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Bonding NiTi to glass with femtosecond laser pulses

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ABSTRACT

Dissimilar joining of shape memory alloy to other materials may find interesting applications in the microelectronics and medical devices, allowing for innovative designs and further miniaturization of parts and devices. Femtosecond laser has been investigated to join NiTi to glass aiming at to assess to which extent NiTi particles will deposit on glass when irradiated by a femtosecond laser beam. This is a non-thermal process and the irradiated areas were observed under SEM with EDS to analyze the morphology of the deposits and changes in the chemical composition. The results show that NiTi can be bonded to glass by femtosecond laser irradiation. Deposited particles show a micrometric granular structure.

1. Introduction

The scale-down of parts especially for the medical and electronic industry has driven the need to develop new manufacturing technologies, including joining. Laser beam technology has been largely investigated for welding and joining for micro- and more recently nano-components. When the scale goes down to few micron or even nanometers melting has to be controlled in the range of a few nanometers The ultra fast pulsed lasers and femtosecond lasers are innovative tools in nanoscopic processing [1,2]. Deposition of structures and spots, with micrometer and nanometer resolution, has a large use in the field of microelectronics and optoelectronics. The medical industry is also a potential beneficiary of such technology.

Femtosecond laser irradiation can result in an ultra fast and non-thermal melting of materials with promising results for joining dissimilar materials in the micro- or nano-scale ranges [3,4]. Femtosecond laser can also synthesis nanoparticles by ablation. Therefore, it is possible to synthesis and joining nanoparticles at the same time: ablate the material or melt the outer surface depositing this on the substrate surface assisted by the beam jet pressure. Limited work exists on the use of femtosecond laser in materials processing and this concerns laser ablation methods for thin film.

Shape memory alloys as NiTi have remarkable properties as biocompatibility, good strength and ductility and research is required to fully exploit their potential in innovative applications [5,6].

Microdeposition of metal structure on quartz substrate was studied by Tam et al. [7] using different ablation energies. Gold thin films were used as donors. Lines with heights from 20 to 120 nm and widths of 2.5–3.3 μm were obtained.

The aim of the present study is to illustrate and detail the effects of femtosecond laser irradiation of NiTi onto a glass substrate identifying the track geometry, the characteristics of the deposited particles both morphological and its chemical composition.

2. Experimental procedure

NiTi coupons of 0.4 mm thick were cleaned and etched in a solution of HF:HNO$_3$:H$_2$0 solution with a dilution of 1:5:10. The coupons were placed on top of glass lamellae and fixed in the laser positioning system. A femtosecond laser from Coherent, Elite Duo USP 1 K was set to impinge on the glass side. Fig. 1 shows the experimental setup comprising: an oscillator at 80 MHz, 800 nm and 10 fs; an amplifier of 1 kHz, 800 nm, 35 fs, a focal lens holder and a 3D sample stage.

Focal point position and traverse speed were varied. Other processing parameters were kept constant as listed in Table 1.

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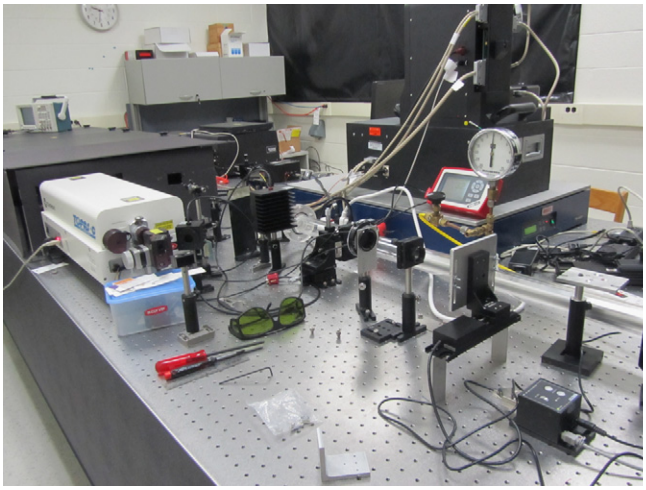

Fig. 1. Experimental set-up.

