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Fast and direct engraving of iridescent lettering on original product surface using laser interference to prevent counterfeiting

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ABSTRACT

We propose the engraving of a unique interference pattern on metal with the use of high-energy 1064 nm laser pulses fired through a Fresnel biprism (FB). The grating is patterned with 500 patterns for 5 ns, and the spacing of patterns can be adjusted according to the physical value of FB. By rotating the FB, the interference pattern is machined into metal to produce an encrypted iridescent character. Encrypted letters are engraved via assigning a serial number and corporate logos to a product (on which the metal is affixed) according to the viewing angle of the interference fringe. The resulting iridescently colored letters or numbers are visible according to their viewing direction. By superimposing letters and numbers, it is possible to store complex passwords, and forgery/counterfeiting can be easily detected by merely using the naked eye and an angle meter.

1. Introduction

With the development of mold, high-resolution printing, and 3D printing technologies, the development of techniques to identify the authenticity of items of interest has attracted considerable interest, particularly with regard to preventing the counterfeiting of money [1–3]. On the other hand, concurrent developments in counterfeiting technology threaten market order, suppliers, and potential consumers [4,5]. However, validating the authenticity of objects requires high-resolution equipment and expertise, which makes the authentication process expensive. Nevertheless, the most popular existing anti-counterfeiting method, involving the fabrication of a mold and stamping of an anti-counterfeit mark, can be replicated easily because of the rapid spread of technology to the mold system; this process is currently significantly more vulnerable than ever before [6]. The most classic form of preventing counterfeiting to date has been watermark technology. Watermarking is a technique that involves the engraving of a shape that is revealed when shining light on the engraving. This technique is applied to money to prevent its forgery, but it is inefficient and expensive when applied to confidential documents containing important information [7–11]. Further, watermarking cannot easily be applied to various kinds of goods such as luxury watches and bags. Meanwhile, important documents such as passports are being RFID-tagged to prevent forgery. While RFID is a sure approach to prevent counterfeiting, an individual's privacy can easily be violated and misused with this approach [12–14]. Thus, the application of such a technique provides a soft target for high-tech thieves, ID thefts, and even terrorists [15,16]. The quick response (QR) code, which is a type of bar code that ensures fast response, can be applied to a product for unique identification. The code can be recognized by the camera of a personal smartphone, and it can be viewed as a catalog of goods. The code offers a form of temporary security and information provision in smart banking. Such codes can easily be copied and used for information transmission or as temporary security codes rather than for counterfeiting prevention [17–20]. In this context, ideal anti-counterfeiting measures should become more inexpensive, be applicable across diverse fields, and not infringe on personal privacy.

Laser engraving technology has been applied to various advanced fields. For example, Recently, femtosecond laser direct writing technology has been used to rapidly fabricate a periodic array pattern on the top surface of InGaN LEDs to improve the efficiency of LED light extraction by over 58% [21].

In this study, we "engrave" an interference pattern on a metal via focusing laser light through a Fresnel biprism (FB, Company: Lattice Electro Optics, Biprism, 1″ × 1″ × 0.375″T-5°, Size: 1″ × 1″ × 0.375″ and Substrate: UV Fused Silica). We irradiate the metal with the laser "interference" beam for 5 ns to engrave more than 400 diffraction patterns at 5 μm intervals. The patterns can also be coded to encrypt serial num-

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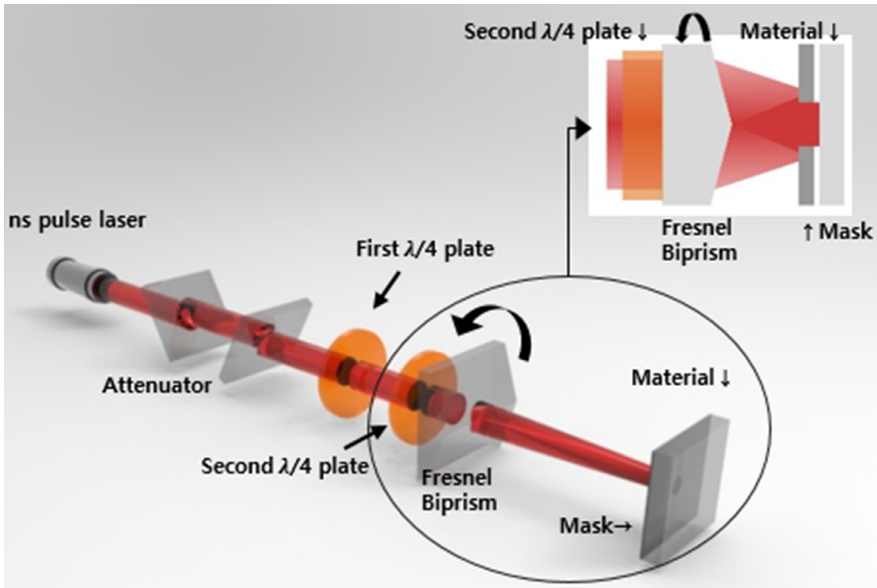

