substrate (Figure 1d) where a 5214 mask was used on both the wafer front and backside and a post-release 100 °C thermal activation was required to set the devices into an upward curl.

RESULTS

XRD data for NiTi (270-1600 nm) on Si in Figure 2 shows that the NiTi has martensite phase present at RT and confirms that the phase change is beyond ambient, which we have confirmed additionally with wafer bow vs T and DSC measurements (not reported here).

Figure 3 shows the trend in measured and predicted radius of curvature for different NiTi/Pt film stacks based on Klein's bimorph model [5]. The model is in excellent agreement for 1.4 μm NiTi on 200 nm Pt, but 20 nm Pt devices deviate significantly from the model prediction. Despite this disagreement, we have obtained devices with very tight ~200 μm R_C using 600 nm NiTi on 20 nm Pt.

Figure 4 shows a SEM image of our tightest curled device with ~200 μm radius of curvature at room temperature, which is nearly flat above 70°C as shown in Figure 5. Figure 6 shows the optical actuation of the 600 nm NiTi on 20 nm Pt devices with 200 μm R_C in ~20 ms.

References

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Figure 1: Process flow for NiTi on Pt MEMS SMA actuators with dry release

Figure 2: XRD spectra for various NiTi thickness on Si confirming martensitic phase at RT

Figure 3: Predicted (solid and dashed lines) and measured (symbols) radius of curvature R_c vs. NiTi thickness for 20 nm and 200 nm Pt bimorphs

Figure 4: SEM image of released and thermally activated 600 nm NiTi on 20 nm Pt devices with thinnest reported radius of curvature of $\sim 200 \mu\text{m}$

Figure 5: Thermal activation of 600 nm NiTi on 20 nm Pt devices between tightly curled at RT and flat at 100 °C

Figure 6: Video frames showing optical actuation of a cantilever array of 600 nm NiTi on 20 nm Pt using a 532 nm, 440 mW laser with intensity of 6 W/cm^2 .