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Tamper-proof holographic markings for high-value goods

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Abstract

We present a fast and reliable laser-based process for the generation of 'tamper-proof' security markings on the surface of metals, such as stainless steel, nickel and nickel-chromium Inconel® alloys. The markings are in the form of phase computer generated holograms (CGHs) and are produced using 35ns long laser pulses of 355nm wavelength. The CGHs contain an array of very shallow (< 0.5µm deep) optically-smooth deformations; each deformation is produced by a single laser pulse that locally melts and evaporates the metal surface. Binary and multi-level CGHs are possible. The holographic structures are designed to form diffractive images containing alphanumeric characters and simple images. The flexibility of the process allows each hologram to be unique. Moreover, the laser-generated holograms can possess additional security features and enhanced appearance. The holographic structures are resistant to abrasion and tampering because they are generated directly on the metal surface. As demonstrated, these structures can be used as security markings for commercially-available (high value) metal goods, e.g. luxury watches.

Keywords: Laser marking; security markings; diffractive optics; phase holograms; metals

1. Introduction

Counterfeiting of genuine products is an illegal practice that causes harm to the global economy, affects consumers and damages business of companies that own the Intellectual Property Rights (IPR). Production and sale of forged goods often reduces revenues and profits of the companies that produce genuine items, as well as may harm well-established reputations of trademarks and brands. Consumers can also be the

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victims of these illegal practices if they are unaware of buying a fake product. Such a good is often a low quality, but also it can be defective, inefficient or even dangerous.

Security marking is essential in combating counterfeiting. By generating 'hard-to-replicate' markings on genuine products, the manufacturers can be always one step ahead from those enterprises that illegally exploit the IPR and product development costs. Standard markings which are seen daily on various products are typically in the form of serial numbers, barcodes, data matrices, QR codes and also images that represent company logos or trademarks. Although these markings can provide a full identification and traceability of products, they can be readily forged and copied onto fake items. Polymer holographic stickers are also used as security markings because they are more robust to local damage and often are tamper-evident. Unfortunately, these holograms are only attached to a product as an adhesive tape and hence a consumer never cannot be sure if the product with a hologram sticker is authentic or forged.

This paper presents a laser-based process that enables the generation of phase holographic structures on the surface of different metals, such as stainless steel, nickel and nickel-chromium Inconel® alloys. These structures can be used as anti-counterfeiting security markings for high-value metal goods, e.g. luxury watches. In contrast to polymer holographic stickers, the laser-generated holograms are indelible and fully tamper-proof, because they are generated directly on the metal surface.

2. Design and generation of phase holographic markings

Figure 1 shows the fabrication procedure of phase holographic structures on the surface of metals. These structures are in the form of computer-generated holograms (CGH). The holograms can be designed by employing an Iterative Fourier-transform algorithm (IFTA), which was described in detail by Wyrowski and Bryngdahl, 1988. The IFTA enables the generation of two-level (binary) and multi-level phase CGHs. In order to increase an effective aperture of the holographic structure, the CGH design is copied several times and tiled in an '*m* × *n*' arrangement. The tiled hologram design is mapped onto the surface of a metal work piece using a focused UV laser beam.

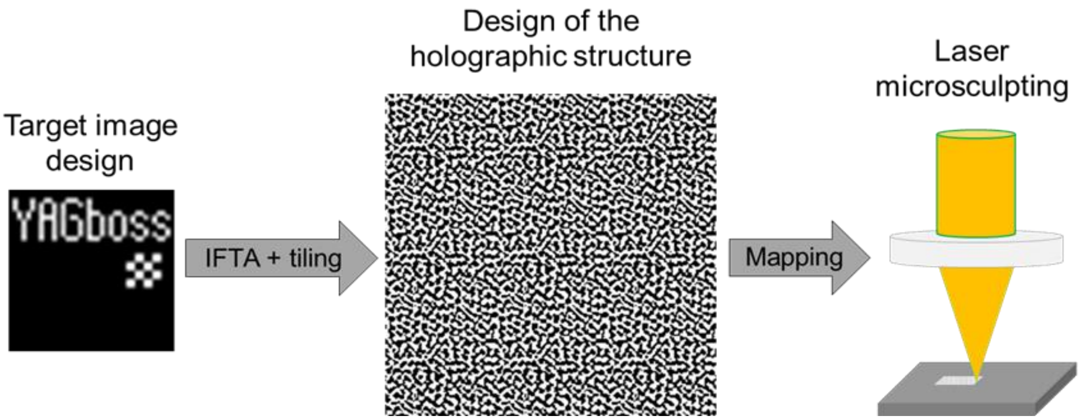

Fig. 1. *Fabrication process of phase holographic structures.*

The phase holographic structures on metals are generated by an 11±2.2µm diameter laser beam of wavelength 355nm and pulse duration 35ns (FWHM). The beam from a diode-pumped Q-switched 10W laser is delivered to the work piece via a 2-axis galvo-scanning system that enables fast generation of the holograms, with the processing speed of approximately 1000 hologram pixels per second. The galvo scan head is combined with the laser such that pulses are delivered on demand to a defined location on the work piece, enabling accurate mapping of the hologram designs with the positioning accuracy of < ±1.5µm, as measured for individual hologram pixels.

