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Direct Laser Patterning as Alternative Method for Production of Thz Components and Plasmonic Structures

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Abstract

In this work we discuss the alternative laser patterning method for fabrication of the frequency selective components, plasmonic structures and compact optics on various metals. Research was focused on demonstration of the suitability of laser DLP process for THz components fabrication. Experiments with different DLP process parameters was performed to find optimal ones for fast fabrication procedure of various THz components. The fabricated structures morphology analysis in terms of shape accuracy and processing quality was estimated. Finally the performance of fabricated components was tested.

KeyWords: Laser Ablation; Micro-Cutting; THz components; Thin film; Foil;

1. Introduction

Recent progress in development of compact THZ sources and sensors cause a potential need of compact optical passive components – filters, lenses, mirror and diffraction gratings for THz imaging systems. The main technology for such components fabrication is photolithography that combines many subprocesses - mask production, surface preparation and cleaning, photoresist coating, masks alignment followed by exposure, photoresist development, sampel etching and cleaning [1]. In some cases, such multistep technique is inefficient in term of time and money, especially for a versatile and small-volume production.

Direct laser patterning (DLP) technology was recently proposed for a mask-less fabrication of THz components such as resonant filters [2], terahertz zone plates with added frequency selectivity [3], and plasmonic metal films [4]. DLP is very convenient for its capability to fabricate micro apertures and surface

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patterns in a broad range of materials including plastics, dielectrics, metals, and others. Laser-based technologies like laser photo-polymerization [5], laser microlens array lithography [6], laser-induced forward transfer [7] were successfully demonstrated for production of THz and infrared metamaterials.

In this work, properties of the frequency selective components and plasmonic structures produced by the direct laser patterning of various metals are discussed. The key advantage of the mask-less DLP technology is flexibility for the design changes in production of THz devices and materials.

2. Results

The DLP system consisting of a laser source, focusing objective and sample positioning stage was used in experiments. For fabrication of THz bandpass filters the cross shaped apertures with a specific length and arm width were cut in 30 µm-thick molybdenum (Mo) foil by scanning the focused laser beam along the predefined ouline [2] (Fig. 1b). The periodically distributed cross-shape apertures were cut in the area of 1 cm^2 (Fig. 1a). The 30 ps pulsed laser source with 355 nm wavelength and maximum pulse energy of 50 µJ at 100 kHz rep rate (Ekspla Ltd.) was used in experimets. Firs axperiments were performed to find the optimal processing parameters for fast aperture cutting while maitaning the final structure quality. For this reason apertures were cut by varying laser pulse energy, scanning speed and number of scan iterations (number of scans).

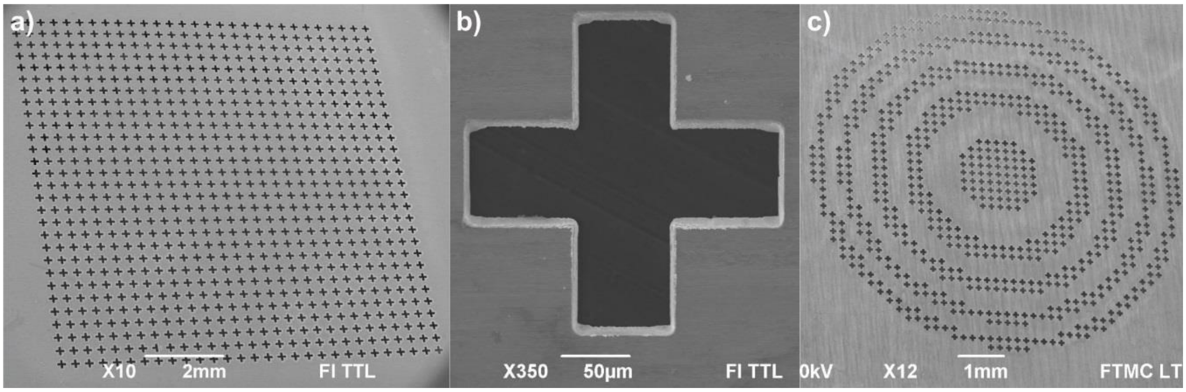

Fig. 1. SEM image of the resonant THz band-pass filter (center transmission frequency 0.7 THz) (a, b) and zone plate with integrated band-pass filter (c) fabricated in the 30 µm-thick molybdenum foil employing the DLP technology.

