Ultrafast laser surface wettability modification on alumina surface

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As a new research area, laser surface wettability modification brings new applications for both laser and materials for industry. The picoseconds (10 ps) pulse laser surface micro-processing over alumina covered aluminium is researched. In the experiment, 10-ps laser pulse is employed and the energy threshold for different laser wavelength and repetition rate is measured. At the repetition rate of 5 kHz, the energy thresholds are: 1 064 nm: 4.0 μJ/pulse, 532 nm: 2.8 μJ/pulse, and 355 nm: 4.2 μJ/pulse. Picoseconds pulse laser is demonstrated feasible in surface scanning at industrial level.

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Alumina covered aluminum has caught the interest of the industry with the advantage of being low cost, low weight and stable. Alumina as a hydrophobic material has a contact angle around 120° for water on its original surface. However, by scanning with laser under a certain parameter, the contact angle can be modified. In some specific situations, the surface contact angle can go down to 10° or even less which is deemed as totally hydrophilic.

Compared with traditional etching process, ultra short laser surface scanning has the benefit of high efficiency, high speed, high selectivity, and high repeatability. However the laser process as a new method, it is desirable to have a comprehensive research to find out what and how different parameters affect the result. Yet not a uniform principle exists approving all researches.

Chemical materials scientists tend to explain this by surface energy theory. They believe when the surface absorbs energy from photons (which equals hv), the chemical bond will be rebuilt into a high energy state. This bond changed surface brings a different wettability[1−3].

The theory of surface microstructure has many supporters[4,5]. Lotus effect is the most common example for this theory. Different surface physical micro structure affects the surface wettability to some extent. While whether this phenomenon achieves a totally hydrophilic surface is to be queried.

Surface hydrate structure can be another explanation for this phenomenon[6−8]. In normal atmosphere, water combine with the surface material and form a $Al_2O_3 \cdot xH_2O$ thin layer, where x typically equals 3 or 4. This part of water comes out when the surface stimulated by some kind of energy for example laser offering the surface wettability is changed.

By doing a systemically experiment and rigorous analyzing its results, a integrated relationship between processing parameters and surface wettability can be found. For more purpose, the true mechanism of that phenomenon can be speculated in reverse.

Laser system used in these experiments consisted of a picosecond laser (High Q Laser IC-355-800 ps Nd:VAN REG AMP), a galvanometer (Nutfield), a working stage (Aerotech Model #: ANT-20G-90), a Function Generator (Tetronix AFG-3021B), and a set of optical systems.

As shown in Table 1, the High Q laser offers a laser with pulse duration of 10 ps. Laser output power is controlled by a polarizer crystal inside the system. The standard deviation power is less than 1% and the beam quality is M^2=1.1.

For lasers of different wavelength going through same optical path, the spot size is only determined by the wavelength and the radius on the lens. Since wavelength is to be researched and cannot be changed, the only way to uniform spot size is to changing the radius on the lens **r** by beam expander.

Using expanders described in Table 2, each laser spot size is finally focused to d=22.6 μm and repetition rates are set at 5, 10, and 20 kHz.

Experiments are done on alumina surface produced by Verona Lasdtre (IT3, www.veronalastre.com). Samples are scanned by low-rate-overlapped-spots and can be seen in Fig. 1. Here spot displacement is 20 μm and remind that spot diameter is 22.6 μm.

After treated, the sample will be studied by drop shape analysis system (Easydrop, KRUSS), scanning electron microscope (SEM), and optical microscope.

Figure 2 presents surface microstructure took by scan-

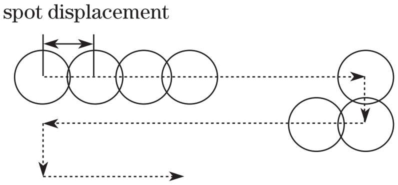

Fig. 1. Feature of scanning area in micro scale.

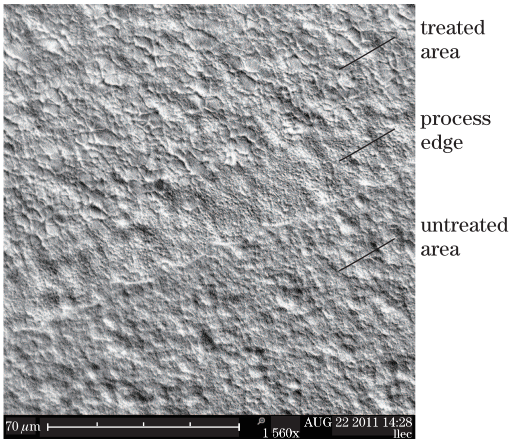

Fig. 2. SEM vision of treated surface. Laser wavelength: 1 064 nm, pulse energy: 5 μJ/pulse, repetition rate: 5 kHz.

Table 1. Working Parameters of High Q IC-355-800 Nd: VAN Regeneratively Amplified Picoseconds (ps) Laser System[9]

Pulse Length (ps)	10		
Repetition Rate (kHz)	5, 10, 20, 50		
Wavelength (nm)	1 064	532	355
Maximum Power (W)	2	0.8	0.4

Table 2. Beam Expander for Each Wavelength

Wavelength (nm)	Beam Expander
1 064	3*
532	2*
355	No Expander Used

ning electron microscope (SEM). In the figure, the top region is scanned by laser pulse and the bottom part is not.

