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Nanosecond laser direct-part marking of data matrix symbols on titanium alloy substrates

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Abstract. In the application of laser marking, the biggest challenge is that machine-readable barcodes with superior quality were not marked consistently. To solve this problem, laser direct-part marking Data Matrix barcode experiments were carried out on titanium alloy substrates, using a Q-switched light-pumped Nd:YAG laser. The microstructure of the symbols was analyzed using an environmental scanning electron microscope (ESEM). The internal micro-stresses of the marked areas were analyzed using X-ray diffractometer (XRD). The influence of the pulse frequency on the symbol contrast is analyzed. Results showed the interaction between the laser and the titanium alloy can be found. This can further explain the physical mechanism of laser direct part marking Data Matrix symbols on titanium alloy substrates.

1. Introduction

In a harsh environment, the two-dimensional (2D) barcode symbol attached to an item is not difficult to be damaged. This is resolved with an approach known as laser direct part marking, which refers to the use of laser thermal effect to produce a permanent mark on the surface of an item. When a laser beam contacts with an item, its light energy is converted into heat energy, which creates a mark on the surface of the item. The mark visibility can be achieved by surface material removal or color change. The difference between the two methods to produce a permanent mark is the average power of the laser used. Surface material removal in laser direct part marking includes laser etching and laser engraving which requires a higher power than laser etching. Whereas color change refers to laser coloring which requires a lower power than laser etching. The intense laser beam may change the color of an item. Meanwhile the item may be damaged owing to the heat effect of the laser which must be avoided. Various materials may react differently to each type of laser marking technique. Owning to the complexity of the interaction between laser and materials, the industrial application of laser marking Data Matrix symbols was affected greatly. A direct effect of the interaction between laser and material is the material damage irradiated by laser. The damage is linked to the laser parameters and the characteristic of the substrate material. So the research on the physical mechanism of laser marking can be transformed into interaction process analysis between laser and materials.

The physical process during laser-material interaction involves many aspects such as heating, absorption, melting, evaporation, reflection, propagation, recoil pressure, piston effect, plasma formation, etc. When the laser energy was absorbed, the subsequent effect will arise. The classical laser physical mechanism was utilized during the investigation of the physical mechanism of laser marking [1-3]. Laser melting [2], ablation [3], plasma and etc. Various laser ablation models were proposed in recent years. Peligrad put forward a melt depth prediction model for quality control of laser surface glazing of inhomogeneous materials [4]. Also Peligrad proposed a muti-input and multi-

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output dynamic model for laser marking of ceramic materials [5]. But research on the physical mechanism of Nd:YAG laser marking 2D barcodes onto titanium alloy has not been reported.

2. Experimental details

2.1. Experimental materials and setup
The substrate materials used throughout this experiment are three TC4 titanium alloy sheets. One is 200 mm×200 mm×2 mm. The other two are 50 mm×50 mm×2 mm. The experimental setup is a solid state laser, Nd:YAG laser, whose applied processing characteristics are shown in Table 1.

Table 1. Processing characteristics of the laser marking equipment.

Processing characteristics	Value
Laser wavelength	1064nm
MAX Q-switch laser power	70W
Pulse duration	80~260ns
Beam quality	M2<10
Marking line width	<150μm
Marking depth	<2.0mm

There are many kinds of 2D barcodes, from which the Data Matrix symbol is selected in the experiment. It encodes the data string 1A2B3C4D5E. Its dimensions are 16×16 modules. The size of the obtained Data Matrix symbol onto titanium alloy substrates is 10×10mm.

Some marked Data Matrix symbols were analyzed using a D8-ADVANCE X-ray diffractometer (XRD), which is copper (Cu) target X-ray tube and θ/θ goniometer. The sample remains level during measurements. The angle repeatability of the goniometer is 0.0001° and its degree of accuracy is ±0.001°. The minimum angle is 0.2°. The XRD is produced by Bruker AXS Company in Germany. Moreover the mark was measured utilizing a Quanta 200 environmental scanning electron microscope (ESEM) whose resolution is 3.5nm.

2.2. Experimental procedure
A Data Matrix symbol was marked in the center of one TC4 titanium alloy when the current intensity is 28A, the pulse frequency is 3 kHz, the filling space is 0.01 mm, the scanning speed is 16.7mm/s. Then a Data Matrix symbol was marked in the center of the other titanium alloy sheet when the current intensity is set to 16A, while other experimental parameters being unchanged. The ESEM photographs (25×) of the Data Matrix symbols for different current intensity are shown in Figure 1 (a) and (b).

In order to compare the effect which laser direct part marking Data Matrix symbols induces on the titanium alloy surface, three samples were prepared. They are unmarked sample, sample marked with 16A and sample marked with 28A. XRD analysis has been used to detect micro-stresses in the marked areas of substrate materials. XRD analysis results are presented in Figure 2.