3. Results and discussion

3.1. Two-level phase holographic structures

UV nanosecond laser pulses are able to produce optically-smooth surface deformations on different metals, as demonstrated in our previous work (see Wlodarczyk et al., 2014). These deformations are generated either by localized laser melting or a combination of melting and evaporation. The shape and dimension of these deformations depends on the laser processing parameters, in particular the pulse energy, and also the chemical composition of a metal. In the case of stainless steel, the laser-generated deformations are typically in the form of optically-smooth craters, whereas on nickel they can be either the craters or small bumps.

Figure 2 shows a fragment of a two-level (binary) phase holographic structure that was generated on the surface of stainless steel. The hologram contains optically-smooth craters of a depth approximately 200nm. The spacing between craters is around 7µm. This structure is able to produce a sharp diffractive image, as shown in Fig. 2d).

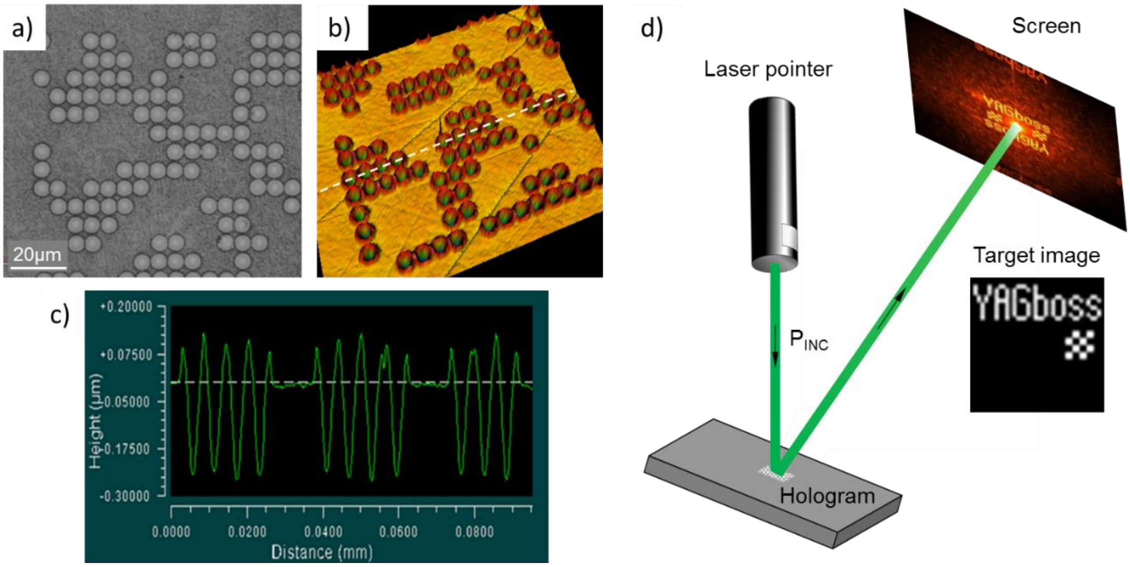

Fig. 2. Fragment of a 'binary' phase holographic structure generated on stainless steel: a) Leica optical microscope image, b) 3D surface profile, c) cross-section of the hologram pixels. The 3D surface profile and cross-section were measured using a Zygo surface profilometer. The hologram readout is demonstrated in d).

The laser-generated holograms can be read by using a low-cost handheld laser pointer. The laser pointer is used to illuminate the holographic structure in order to produce a diffractive image onto a screen in the far field. Typically, the screen must be located at least 1 meter away from the hologram. The binary hologram shown in Fig. 2 produces the 'YAGboss' inscription and a checkerboard pattern, making this consistent with the target image design, but there is also a 'twin' image that is rotated with respect to the other by 180 degrees. In addition, there is an undiffracted 0^{th} order beam. The appearance of the 'twin' image is a consequence of the hologram having only 2 phase levels, whereas the undiffracted beam results from the curved shape of the hologram pixels that introduces a non-discrete phase shift.

3.2. Multi-level phase holographic structures

The laser process also enables the generation of multi-level phase holographic structures on different metals. This is possible because our UV nanosecond-pulsed laser system is capable of repeatedly producing the laser-induced surface deformations of a specific depth with a depth accuracy of ±25nm. The multi-level holograms are particularly interesting as security markings because they cannot be simply generated by laser ablation.

