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Electron irradiation effect on the reverse phase transformation temperatures in TiNi shape memory alloy thin films

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Abstract

In this work, Ti–Ni shape memory alloy thin films were irradiated by 1.7 MeV electron with three types of fluences: 4×10^{20}, 7×10^{20} and $1 \times 10^{21}/m^2$. The influence of electron irradiation on the transformation behavior of the TiNi thin films were investigated by differential scanning calorimetry. The transformation temperatures A_s and A_f shifted to higher temperature after electron irradiation, the martensite was stabilized. The electron irradiation effect can be easily eliminated by one thermal cycle. The shifts of the transformation temperatures can be explained from the change of potential energy barrier and coherency energy between parent phase and martensite after irradiation.

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Keywords: TiNi thin films; Electron irradiation; Martensitic transformation; DSC

1. Introduction

TiNi thin films have attracted much attention in recent years as intelligent and functional materials for their unique properties, such as shape memory effect (SME), large energy density, pseudoelasticity and high damping capacity. TiNi thin films based micro-actuators will become the actuator of choice in many aspects in rapidly growing field of micro-electro-mechanical systems (MEMs), but there still

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exist some critical issues and problems in the development of TiNi thin films which has been discussed in [1]. The SME and pseudoelasticity originate from martensitic transformation and its reverse transformation. The shape memory alloy thin films also can be used in nuclear fusion technology and spatial technology. And the effects of irradiation on the transformation behavior of shape memory alloys are questions of vital interest. Two interesting behaviors during irradiation have been reported on the bulk shape memory alloy materials. One is the irradiation induced amorphization of TiNi using both electron [2–5] and ion irradiations [6–9], and the other is the shift of the martensitic and its reverse transformation temperatures after irradiation [10,11]. There is a little report on the irradiation on the SMA thin films (few micrometers thickness). Goldberg et al. [12] investigated the irradiation effect of multi-energy He^+ (1.20–1.95 MeV) on the transformation behavior, they found a decrease of the transformation temperatures and an increase of the transformation hysteresis, however no significant change in the crystallography at a fluence lower than 0.01 dpa (displacement per atom). The TiNi thin films also can be amorphized by Ni ion irradiation [13,14], which results in two-way shape memory effect. The electron fluence is needed to reach $10^{25}/m^2$ to observe the decrease of transformation temperature and amorphization [2–5]. Our recent experiment and theory studies show that the small electron fluence ($10^{21}/m^2$) also has a great effect on the transformation behavior [15–19], this results are different with that high fluence. There is no publication reporting the irradiation of thin films with such low fluence. In this work, the electron irradiation effect of small electron fluence on the transformation temperatures of TiNi thin films was investigated by Differential Scanning Calorimeter (DSC).

2. Experimental

TiNi thin films with a thickness 4.5 μm were prepared by co-sputtering of a TiNi target and a Ti target on (1 0 0) silicon wafers with a 1 μm thick SiO_2 buffer layer using a magnetron sputtering equipment, Coaxial MSS3A, England. The substrate temperature was 450 °C and the substrate holder was rotated during deposition to achieve the uniform deposition. The base pressure was 1×10^{-7} Torr. The argon pressure was 1.0 mTorr during deposition and the substrate-to-target distance was 100 mm. Chemical compositions of the films were investigated by energy dispersive X-ray spectrometry (EDX). Measurements were done on 5 different regions on each of the sample, and the average value is Ti50.2Ni49.8. The detailed film characterization results can be found in [20].

The TiNi films were irradiated with 1.7 MeV electron at a fluence rate of $3.1 \times 10^{16} m^{-2} s^{-1}$ in the Electron Electrostatic Accelerator of the Key Laboratory for Radiation Physics and Technology of Education Ministry of China located in Chengdu. The temperature of the samples during the irradiation was controlled by circulating water. The experimental conditions of the electron irradiation were shown in Table 1.

The transformation behavior of the unirradiated and irradiated samples was measured using Differential Scanning Calorimetry. The measurements were performed with a Differential Scanning Calorimeter (DSC131) with a heating/cooling rate of 10 °C/min under nitrogen flow with a flow rate of 40 ml/min. The TiNi films pealed from the substrate were placed in an aluminum pan. The pans were sealed and placed in the measuring chamber of a differential scanning calorimeter. The start and the end of the transition were determined as the intersections of a base line and the tangents to each peak. Three transformation cycles were performed in this work to evaluate the effect of thermal cycle on the transformation behavior after electron irradiation.

Table 1
Experimental conditions of the electron irradiation

Samples	Conditions of the electron irradiation with an energy of 1.7 MeV and a flux of $3.1 \times 10^{16} m^{-2} s^{-1}$
1#	Unirradiated
2#	Irradiated for 3.5 h to a fluence of $4 \times 10^{20} m^{-2}$
3#	Irradiated for 6 h to a fluence of $7 \times 10^{20} m^{-2}$
4#	Irradiated for 9 h to a fluence of $1.0 \times 10^{21} m^{-2}$