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Fresnel Lenses fabricated by femtosecond laser micromachining on Polymer 1D Photonic Crystal

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Abstract: We report the fabrication of micro Fresnel lenses by femtosecond laser surface ablation on polymer 1D photonic crystals. This device is designed to focus the transmitted wavelength of the photonic crystal and filter the wavelengths corresponding to the photonic band gap region. Integration of such devices in a wavelength selective light harvesting and filtering microchip can be achieved.

1. Introduction

The miniaturization and integration of optical devices has great advantages and is a sure step forward in achieving very efficient lab on chip devices. Integrating many different functionalities in the same device not only makes it more versatile and robust and goes in the direction of cost reduction. Femstosecond laser (fs-laser) micromachining is the technique we employ to develop and fabricate such devices.

Femstosecond laser (fs-laser) micromachining is a versatile tool for fabricating complex microfluidic, optofluidic networks and circuits. This technique can be used in surface as well as bulk micro structuring of transparent, and on the surface for opaque materials. Inarguably, the biggest advantage of the technique lies in the fact that it does not require masking steps, allowing fabrication of inherent 3D structures [1]. The other fabrication techniques like photo lithography involve cumbersome masking steps, rendering the technique inefficient in terms of rapid prototyping. Alternative fabrication technique employ nanosecond and picoseconds laser pulses for micromachining, but thermal effects play spoilsport in these methods. In fs-laser micromachining, the rapid deposition of energy and the absence of thermal effects due to ultrashort pulses initiates non linear absorption processes, thus restricting the damage only to the focal volume [2]. Also, the ablation threshold is reduced and the material removal is instantaneous, leading to very precise micromachining.

Fresnel lenses with their properties like high numerical apertures and small focal lengths are desirable in applications concerning light harvesting for microfluidic based sensors. Binary Fresnel lenses (BFL) are the preferred choice for integrated devices, due to the ease of fabrication. Polymer-based BFLs on PMMA substrates have been reported very recently [3]. Polymeric materials offer many advantages in terms of low cost and ease of microstructuring. In this work we propose integration of polymeric BFLs on polymeric 1D photonic crystals (1DPC) [4], allowing the achievement of wavelength selective focusing and filtering in the same device.

2. Femtosecond laser micro fabrication of Fresnel lenses

The design of BFLs is governed by the following equation for the radius r of outermost zone, given by;

$$r^2 = 2j\lambda f \tag{1}$$

where, j is the number of the zone, λ is the wavelength of light in vacuum, and f is the focal length of the lens. The 1DPC was fabricated by spin coating of alternating layers of two different polymers, Polystyrene mono carboxy terminated and Cellulose acetate, with refractive indices of 1.58 and 1.475 respectively. BFLs with focal length of 5mm, 1mm and 0.5 mm were fabricated on 1DPC.

A high repetition rate Yb:KGW diode pumped, fs-laser based on chirped pulse amplification was used for fabricating the BFLs. The amplifier produced femtosecond pulses at 1030nm with 280fs pulse duration, which were converted to second harmonic at 515nm . The sample was translated by a 3 axis stage for achieving the desired lens. The pulse energy was set to 2nJ, at 500KHz repetition rate. The speed of fabrication was set at 0.1mm/s. The pulse density was 500,000 pulses/mm. Each BFL zone was created by close concentric circles, with a pitch of 600nm between each other. This ensured a good quality zone with sufficient overlap of the ablated regions. Figure 1 is the image of the 5mm focal length BFL fabricated on the 1DPC with a transmission at 520nm and band gap at 630nm. The reflectivity at the band gap was about 30%.

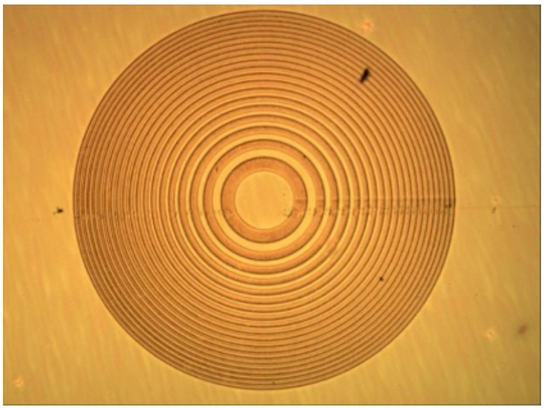

Figure 1. The image of 5mm focal length BFL fabricated on 1DPC by fs-laser micromachining

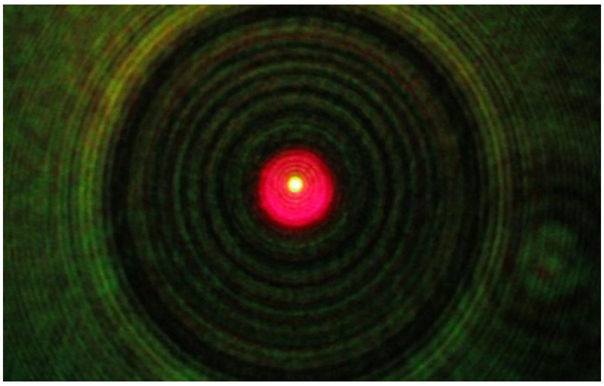

Figure 2. Image of the focal spot of Fresnel lens fabricated on the polymer 1DPC

3. Initial Results

To check the operation characteristics of the fabricated BFL, we impinge on the device both green light at 530 nm and red light at 630nm. The BFL is designed to focus the light at 520nm, corresponding to maximum transmission of the 1DPC. Figure 2 indeed demonstrates the selective focusing of the green light. It is clear from the figure that the device works as expected. Even though the band gap is around 630 nm we still see some red light in the picture since the 1DPC has a reflectivity of only 30%. Nevertheless, the experiment is a good proof of principle. The focal lengths were measured and were in good agreement with the expected values. The efficiency of the BFL's fabricated was found to be around 12.5 %, while the maximum theoretical efficiency is 40%. This can be attributed to residual roughness of the surface of the 1DPC and also non homogeneous depth of the rings of the Fresnel lens.

The future work lies in improving the efficiency of the filtering by 1DPC and of the focusing by BFLs. The former involves testing different combinations of polymers, with different refractive indices, while the latter involves better tuning and control of fabrication parameters.

4. References

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