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Rapid thermal annealing of Ti-rich TiNi thin films: A new approach to fabricate patterned shape memory thin films

Y. Motemani [a], M.J. Tan [a,*], T.J. White [b,c], W.M. Huang [a]

[a] School of Mechanical & Aerospace Engineering, Nanyang Technological University, Singapore 639798, Singapore
[b] School of Materials Science and Engineering, Nanyang Technological University, Singapore 639798, Singapore
[c] Center for Advanced Microscopy, Australian National University, Canberra, ACT 2601, Australia

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ABSTRACT

This paper reports the rapid thermal annealing (RTA) of Ti-rich TiNi thin films, synthesized by the co-sputtering of TiNi and Ti targets. Long-range order of aperiodic alloy could be achieved in a few seconds with the optimum temperature of 773 K. Longer annealing (773 K/240 s), transformed the film to a poorly ordered vitreous phase, suggesting a novel method for solid state amorphization. Reitveld refinement analyses showed significant differences in structural parameters of the films crystallized by rapid and conventional thermal annealing. Dependence of the elastic modulus on the valence electron density (VED) of the crystallized films was studied. It is suggested that RTA provides a new approach to fabricate patterned shape memory thin films.

1. Introduction

TiNi-based shape memory alloy thin films are attractive as actuation materials in micro-electro-mechanical systems (MEMS), such as: micro-valves, micro-fluid pumps and micro-grippers [1–5]. When prepared at low temperatures, the as-deposited state of the sputtered thin films is aperiodic and annealing is necessary to realize a transition to the crystalline state [6]. Consequently, understanding the nature of this process is critical for microstructural control and optimization for MEMS actuators.

Based on the employed heating source, there are two general techniques to crystallize the films after deposition: the first is conventional thermal annealing (CTA) using an electric tube furnace at high vacuum with ramping rate less than 100 K/min, and the second is rapid thermal processing with an electromagnetic irradiation source with ramping <100 K/s in controlled atmosphere.

There has been extensive research to optimize crystallization procedures of TiNi-based thin films by CTA, where temperatures from 673 to 773 K and ramp rates <100 K/min are typically employed [7–12]. However, few studies have been done to investigate the crystallization of these thin films with different heating mechanism like irradiation (rapid thermal processing). There are a few researches on the ability of a laser annealing to selectively crystallize an amorphous TiNi film [6,13–15]. Tong et al. [16] have investigated the crystallization behavior of TiNiCu ribbons modified by rapid thermal annealing (RTA), where the samples is annealed by irradiation of the photons from a halogen lamp and showed ability of RTA to crystallize the ribbons in a shorter dwell times allowing more precise control of microstructure and functionality. There remain many aspects of rapid thermal annealing of thin films to be studied.

In this paper, a systematic study was carried out of the crystallization behavior of Ti-rich NiTi thin films, during RTA. Ti-rich TiNi films prepared by magnetron co-sputtering of TiNi and Ti targets at room temperature were annealed by either rapid or conventional thermal annealing and examined by X-ray diffraction (XRD). Structural parameters of the films crystallized by RTA and CTA were studied by quantitative X-ray diffraction. On this basis, we examined the electronic structures of the crystallized samples and correlated them to the mechanical properties. Finally, we proposed a new technique to fabricate patterned TiNi-based shape memory thin films using RTA treatment.

2. Experimental details

TiNi films were prepared by co-sputtering of Ti50Ni50 and Ti targets at a base pressure $<1.5 \times 10^{-6}$ Torr onto rotating 4-in. Si(1 0 0) wafer substrates at room temperature. In this manner, uniform coatings were obtained at a substrate-to-target distance 100 mm and an argon partial pressure of 1.5 mTorr. Film composition was estimated by energy dispersive X-ray spectroscopy conducted in a scanning electron microscope operated at 20 keV (Table 1).

* Corresponding author. Tel.: +65 67905582; fax: +65 67911859.
E-mail address: MMJTAN@ntu.edu.sg (M.J. Tan).

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