Fig. 1. Schematic for laser interference processing pattern through Fresnel biprism (FB). Inset shows the expanded image of the biprism optical system. An interference beam is generated according to the rotation angle set for the rotatable FB. To ensure accurate rotation of the interference fringe, a quarter-wave ($\lambda/4$) plate is positioned perpendicular to the rotating FB along the optical rotation axis. The mask serves as the aperture of the interference beam.

bers by aligning the metal target at different laser "processing" angles. This "directly processed" metal shines with a unique iridescent color because of the presence of interference fringes. Importantly, any desired letter or character can be engraved via the interference fringe pattern, which allows visual confirmation of the product authenticity. In our approach, the FB is used to create an interference beam to engrave patterns into the metal at several angles. Thus, different rotation angles of the FB correspond to different characters that can be observed according to the viewing angle (corresponding to the engraving angle of the interference pattern). This approach affords unique identification over that possible with the traditional mold. Importantly, the desired characters can be engraved at high speeds. Finally, the product cannot be counterfeited even with the use of fine and high-quality mold technology since each interference pattern is angle-specific. Thus, a unique identification serial number and (for example) the company's logo can be directly engraved on the product. In general, high-resolution anti-counterfeiting equipment is expensive, and further, advanced manpower is required to determine forgery. However, with our proposed method, the authenticity of a product and its serial number can be visually examined without the use of expensive counterfeit identification devices or expert human resources. Our approach does not involve a metal mold; the identification is directly incorporated into the metal by laser machining, and interference fringes are engraved on the metal. Thus, one can visually confirm whether or not the engraving is a real anti-counterfeit mark.

2. Experimental method

In our approach, a periodic pattern of micro-spacings is very precisely engraved by a laser with the use of a Fresnel biprism (FB) [22,23]. Fig. 1 shows the experimental setup for engraving interference gratings on a polished SUS 304 surface using a 1064 nm high-energy pulsed laser. The laser intensity can be controlled via the attenuator; this is required because the degree of laser light absorption is different for different materials. The linearly polarized beam of the laser is transformed into a circularly polarized beam by the first quarter-wave ($\lambda/4$) plate. A second $\lambda/4$ wave plate is additionally used to avoid the polarization effect caused by the FB rotation. Subsequently, the circularly polarized beam is converted into linearly polarized light by the second $\lambda/4$ wave plate. At this time, if the second $\lambda/4$ wave plate is rotated about the z-axis, the linear polarization also correspondingly rotates. Therefore, the first $\lambda/4$ wave plate must be fixed, and the second $\lambda/4$ wave plate must be rotated together with the FB. When the FB is rotated, the interference fringe also correspondingly rotates, i.e., the generated pattern is also rotated. The interference pattern can be accurately engraved on the specimen at different angles because the system allows a high angular resolution of the FB rotation. The characteristics of the diffraction grating pattern generated by the FB depend on the distance of the specimen from the FB. Thus, the size of the lettering can be adjusted by arbitrarily decreasing the size of the micropattern with the use of a specific mask. That is, a smaller hole size of the mask yields a smaller character size. With the use of a mask with dimensions of 2 mm × 2 mm, one laser pulse can generate 400 interference fringes with a fringe width of 5.3 µm. It should be noted that when the polished metal is processed with this "direct" laser interference, a unique iridescent color pattern is visible (because of diffraction). This process of engraving letters on metal is defined as metal lettering in the study.

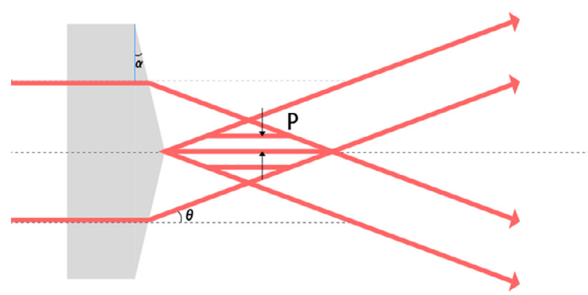

Fig. 2. Fresnel biprism (FB) beam refraction direction and angle at FB surface.

3. Results & discussion

Fig. 2 shows the schematic of the one-beam interference optics, i.e., the FB. Such systems based on an FB afford high laser fluence because of the interference of two beams.

Here, the period of the light distribution can be expressed as Eq. (1).

$$\left(\vec{k}_i - \vec{k}_j\right) \cdot \vec{\gamma} = \left(\hat{\imath} 2k_0 \sin\theta\right) \cdot \left(\hat{\imath}x + \hat{\jmath}y\right)$$
$$= 2k_0 \times \sin\theta = 2\pi \ (i,\ j = 1,\ 2) \quad (1)$$

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