Table 1
Fixed processing parameters.

Laser beam power	1.8 kW
Pulse duration	35 fs
Pulse frequency	1 kHz

Samples were produced with the laser beam impinging on the NiTi surfaces, with a defocus of 5 mm and travel speeds varying between 0.01 and 1 mm/s.

In one of the samples two runs were made with the aim of trying to melt the NiTi particles on the glass surface and verify if these would bond with the NiTi. The surface of the glass shows a darker color when lower speed was used. This might be due to less contact between the surfaces of the two materials due to more severe ablation that occurs with the lower speeds, when a higher energy density is used NiTi plate.

The irradiated laser tracks visually showed higher and more uniform deposition of NiTi and were characterized using electron scanning microscopy in backscattered and secondary emitted radiation. Compositional changes resulting from processing were determined by EDS in a Jeol Scanning Electron Microscope (SEM) with an energy dispersive spectrometer (EDS) from Oxford Instruments model INCAx-sight. Semi-quantification microanalysis was made using ZAF correction procedure.

3. Results and discussion

Observing the glass surfaces under SEM it was seen geometrical and structurally uniform tracks free of cracks with micrometric NiTi particles incrusted. No evident differences were noticed for the different traverse speeds tested.

The tracks had about 800 μm (Fig. 2) width and exhibited a micrometric roughness with a rippling surface structure. The micro-strips were seen to be constituted by small re-solidified NiTi droplets that follow a pattern arrangement along the laser traveling direction. The irradiated track borders show a higher particle concentration. For the laser fluence used the laser ablated the material, melted the NiTi and loaded a shockwave impact onto the material which expelled the molten droplets to the glass sides and to the front edge in a two dimensional thermal distribution as observed by Hu et al. [1,8]. The basic processes during laser ablation such as excitation, melting, and material removal are temporally separated when femtosecond laser pulses are applied, Excitation takes place in the range of femtoseconds (duration of the laser pulse), melting roughly in the picosecond regime and the final material removal may take up to several nanoseconds.

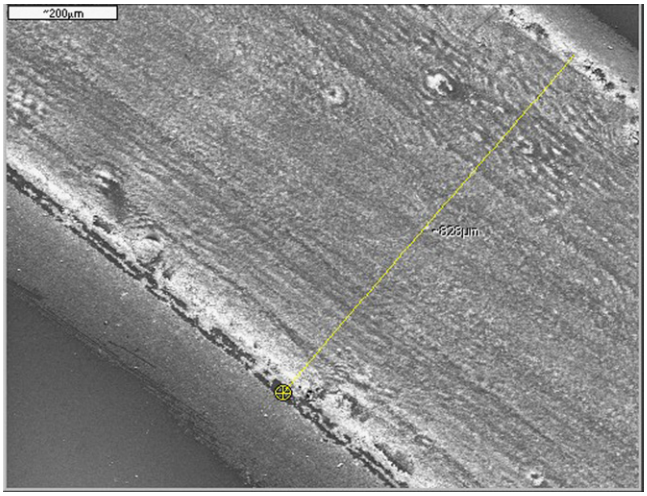

Fig. 2. Overall aspect of a laser track.

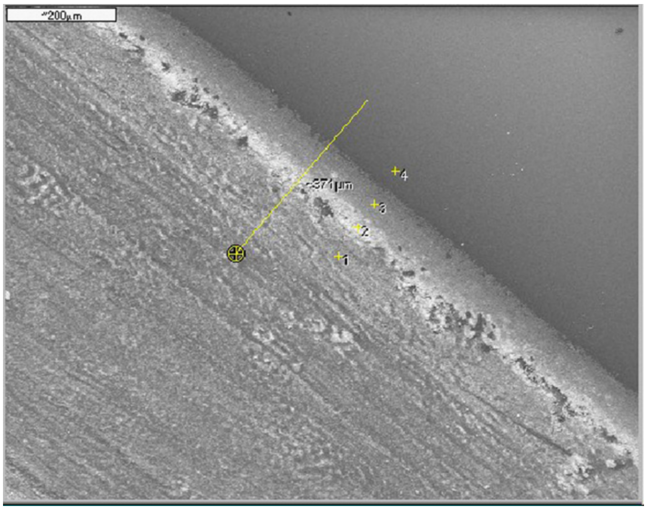

Fig. 3. EDS analysis along a line orthogonal to the traveling direction.

