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Laser cleaning of particle and grease contaminations on the surface of optics

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ABSTRACT

In the high power laser facility, surface contaminations on the optics will worsen the laser beam quality and damage the optics. Particle and grease contaminations are two of the usual contaminations on the surface of optics. In this work, the 1064-nm laser induced plasma shockwave cleaning is utilized to remove SiO_2 particle contaminations on the K9 glass surface. The results indicate the removal ratio can reach above 95%. The effects of parameters (particle position, laser gap distance and laser energy) on the cleaning efficiency have been studied in the case of single pulse laser cleaning. In addition, CO_2 laser (10.6 μm) is utilized to remove the dimethylsilicone oil contaminations on the gold-coated K9 glass surface. The results show that CO_2 laser can effectively remove the dimethylsilicone oil by properly controlling the laser parameters. The cleaned area increases with the increased laser power or irradiation time when the other parameters are constant.

1. Introduction

In order to clean particles on the surface of chips in electronic industrial production, laser cleaning was studied in the middle 1980s. At present, laser cleaning has widely been investigated and used in many fields, e.g., microelectronics, rust removal, paint removal, restoration of cultural relics [1–6]. According to the different mechanisms of interaction between laser and surface contamination, the removal mechanisms can be classified as dry laser cleaning mechanism [6–9], steam laser cleaning mechanism [10,11], laser plasma shockwave [12–14], and surface acoustic wave mechanism [15]. Various kinds of contaminations can be removed from different substrates by the different laser cleaning methods.

In the high power laser facility, surface contaminations on the optics will worsen the laser beam quality and damage the optics. For the reliability of the laser facility, it is necessary to investigate the cleaning technique to solve the contamination problem. It is known that the conventional cleaning techniques (e.g., ultrasonic and megasonics, wiping and scrubbing) are recognized as inadequate for micron or submicron particles, the problems being ineffectiveness, addition of contaminations, and possibility of damaging delicate optics [1]. As a non-contact cleaning method, laser cleaning can effectively remove contaminations without damage to the optics, which could meet the need of laser facility operations.

Particle and grease contaminations are two of the usual contaminations on the surface of optics. In this work, 1064-nm laser induced plasma shockwave cleaning is utilized to remove SiO_2 particle contaminations on the K9 glass surface. CO_2 laser (10.6 μm) is utilized to remove the dimethylsilicone oil contaminations on the gold-coated K9 glass surface. Optical microscopy, dark field imaging, UV–vis–NIR spectroscopy and FT-IR spectroscopy are used to record and analyze the cleaning effect. The effects of many parameters (particle position, laser gap distance, laser energy and irradiation time) on the cleaning efficiency have been studied.

2. Removal of particle contamination

Particle contamination is one of the usual contaminations on the surface of optics. In the optical laboratory environment, the mostly composition of the particle contaminations is SiO_2 particles. In this work, the SiO_2 particles on the K9 glass surface were cleaned by laser plasma shockwave cleaning. The process of laser plasma shockwave cleaning can be described as follows: the airborne breakdown above the K9 glass surface occurred due to the intense electric field induced by the focused laser pulse. At that time, the gas was ionized and rapidly heated, producing a shockwave at the focus of a laser beam. The SiO_2 particles on the K9 glass surface can be removed by the shockwave. A Nd:YAG (1064 nm) laser was used to produce laser plasma shockwave.

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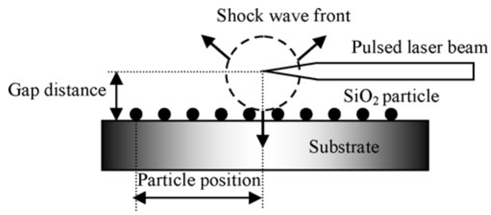

Fig. 1. Experimental schematic for the SiO_2 particles removal from K9 glasses with 1064 nm laser.

2.1. Experiments

The SiO_2 particles (15 nm in diameter) were dispersed in alcohol and vibrated for 30 min in an ultrasonic cleaner. The solution was then agitated for 2 h by a magnetic stirrer to obtain a uniform suspension. After that, the 30 × 30 × 3 mm K9 samples were placed on the rotator and the suspension was dropped on the samples. The rotator speed was 1000 circle/min and the duration was 10 s every time. The process was repeated for 4 times for each contaminated sample.

The schematic diagram of the cleaning process is shown in Fig. 1. The cleaning experiments were performed using a Q-switched Nd:YAG laser at 1064 nm with a pulse width of 10 ns. The laser beam was parallel to the K9 surface and focused above the area to be cleaned by a focal lens. The airborne breakdown occurred only when the laser energy was above 70 mJ in this work. There was a big audible snapping sound during the sparking process. The particle position and laser gap distance are defined in Fig. 1. The particle position is defined as the distance between the projection point of laser focus and the center of the particle. The laser gap distance is defined as the distance between laser focus and the substrate surface.