It can be recognized that the original surface on the bottom is fluffier compare with that on the top. The surface that located on the edge area is scanned multiple times. It appears like a physical press by mechanical force is place on the surface rather than laser energy pulses.

Figure 3 is cross-sectional phonograph of droplet features near energy threshold. Contact angle decreases with the increasing of pulse energy.

Figure 4 presents alteration of surface wettability, which reflected by the contact angle, go with laser pulse energy under different repetition rate in each laser wavelength. At laser wavelength of 1 064 nm, the energy threshold lies in the range from 4 to 4.5 μ/pulse for contact angle of 10° or below. The lowest energy threshold appears at the repetition rate of 5 kHz and the energy threshold grows when the repetition rate increases. In the 532-nm group the contact angle remains at over 100° before 2 μJ/pulse. But it has a rapid decrease in next few steps. The thresholds at 5 and 10 kHz are 2.6 and 2.8 μJ/pulse, respectively, and grow a little bit higher at repetition rate of 20 kHz to 3.6 μJ/pulse for achieving a totally hydrophilic surface. At 50 kHz, the laser output pulse energy decreases heavily and is not able to reach material's threshold. So there is no data at 50 kHz for this case. At laser wavelength of 355 nm, the energy threshold of 5 and 10 kHz locals quite near at about 4 μJ/pulse.

Compared with the results of IR (1 064 nm) laser, the threshold at 532 nm laser is much lower. It can be said that alumina surface has a higher processing efficiency for green laser in this surface treatment. When turns to 355-nm group, it can be noticed that again the threshold increased with the increasing of repetition rate. The threshold is around 4 μJ/pulse which is similar to that under IR laser.

Figure 5 shows the contact angle affected by laser wavelength at the repetition rates of 5, 10, and 20 kHz.

The energy thresholds at 5 kHz are 1 064 nm: 4.0 μJ/pulse, 532 nm: 2.8 μJ/pulse, and 355 nm: 4.2 μJ/pulse.

The thresholds slightly increase with the growth of

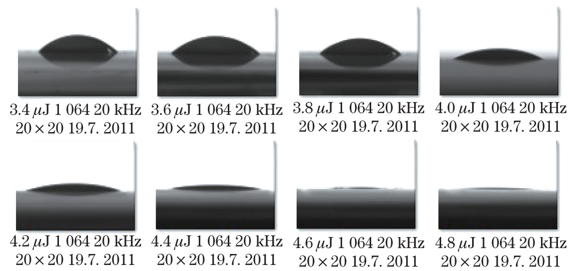

Fig. 3. Contact angle change in different pulse energy at the parameter of: repetition rate: 20 kHz, wavelength: 1 064 nm.

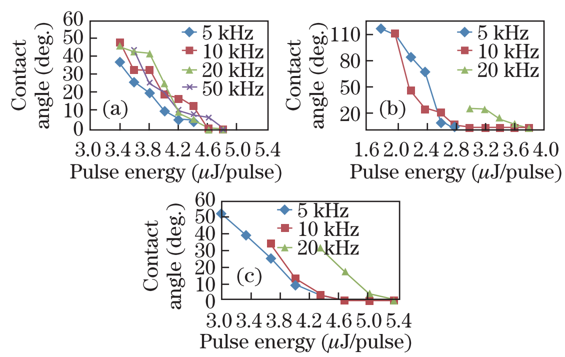

Fig. 4. Contact angle values at different pulse energies when laser wavelengths are (a) 1 064, (b) 532, and (c) 355 nm in different repetition rates.

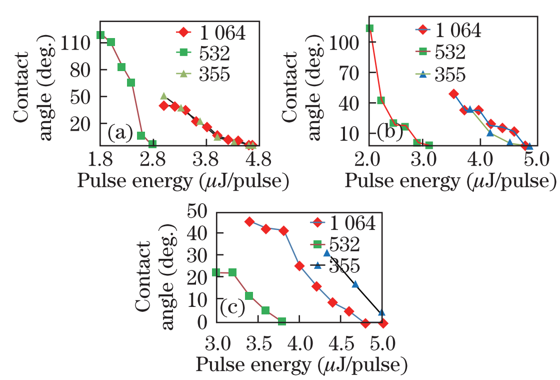

Fig. 5. Contact angle at different pulse energies when repetition rates are (a) 5 (b), 10, and (c) 20 kHz in different laser wavelengths.

repetition rate. At 20 kHz, they are 1 064 nm: 4.4 μJ/pulse, 532 nm: 3.4 μJ/pulse, and 355 nm: 4.9 μJ/pulse.

It can be noticed that the lasers at 1 064 and 355 nm have a very similar threshold of pulse energy for a contact angle below 10° under all repetition rates. However for the green laser, the requirement of pulse energy for same contact angle is much lower.

In conclusion, single laser scanning on alumina covered aluminium surface at pulse length of 10 ps, wavelengths of 1 064, 532, and 355 nm, repetition rates of 5, 10, and 20 kHz is studied. According to the results, the relationship between surface contact angle and laser parameter is founded. For application, higher repetition rate allows faster speed, but at the same time calls for slightly higher pulse energy. 532-nm laser has higher energy efficiency compeer with infrared and ultraviolet laser in this process. Further work can be located on laser with higher repetition rate and energy density. For example femtosecond laser typically can be employed in scanning. Also optical path can be improved. Laser group in University of Liverpool have done deep research in application of spatial light modulator (SLA) in laser path achieving multiple beam process. Moreover the reverse mechanism and its dependency are worth researching.

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