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Realization of diverse displays for multiple color patterns on metal surfaces

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ABSTRACT

Enhanced colors can be formed when white light is irradiated on the surface ripples induced by femtosecond laser. In this paper, we have demonstrated the ability to display the diverse colors by simultaneously adjusting the incident white light angle and the ripples orientation. Furthermore, our investigation revealed that multi-patterns constituted by ripples with different orientations could be designed on metal surfaces. The diverse display for the desired ones can be realized by exquisitely varying the incident light angle and rotating sample angle. More interestingly, it is found that, although the same patterns could be displayed under different conditions, the colors might be different. These findings can provide a novel method to carry and identify high quantity of information, which may find potential applications in the fields of information storage, identifying codes and anti-counterfeiting patterns.

1. Introduction

The creation of colorful metals produced by Laser Induced Periodic Surface Structures (LIPSS) has drawn considerable attention in recent years [1–6]. These LIPSSs can be considered as a kind of grating structures, which could play important roles in modifying the optical properties of metal surfaces in a very versatile way [1–6]. The widely accepted theory believed that the formation of LIPSSs was the result of the interference between the incident laser beam and the surface-scattered wave [5–20]. In addition, it is indicated that the ripples (LIPSSs) orientation usually is perpendicular to the polarization of laser pulse [1,5]. The correlation of ripples orientation and laser polarization offers us an opportunity to skillfully utilize the laser polarization as a control parameter to write diverse displayed patterns on metal surfaces [5,6]. Specific color patterns can be generated due to the diffraction of light by producing polarization dependent structures [5,6]. Color effects can be diversely displayed by altering the incidence angle of white light, which is used to irradiate the patterns constituted by ripples with different orientations [6]. Although many works have been reported to explore how to use the laser polarization dependent ripples to obtain the needed optical diffractive effects, there are still few researches on systematical study of the combined influence of incident light angle and the ripples orientation on the color effects. Also there are few reports on the diverse displays for multi-patterns which are fabricated in the adjacent locations on the metal surface and constituted by ripples with different orientations.

In this paper, we not only discussed the combined influence of incident light angle and the ripples orientation on the diversity of structural colors, but also proposed the possibility of realizing the carry and diverse display of multi-patterns. Our investigation may find applications in the fields of information storage, identifying codes and anti-counterfeiting patterns and so on [5,6,13].

2. Experimental

The fs laser-induced surface ripples experiments were conducted by employing a femtosecond laser micro/nano machining system, as shown in the schematic diagram of the experimental set up (Fig. 1(a)). The linearly polarized pulse, delivered from a regenerative amplified Ti: Sapphire femtosecond laser system (Coherent) at the repetition rate of 1 kHz, central wavelength of 800 nm, was focused onto the mirror polished 316 L stainless steel surface. Before the laser irradiation, the polarization direction of the laser pulse was adjusted by a linear Glan–Taylor polarizer. The scanning was realized by using a computer controlled high precision x–y galvo mirror. The beam diameter focused onto the sample surface was about 20 μm. The laser induced surface structures

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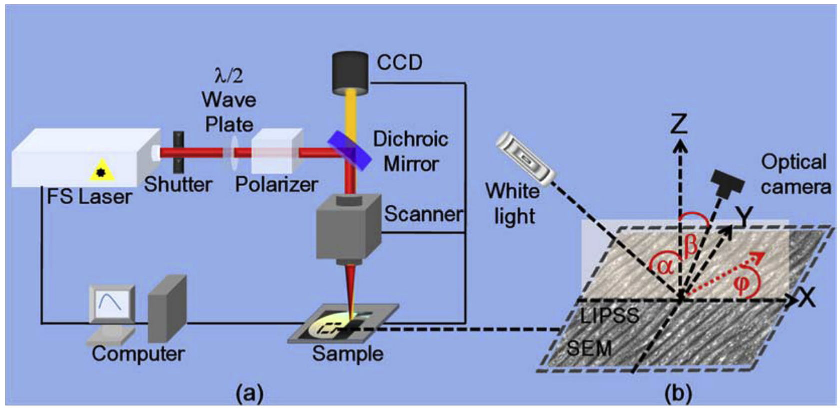