Close to the border of this shockwave impact, the glass substrate was free of particles but no cracking was observed.

From the element analysis performed under EDS, it can be seen NiTi in equiatomic form is present in these regions as shown in Fig. 3 along a line starting within the track to the substrate, crossing the boundary area with higher particle concentration.

EDS analysis of points 1–4 in previous figure confirms the existence of NiTi in the track at points 2 and 3, but in point 1 the signal was weaker thus the concentration was lower. Point 4 concerned just glass (Fig. 4).

The particle concentration is different in each border suggesting that the beam traveling direction has an effect on the particle distribution within the track (Fig. 5).

A high magnification of the granular structure in the middle of the track shows several interesting features (Fig. 6).

The droplets of re-solidified NiTi were micrometric and arranged in a coli-flower-like structure with an average dimension of 2 μm. In areas where this structure does not exist, a dimple surface structure was observed suggesting that a good interface was formed with a ductile rupture mode, showing that NiTi nanoparticles were bonded to glass.

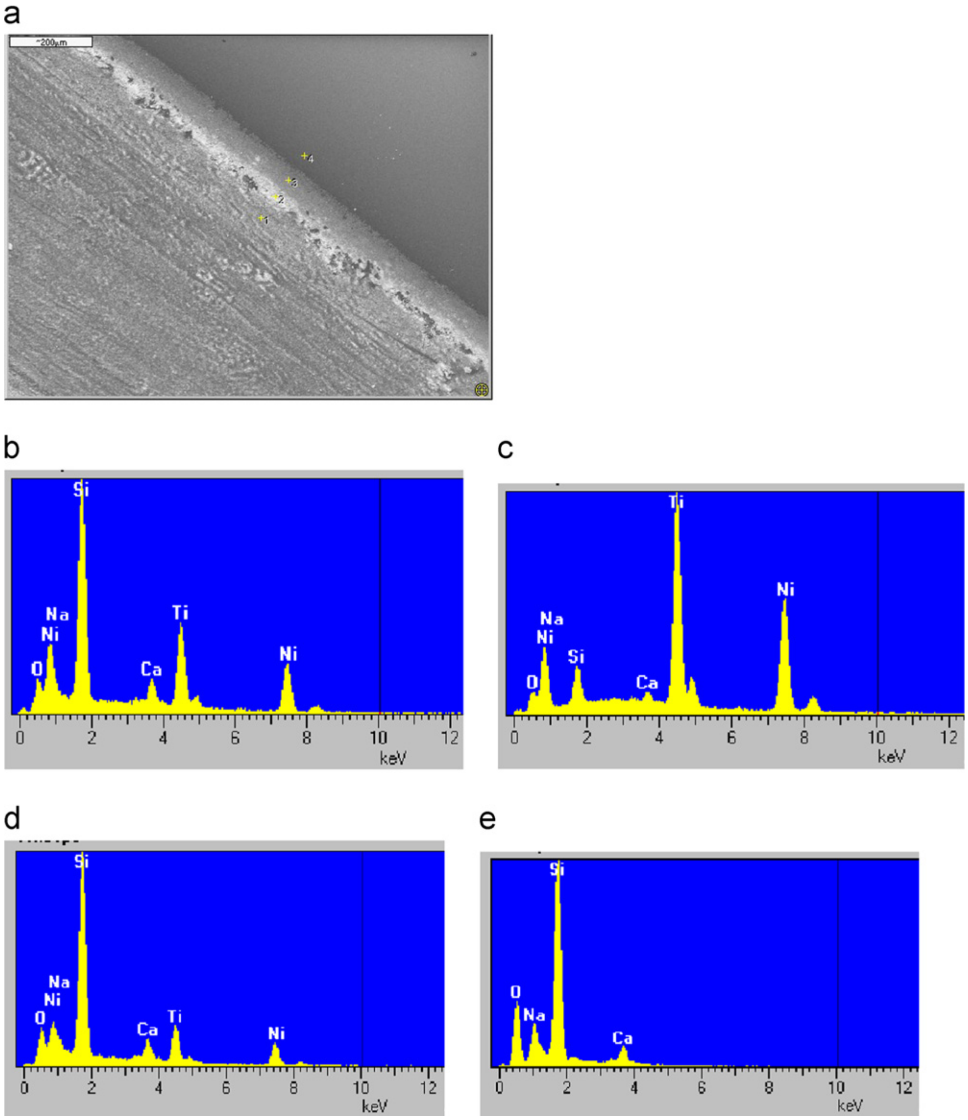