Eighteen Data Matrix symbols were marked when the pulse frequency is 1, 2, 3, 4, 5, 6, 7, 8, 9,10, 12, 15, 17, 19, 22, 28, 34, 40 kHz respectively. Fourteen symbols are marked when the pulse frequency is within its operating range and four symbols are marked when the pulse frequency is beyond its operating range. The images of representative Data Matrix symbols are given in Figure 3 (a), (b), (c) and (d).

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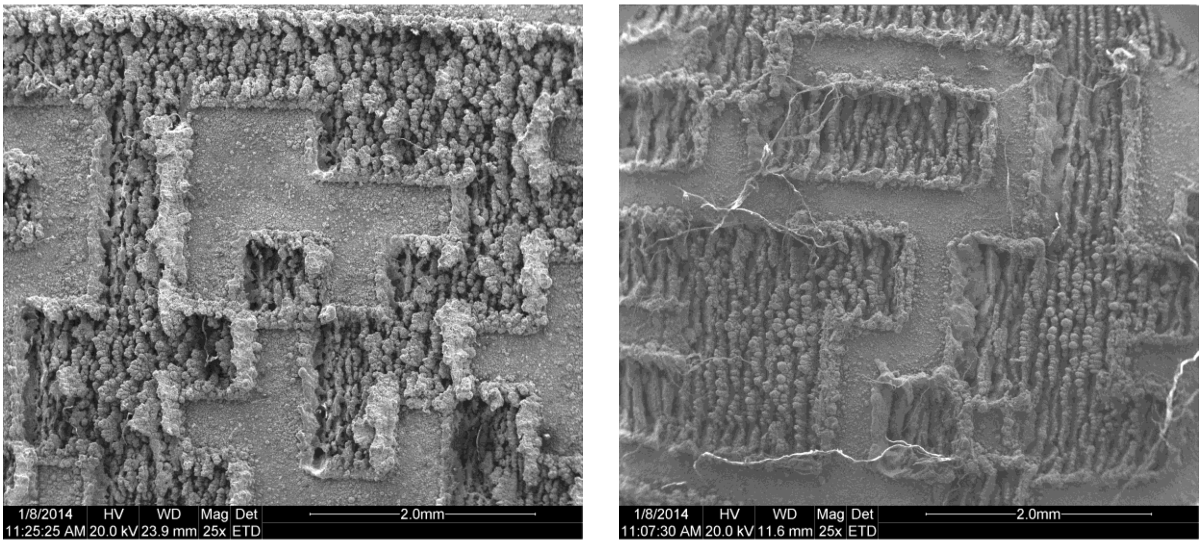
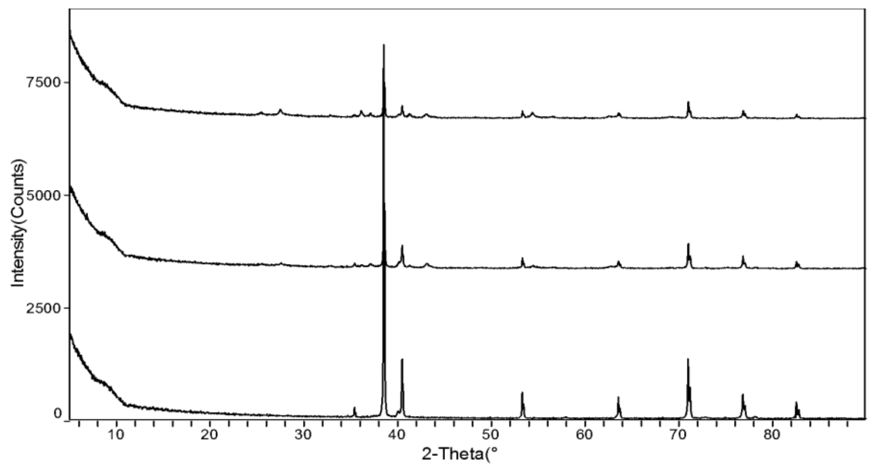
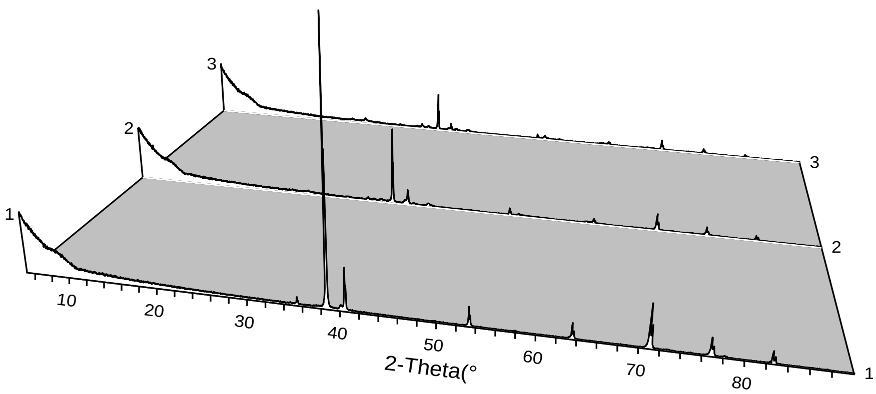


(a) (b)

Figure 1. ESEM photographs (25×) of the Data Matrix symbols for different current intensity: (a) 16A. (b) 28A.