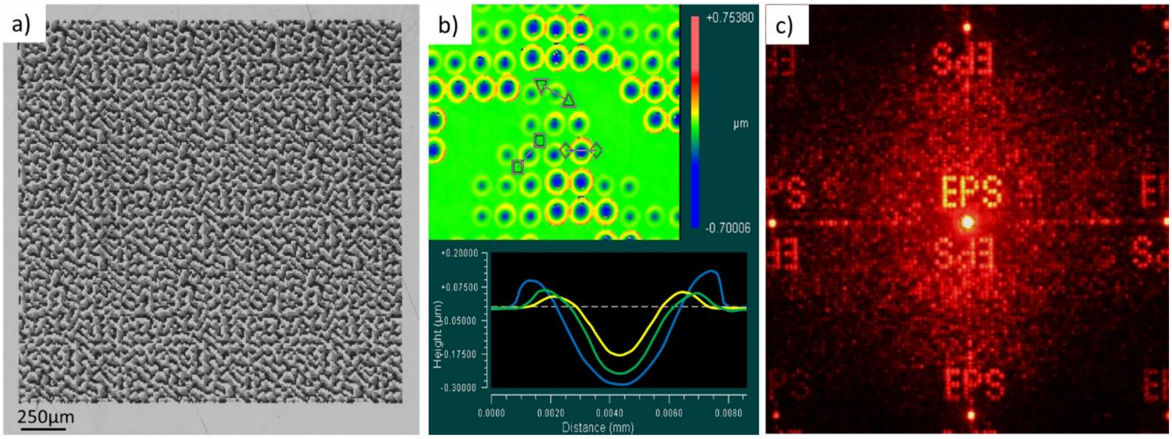

Fig. 3. Four-level phase holographic structure generated on the surface of stainless steel: a) optical microscope image, b) cross-section of the hologram pixels (measured using a Zygo surface profilometer). The diffractive image produced by a multi-level phase hologram is shown in c).

Figure 3 shows a four-level phase holographic structure that was generated on stainless steel. This structure contains optically-smooth craters of three different specific depths, as can be seen in Fig. 3b). These craters provide additional phase shifts to the structure, thus the intensity symmetry between the target and twin image can be broken, as demonstrated in Fig. 3c).

3.3. Tamper-proof security markings for luxury watches

The holographic structures can be generated on commercially-available metal products. Figure 4a) shows the laser-generated 'binary' hologram on the surface of a brand new stainless steel watch back cover. This structure contains approximately 320,000 optically smooth-craters and was generated in 5 minutes and 40 seconds. The hologram produces a strong diffractive image with the "#000" inscription, as demonstrated in Fig. 4b).

In order to evaluate the robustness of the laser-generated holograms to subsequent surface abrasion due to handling and wear, severe scratches were created by hand on the watch back cover surface using an abrasive paper (grit P120), as can be seen in Fig. 4c). Despite severe surface damage within the hologram area, this structure was still capable of producing a readable diffractive image, as demonstrated in Fig. 4d). This demonstrates that the laser-generated holograms are robust to local damage and hence are suitable as anti-counterfeiting (tamper-proof) security markings on many commercially-available metal products.

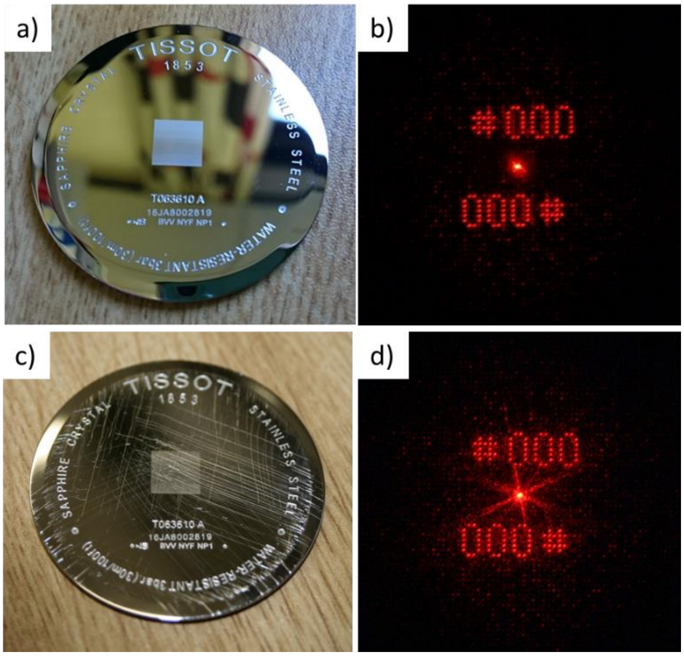

Fig. 4.: a) Brand new watch back cover with the embedded holographic structure, b) diffractive image produced by this hologram, c) the same watch back cover with severe scratches within the hologram structure, and d) diffractive image produced by the mechanically-damaged hologram.

4. Conclusions

We present a laser-based process that enables the generation of indelible and 'tamper-proof' security markings directly on a metal surface. The markings are in the form of phase holographic structures which are robust to local damage and mechanical abrasion. These structures can be easily generated on commercially-available high-value metal products, e.g. luxury watches, and used as security markings.

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