In the scanning mode, the contaminated sample was scanned twice and a region was cleaned by the laser with a frequency of 1 Hz and energy of 81.2 mJ. The scanning speed was 1 mm/s and the laser gap distance was 1 mm. In the case of single pulse laser cleaning, some contaminated samples were cleaned at the laser gap distance of 0.5 mm and the other contaminated samples were cleaned at the different laser gap distances at the laser energy of 85 mJ. In addition, some contaminated samples were cleaned at the laser gap distance of 0.5 mm under the different laser energy.

An optical microscope was used to observe the surface contaminations before and after cleaning. Dark field imaging was utilized to record the whole gold-coated samples. A UV–vis–NIR spectrometer was used to obtain transmission spectra before and after cleaning. The Image-pro software was used to determine the area of particle contamination on the sample surface to calculate the removal ratio.

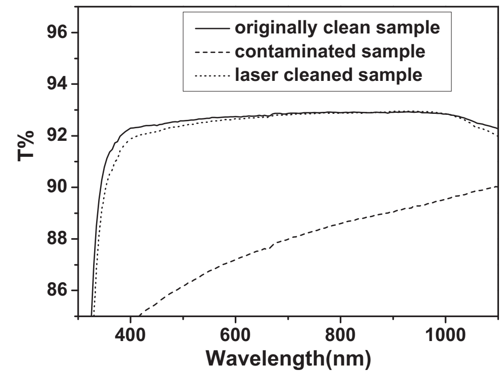

Fig. 3. Transmission spectra of K9 glass before and after cleaning.

2.2. Results and discussion

Fig. 2(a) shows the dark field image of the whole contaminated K9 glass after local scanning. In the picture, there is an obvious boundary. The left of the sample is the laser cleaned area and the right is the un-cleaned area with contaminated particles on the surface. Fig. 2(b) and (d) are the 50× surface morphology images of the laser cleaned area and un-cleaned area, respectively. Fig. 2(c) is the 5× surface morphology images of the boundary area, where the number of particle contamination decreases gradually from the right to the left. The contrast between two areas indicates that the cleaning effect is good. Fig. 3 shows the UV–vis–NIR transmission spectra of the gold-coated K9 glass before and after cleaning. It can be concluded that the transmission decreases after contamination. After cleaning, the transmission nearly returns to that of the originally clean sample.

The single pulse laser cleaning experiments was conducted and the curves of particle removal ratio versus particle position and laser gap distance and laser energy are plotted in Fig. 4. The removal ratio η can be defined as $\eta = (1 - S/S_t) \times 100\%$, where S_t is the area of particle contamination before cleaning, S the area of particle contamination after cleaning. For reliability, the micrograph was measured for several times to obtain the average value.

Fig. 4(a) shows the curve of removal ratio versus particle position at laser energy of 85 mJ and laser gap distance of 0.5 mm,

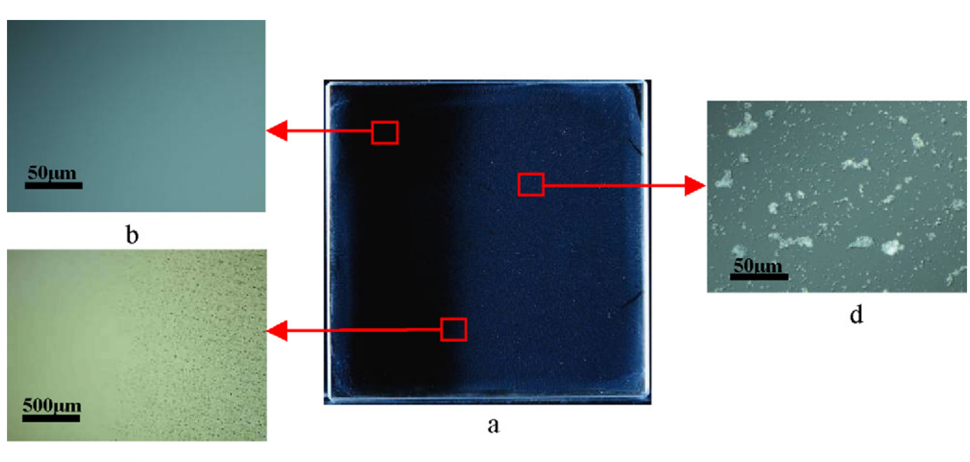

Fig. 2. (a) Dark field pictures of the K9 glass after laser cleaning; (b) 50× surface morphology of the cleaned area; (c) 5× surface morphology of the contrast area; and (d) 50× surface morphology of the un-cleaned area.