The center wavelength of the band pass filter depends on the length of the cross aperture as $\lambda_{max} = 2.1L$ [1]. The width (W) and period (P) for filter fabrication was chosen respectively $W = 0.3L$ and $P = L/0.65$. The production time of the band-pass filter depends on the structure period, laser scanning speed, number of scans and total fabrication area. Fig. 2 presents the SEM images of cross apertures outlet cut in the molibdenum foil using different procesing parameters. The results shows that aperture shape acurancy is better when the longer time it takes to fabricate that filter. However there is a combination of processing parameters that coresponds to the same processing time but produces different aperture quality (Fig. 2a,b). The more accurate the aperture shape is the better wuold be the performanse of the band pass filter.

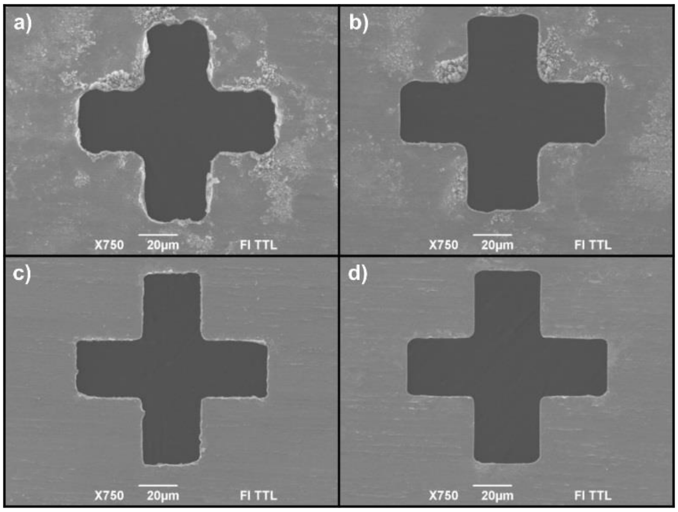

Fig. 2. The SEM image of ablated cross shaped holes outlet in molybdenum film using different processing parameters (pulse energy\scan speed\number of iteration\1 cm^2 fabrication time): a) 11.3 µJ \ 100 mm/s \ 25 \ 34 min.; b) 11.3 µJ \ 25 mm/s \ 10 \ 34 min.; c) 9.1 µJ \ 10 mm/s \ 5 \ 36 min.; d) 9.1 µJ \ 10 mm/s \ 10 \ 72 min.;

The laser cut quality also have to be considered as it affects the filter performance too. For this reason the experiments on laser cutting of Mo film using femtosecond (300 fs, 355 nm, 20 µJ at 100 kHz, Light Conversion Ltd) laser was also performed and resulted in much better cut quality (Fig. 3).

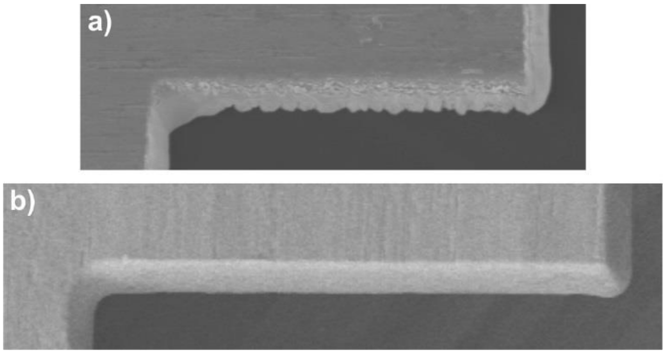

Fig. 3. SEM image of the cross shaped aperture fragment made in molibdenum foil using 30 ps (a) and 300 fs (b) pulse laser with optimized procesing parameters.

