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Property change during nanosecond pulse laser annealing of amorphous NiTi thin film

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Abstract. **Nanosecond lasers of different intensities were pulsed into sputter-deposited amorphous thin films of near equiatomic Ni/Ti composition to produce partially crystallized highly sensitive *R*-phase spots surrounded by amorphous regions. Scanning electron microscopy having secondary and back-scattered electrons, field emission scanning electron microscopy, optical microscopy and X-ray diffraction patterns were used to characterize the laser treated spots. Effect of nanosecond pulse lasering on microstructure, morphology, thermal diffusion and inclusion formation was investigated. Increasing beam intensity and laser pulse-number promoted amorphous to *R*-phase transition. Lowering duration of the pulse incidence reduced local film oxidation and film/substrate interference.**

Keywords. **SMA; NiTi; pulse laser; thin film; crystallization.**

1. Introduction

NiTi possesses a series of interesting properties like ability to recover large transformation work, high actuation/weight ratio, shape recovery, damping capacity, chemical resistance, biocompatibility and pseudoelasticity (Fua *et al* 2004; Shaw and Crone 2004). Its microstructure and properties are, however, drastically sensitive to composition, thermomechanical treatment, heat evolution and prevailing stable and/or pseudo-stable phase presence (Busch and Johnson 1991; Ishida *et al* 1995; Zhang *et al* 2003; Ni *et al* 2005; Zhan *et al* 2006). Fast response, instant actuation and precise control of deformation and force are ideal capabilities anticipated from microelectromechanical systems (MEMs). In order to achieve these features, a small thermal hysteresis is most desirable. Nearly all NiTi martensitic transformations associate with wide temperature hysteria. The rhombohedral (*R*-phase) transition of the NiTi shape memory alloy (SMA) exhibits, however, a small thermal hysteresis of 1·5 °C which makes it desirable for delicate functional uses.

Due to fast sensing power and high actuation speed, NiTi thin films can be used in elegant applications like microsensors, light valves, nerve clamps, microelectrodes, microwrappers, microvalves, micropumps, invasive instruments, actuated microendoscopes, implantable drug delivery devices, nanoscale shape memory actuators, sensor microarray for infrared radiation and on-off optical switches of spatial light modulators (Kohl *et al* 1999, 2000; Seguin *et al* 1999; Makino *et al* 2000; Takeuchi and Shimoyama 2000; Luskin and Palmstrom 2004; Wang *et al* 2005; Zamponi *et al* 2007; Chan *et al* 2008; Wood *et al* 2008). NiTi thin plates are generally made by physical vapour deposition because of weak workability of NiTi cast SMAs (Bellouard *et al* 1999; Xu *et al* 2006; Bellouard 2008). High-intensity laser treatment results in fast heating/cooling processes which retard martensite formation by promotion of the non-perpendicular lattice inversion. Crystallization into high-temperature austenitic (B2) phase results in thin-film property change. Thermal defects caused by frequent heating/cooling cycles are not desirable because of the unwanted influence on transformation temperatures which results in the malfunction of the manufactured microelectromechanical systems (MEMs) (Xu *et al* 2006).

Pulse lasering results in faster actuation response than conventional furnace annealing or continuous wave (CW) laser-treatment (Krishna *et al* 2007; Birnbaum *et al* 2008; Clare *et al* 2008). Selective laser melting has, for example, resulted in formation of a high aspect ratio and a three-dimensional NiTi microelectromechanical compartment as reported in earlier studies (Krishna *et al* 2009; Sadrnezhaad *et al* 2009; Zanotti *et al* 2009). Advantage of laser annealing is development of a biasing force which results in a back-to-preliminary-state tendency not achievable in traditional heat treatment processes. Laser heating results in formation of thermoelastic crystalline areas surrounded with wide amorphous regions exploitable in design of many functional systems (Fua *et al* 2004). Furnace cooling can decrease the residual stresses that may remain throughout the layer (Xu *et al* 2006).

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