Fig. 1. (a) Experimental setup for stainless steel surface structuring. (b) Schematic illustration of color measuring system.

morphology was observed by a Field Emission Scanning Electron Microscopy (FESEM) (JSM-6700F). Schematic illustrations of measuring the optical properties were shown in Fig. 1(b). A digital optical camera (Cannon) was used to take the pictures of the structural colors. During the process of taking pictures, the surface ripples were irradiated by an unpolarized white light source from a LED lamp. For an objective evaluation of color effect, a spectrometer (Ocean Optics, USB2000) was used to measure the reflectance spectra diffracted by the formed ripples, if necessary. All measurements were carried out in dark to avoid stray lights from the surrounding environment.

3. Results and analysis

Based on experimental investigation, a series of processing parameters were optimized to satisfy the optimum condition for generating ripple structures. In this experiment, the pulse overlap was set to 32%, the line space was fixed at 20 μm, and the laser fluence was chosen as 1.1 J/cm^2. Under the processing parameters, a circle pattern with diameter of 6 mm was fabricated on the stainless steel surface. The SEM images indicate that periodic ripples with period of d = 540 nm, and orientation to be perpendicular to the polarization orientation of laser pulse were formed [5,6,14–17].

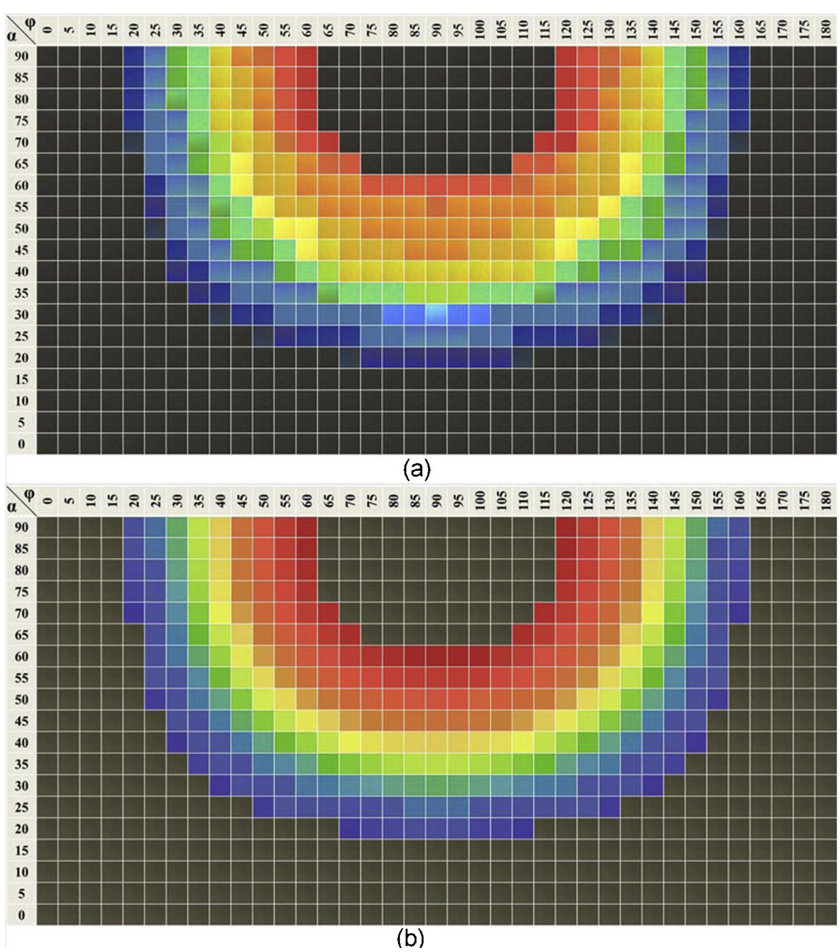

Fig. 2. (a) Photograph of the structural colors observed at different incidence angles and ripples orientations. (b) The simulation results of the structural colors.