DLP with femtosecond laser and optimized procesing parameters was used for more sophisticated optical components – terahertz zone plate with integrated resonant apertures (TZP), production (Fig. 1c). The focusing charakteristics of such zone plates showed better performance that the same zone plate without band-pass filter (more details in Ref.8).

The thickness of the metal has a little influence on the transmission spectrum of the filter if it is smaller than the length of the cross aperture. Otherwise, the thinner metal foil is needed, but the thinner metal foil is less rigid. Consequently, the best way is to use a thin metal film deposited on a substrate made of transparent for THz radiation material. In this case, we used a 25 µm-thick polyimide (PI) with the 50 nm-thick molybdenum film deposited on top. The direct laser ablation was used to open the cross-shaped areas on the metalized PI (Fig. 4).

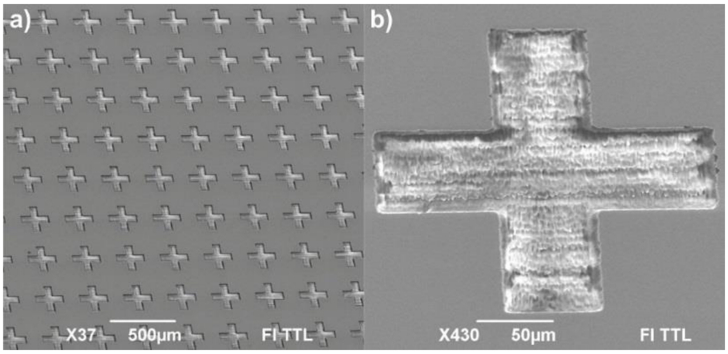

Fig. 4. SEM images of the resonant THz band-pass filter made in the Mo film on the PI substrate designed for the peak transmission at 0.54 THz;

The ablation strategy for Mo/PI sample was different than for Mo foil. In case of Mo foil the laser spot was scanned only along the contour of the cross-shaped apertures (Fig. 5a). At the same time the laser spot on Mo/PI sample should be scanned all over the area of the cross opening with small steps of 2 µm ((Fig. 5b) that would require more fabrication time. However, in the Mo/PI case, only one scan with the maximum speed (200 mm/s) was needed to remove the metal film while in case of the Mo foil, at least 3 scans with the 50 mm/s speed was required for the intermediate quality results (when femtosecond laser is used). Fig. 5c presents the fabrication time dependence on the center frequency of the filter made in 20x20 mm^2 area. The fabrication time in the Mo film on PI does not depended on the center frequency of the filter (on the size of the crosses and structure period) while it increases linearly in case of the Mo foil. It follows that thinner metal layers should be selected for faster production of the filters with a centre frequency higher than 0.7 THz.

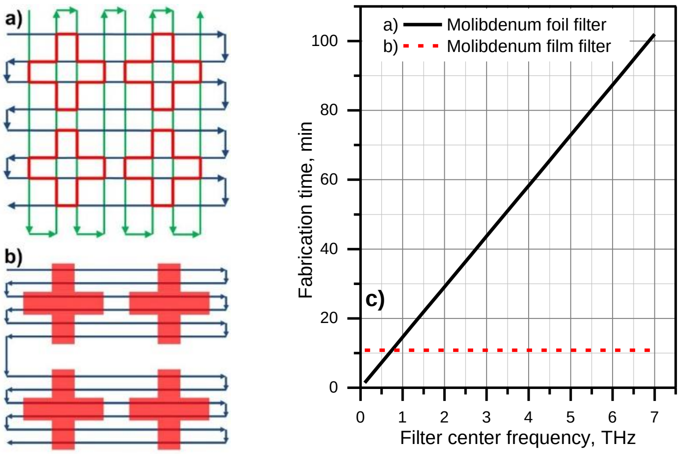

Fig. 5. Strategies of laser beam scanning of DLP system for the cross-shaped hole formation in the stainless steel foil (a) and the molybdenum film on the polyimide substrate (b) and dependence of the fabrication time on the canter frequency (c) of the filter made in the 20x20 mm^2 area of the Mo foil (black line) and the Mo film deposited on the PI substrate (red line). The Fabrication parameters for the Mo foil were: scan speed - 50 mm/s, process iterations – 3; and for the Mo film on PI were: 200 mm/s and one iteration, respectively.

