Ultra-Small Hysteresis of Submicrometer Shape Memory Alloys Prepared by Biased Target Ion Beam Deposition for Actuation Applications

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Shape memory alloys (SMAs) in the form of thin films are attractive for planar integration into small-scale systems, as the work output per unit volume of SMAs is touted as the highest among all smart materials. Our recent work has shown that biased target ion beam deposition (BTIBD) is a novel thin film fabrication technique that produces SMA thin films with attractive characteristics compared to conventional sputtering technology such as: reduced roughness on film surface; minimal diffusional interface between film/substrate; and transformable crystal phases. (See references[1-3] for details) Conventional SMA films are fabricated with thicknesses on the order of 1 micrometer; this work explores some of the thinnest films to date. A unique, fundamental advantage of BTIBD is that the technique possesses a unique ion source to generate high-ion-density, low-energy ion beam, as in Figure 1, and an ultra-low processing pressure (down to 10^{-4} Torr, in contrast to 10^{-3} Torr in conventional sputtering). The physical mechanism in Figure 2 explains film growth in BTIBD in contrast to conventional sputtering.

Herein[4], we demonstrate using temperature-dependent stress measurements the shape memory behavior of submicrometer nickel-titanium (NiTi) shape memory alloy thin films deposited by co-sputtering Ti target and Ni target in BTIBD. The as-deposited NiTi thin films are often amorphous and crystallization by rapid thermal annealing is investigated. X-ray diffraction reveals that the crystallized films are in the R-phase, as shown in Figure 3. This work demonstrates that the typically metastable R-phase exhibits a stable phase transformation. Figure 4(A) shows the thermally-induced shape memory behavior. The attendant hysteresis is smaller than conventional films (Figure 4(B)); moreover, the hysteresis is repeatable. The revealed ultra-small hysteresis allows fast response in actuation, which is necessary for advanced actuators in nanoscale devices.

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[2] H. Hou, R. F. Hamilton, and M. W. Horn, J. Vac. Sci. Technol., A **33**, 040601 (2015).
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[4] H. Hou, R. F. Hamilton, and M. W. Horn, In preparation.

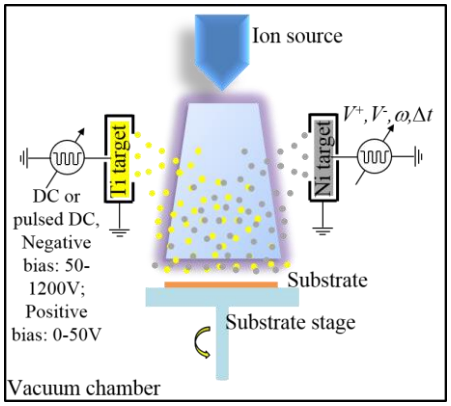

Figure 1: Biased target ion beam deposition (BTIBD): Separate Ti target and Ni target are used with individual control of biasing on each target.

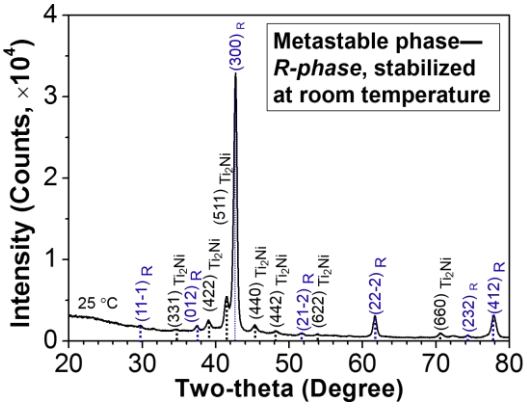

Figure 3: X-ray diffraction spectra for BTIBD thin films at room temperature: R-phase is identified and is stable. A second phase, Ti_2Ni, is also present.

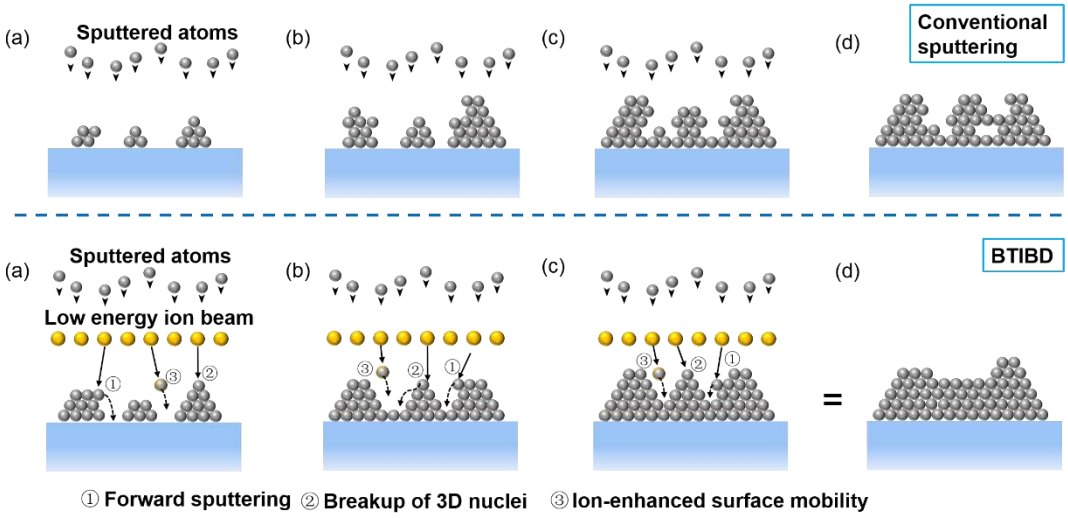

Figure 2: Physical mechanism of film growth in BTIBD versus conventional sputtering: Low energy ion beam in BTIBD allows controlling of adatom energy in order to tailor the properties of thin films.

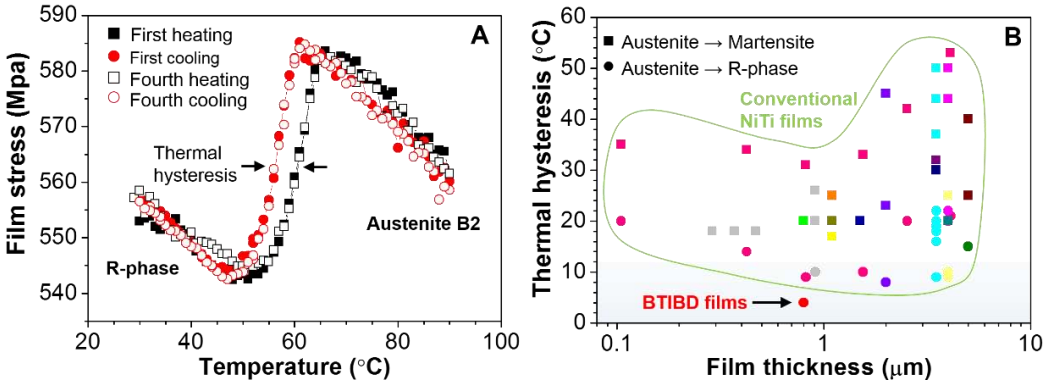

Figure 4: Thermal hysteresis in BTIBD thin films: (A) Repeatable stress-temperature behaviors with small hysteresis after the first and fourth heating-cooling. (B) Small hysteresis in BTIBD thin films versus conventional films.