Fig. 4. EDS analysis across the track in (a).

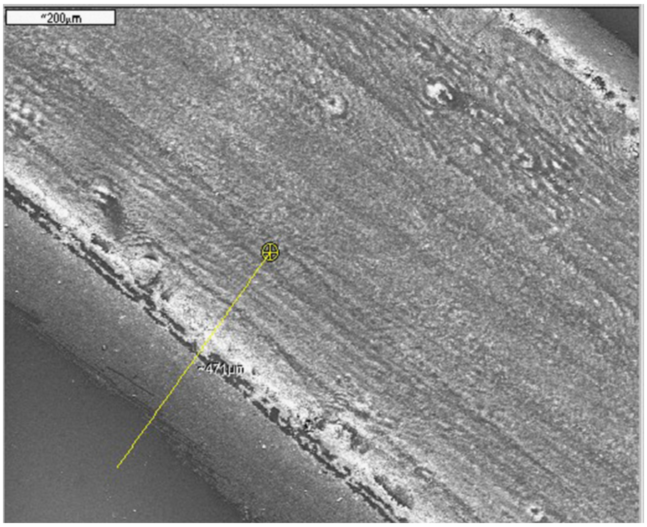

Fig. 5. Particle concentration distribution.

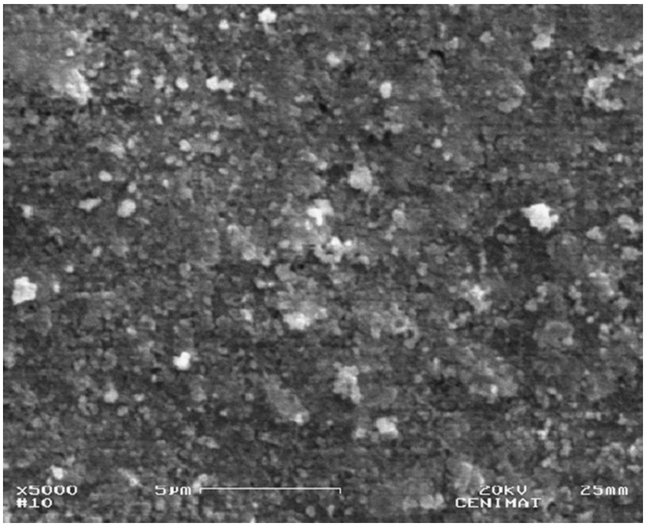

Fig. 6. Granular structure in the center of the NiTi track.

In order to investigate the adhesion, a scratch test was made across a track by hand with a knife and then observed under optical microscopy with a magnification of 200 ×. A scratch was seen on the surface that did not fully remove the deposit.

4. Conclusions

Glass surfaces can be micro engineered controlling the femtosecond laser process for depositing NiTi particles in a pattern controlled by the laser beam intensity, proving NiTi can be bonded to glass.

The laser beam produces micrometric droplets of molten metallic NiTi projected onto the surface by a shockwave produced in two directions, along and perpendicular to the laser traveling direction.

Deposited NiTi particles show a micrometric granular structure. In small areas where this structure does not exist, a dimple surface structure was observed suggesting that a good interface was formed with a ductile rupture mode. After a simple scratch test across a track the deposit was not fully removed suggesting a good adherence to the glass substrate.

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