DLP was also used for the reflective diffraction grating groove formation on the aluminum surface. The periodically distributed cross-shaped grooves with 80 µm depth, 60 µm length and100 µm period were formed on the area of 20x20 mm^2 aluminum surface (Fig. 6). The fabrication procedure was the same as for the molybdenum foil, except that only two runs per cross were needed, due to a thin cross arm width. Nevertheless, the production took about 85 minutes because 105 number of scans was needed to reach the 80 µm depth of the grooves.

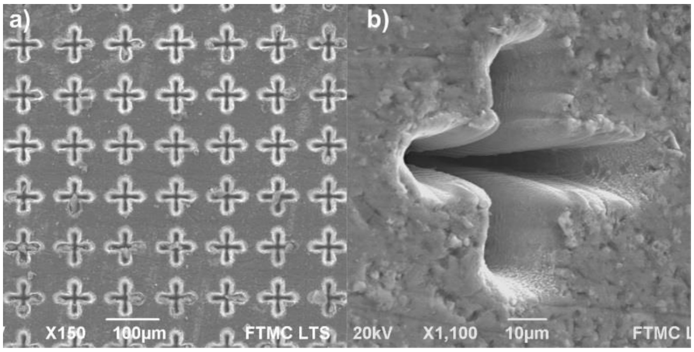

Fig. 6. SEM image of the periodically distributed cross shaped grooves formed on aluminium surface using DLP with laser scan speed – 100 mm/s and number of scans – 105.

Finally, the spectral performance of the THz filters fabricated by the DLP on Mo foil and Mo film deposited on polimyde substrate was characterized and is presented inFig. 7. The peak transmittance of the resonant filters made of the Mo foil and the Mo film supported by PI substrate was in the range of 90%-95% and 30-40%, respectively.

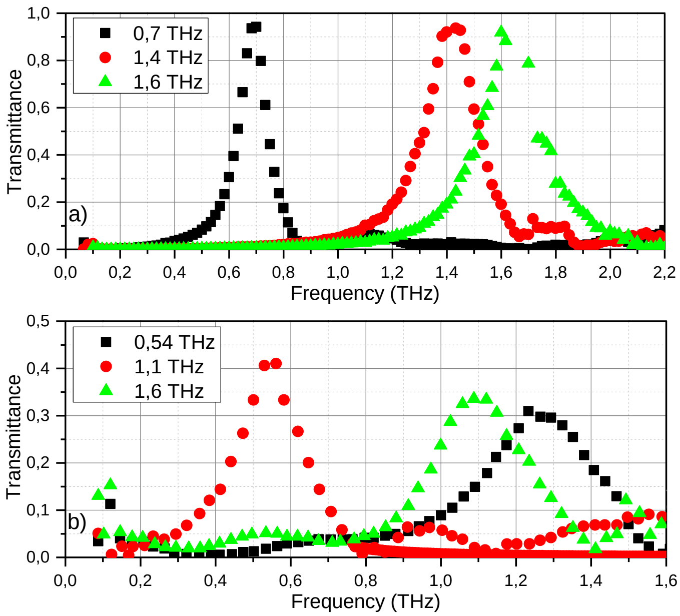

Fig. 7. Measured transmittance of the THz band-pass filters designed for different peak frequencies on Mo foil (a) and Mo film deposited on polimyde substrate (b).

3. Summary

It was showed that DLP was suitable as a one-step technology for fabrication of the THz metal mesh filters, zone plates and reflection gratings. The quality of fabricated structures was sufficient to fulfill the performance requirements for a certain THz components. Also, it was showed that same laser fabrication system can be used for fabrication of different types of materials that are needed for particular THz components.

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