(a)



(b)

Figure 2. X-ray diffraction graphs for θ in the range of 0-90 º(a) a two-dimensional representation (b) a tridimensional representation: (1) unmarked sample. (2) sample marked with 16A. (3) sample marked with 28A.

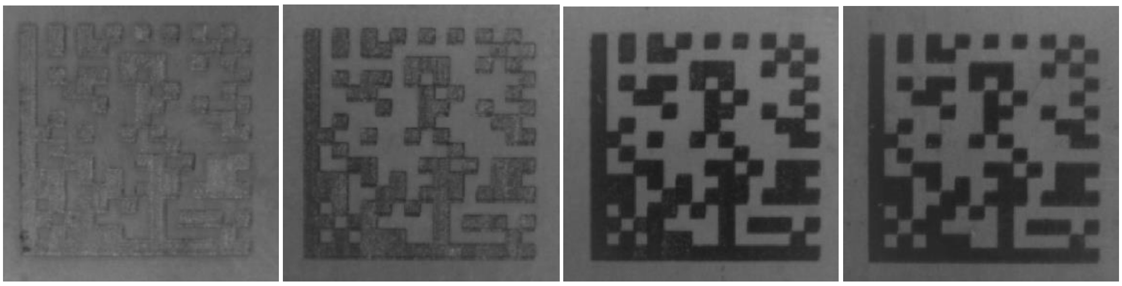


Figure 3. Image of laser marked Data Matrix symbols for different pulse frequency: (a) 12 kHz. (b) 15 kHz. (c) 22 kHz. (d) 40 kHz.

3. Results and discussions

Figure 1(a) and (b) shows the marked area is more rough than unmarked area and some dust residues were not been removed completely. Leone [6] studied the relationship between the symbol contrast and roughness. The symbol contrast increases with roughness when it is less than 4μm, beyond this limit, the symbol contrast is independent of roughness. In Figure 1(a) and (b), the roughness of the marked areas are all more than 4μm, so the symbol contrasts are not much different.

As seen in Figure 2, there is no appearance of new diffraction peaks or increase in the width of the diffraction peaks in the marked areas. So there are not any modifications in the nature of the phases and its structure. Mainly, the microstructure is not affected. There is no displacement of diffraction peaks initially recorded on the unmarked material. Therefore, one can say that there are no internal stresses as a consequence of laser marking Data Matrix symbols on substrate materials. In all, it is feasible for titanium alloy substrates to be marked Data Matrix symbols by nanosecond laser.

The symbol contrast of the Figure 3(a) (b) (c) and (d) is 0.2807, 0.4818, 0.7107 and 0.6860 respectively. In fact, the two marks (a) and (b) are obtained by laser etching which involves material removal, leaving an engraved mark. Whereas the two marks (c) and (d) are produced by laser discoloration which uses a lower energy density than laser etching, leaving a flush and smooth mark. Laser discoloration involves the superficial oxidation of certain elements, but it didn't involve material removal, Variations in the color change may be achieved by varying the laser parameters, and a variety of cosmetic effects can be obtained.

4. Conclusions

A nanosecond laser was utilized to mark several Data Matrix symbols on titanium alloy substrates in the experiment. Owing to the fact that laser marking involves material removal, the marked area is more rough than unmarked area. Laser discoloration can also produce a permanent mark, except for laser etching which requires a higher power than laser discoloration. In order to compare the effect which laser marking induces on the substrate material, three samples were prepared. They are unmarked sample, sample marked with 16A and sample marked with 28A. XRD analysis results show the microstructures of the marked substrate materials are not damaged and there is no internal stresses as a consequence of laser marking. So it is safe for titanium alloy substrates to be marked by nanosecond laser.

5. Acknowledgments

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6. References

[1] Sanner N, Huot N and Audouard E 2007 Direct ultrafast laser micro-structuring of materials using programmable beam shaping *Opt. Laser Eng.* **45** pp 737-41

[2] Valette S, Audouard E and Harzic R L 2005 Heat affected zone in aluminum single crystals submitted to femtosecond laser irradiations *Appl. Surf. Sci.* **239** pp 381-6
[3] Yilbas B S, Shuja S Z and Khan S M A 2011 Laser repetitive pulse heating of tool surface *Opt. Laser Technol.* **43** pp 754-61
[4] Peligrad A A, Zhou E and Morton D 2001 A melt depth prediction model for quality control of laser surface glazing of inhomogeneous materials *Opt. Laser Technol.* **33** pp 7-13
[5] Peligrad A A, Zhou E and Morton D 2001 A multi-input and multi-output dynamic model for laser marking of ceramic materials *J. Laser Appl.* **14** pp 31-8
[6] Leone C, Genna S and Caprino G 2010 AISI 304 stainless steel marking by a Q-switched diode pumped Nd:YAG laser *J. Mater. Process Tech.* **210** pp 1297-303