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Thin-films microstructuration through photolithography

Microestructuración de películas delgadas mediante fotolitografía

ALVARADO-LÓPEZ, Joel Isaac†[1], INCLAN-LADINO, Adriana[2], LÓPEZ-VILLEGAS, Rubén[3] and TELLEZ-LIMON, Ricardo*[4]

[1]Instituto Tecnológico de Nuevo León. Av. Eloy Cavazos 2001, Colonia Tolteca, CP 67170, Guadalupe, Nuevo León, México.
[2]Facultad de Ciencias Físico Matemáticas, Universidad Autónoma de Nuevo León. Av. Universidad S/N, Ciudad Universitaria, CP 66451, San Nicolás de los Garza, Nuevo León, Mexico.
[3]Unidad Monterrey, Centro de Investigación Científica y de Educación Superior de Ensenada. Alianza Centro 504, PIIT, CP 66629, Apodaca, Nuevo León, Mexico.
[4]CONACYT – Unidad Monterrey, Centro de Investigación Científica y de Educación Superior de Ensenada. Alianza Centro 504, PIIT, CP 66629, Apodaca, Nuevo León, Mexico.

ID 1st Author: *Joel Isaac, Alvarado-López* / **ORC ID**: 0000-0002-7633-6040

ID 2nd Coauthor: *Adriana, Inclan-Ladino* / **ORC ID**: 0000-0002-7032-5172, **CVU CONACYT ID**: 483091

ID 3rd Coauthor: *Rubén, López-Villegas* / **ORC ID**: 0000-0003-2568-793X, **CVU CONACYT ID** 200899

ID 4th Coauthor: *Ricardo, Tellez-Limon* / **ORC ID**: 0000-0002-8028-9216, **CVU CONACYT ID** 290862

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Abstract

In recent years, micro and nanotechnology have undergone a rapid development due to their applications in different scientific areas such as metaphotonics, an emerging branch of optics that studies the interaction of light with micro and nanostructured metamaterials. Our particular interest is the development of integrated metaphotonic devices for lab-on-a-chip biosensing applications. A widely used technique for the manufacture of integrated optical devices is photolithography, which is based on the processing of UV-light-sensitive photoresists to create masks for the deposition of thin films and generate the desired devices. In this contribution, we present an experimental methodology for the patterning of plasmonic waveguides using a photolithography system for printing SU-8 photoresist masks on glass substrates. We show the necessary parameters to optimize the photoresist printing (beam waist, focal distance and fluence) under normal conditions and the characterization of the samples through atomic force microscopy. Due to the aspect ratio between the width of the waveguides and thickness of the photoresist, the obtained results approach us to the development of multilayered systems for new integrated metaphotonic devices.

Photolithography, Metaphotonics, Integrated optics

Resumen

En años recientes la micro y nanotecnología se han desarrollado rápidamente por sus aplicaciones en diferentes áreas científicas como la metafotónica, rama emergente de la óptica que estudia la interacción de la luz con metamateriales micro y nanoestructurados. Nuestro interés particular es el desarrollo de dispositivos metafotónicos integrados para aplicaciones de biosensado tipo lab-on-a-chip. Una técnica ampliamente utilizada para la fabricación de dispositivos ópticos integrados es la fotolitografía, la cual está basada en el procesamiento de foto-resinas sensibles a la luz UV que permiten crear mascarillas para depositar películas delgadas y generar los dispositivos deseados. En este trabajo presentamos una metodología experimental para la impresión de guías de onda plasmónicas haciendo uso de un sistema de fotolitografía para imprimir mascarillas de foto-resina SU-8 sobre sustratos de vidrio. Mostramos los parámetros necesarios para optimizar la impresión de la foto-resina (cintura del haz, distancia focal y fluencia) en condiciones normales y la caracterización de las muestras mediante microscopía de fuerza atómica. Debido a la relación de aspecto entre el ancho de las guías y espesor de la foto-resina, los resultados obtenidos nos acercan al desarrollo de sistemas multicapas para nuevos dispositivos metafotónicos integrados.

Fotolitografía, Metafotónica, Óptica integrada

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* Correspondence to Author (Email: rtellez@conacyt.mx)
† Researcher contributing as first author.

Introduction

In recent years, micro and nanotechnologies have been rapidly grown because of their applications in different research areas. Such is the case of metaphotonics, an emerging field of optics that studies the interaction of light with micro and nano-structured metamaterials, taking into account, both, electric and magnetic field interactions. Of our particular interest is the study of integrated metaphotonic devices for the development of a new generation of lab-on-a-chip biophotonic sensors.

The operation principle of these novel devices is based on the excitation of plasmonic resonances in metamaterials through photonic guided modes. These systems allow light focusing in submicron regions, serving as transductors for single molecule detection.

However, for the fabrication of these devices is necessary to use expensive and advanced technologies, such as electron beam lithography. An alternative is photolithography, a versatile and low-cost technique that has been widely used for the fabrication of electronic transistors and microcontrollers. Although the size of the patterns that can be printed with this technique are diffraction-limited, they can be very useful for the development of micrometric metaphotonic systems, such as metalenses, integrated gratings or plasmonic waveguides.

In this contribution, we explore the use, advantages and limitations of a simplistic photolithography setup as a platform for the fabrication of integrated metaphotonic devices. To this purpose, we developed an experimental methodology for SU-8 photoresist patterning on top of glass substrates. We describe the system and show the optimization of the principal optical parameters required for a proper photoresist micro-patterning. We also show the characterization of the fabricated samples by making use of optical microscopy and atomic force microscopy (AFM). Due to the aspect ratio between the width and thickness of the printed patterns, the obtained recipe opens new perspectives for the development of multilayered metaphotonic systems, that can be applied, for instance, as non-reciprocal waveguides or hyperbolic metamaterials for biosensing. These objectives are part of the Project “Cátedras-CONACYT” entitled “Development of communication and biosensing systems for e-health applications”.

Methodology

For the photo-resist patterning, the samples were prepared as follows. First, a 1cm x 1cm glass substrate was deeply cleaned using dishwashing detergent, isopropyl alcohol and acetone, and was dried with pressurized air. After pouring some drops of SU-8 negative photoresist on the substrate, the sample was spinned-up at 3000 rpm for 30 s with a spin-coater. Finally, the sample was soft baked at 100° C for 1 minute with a hot plate.

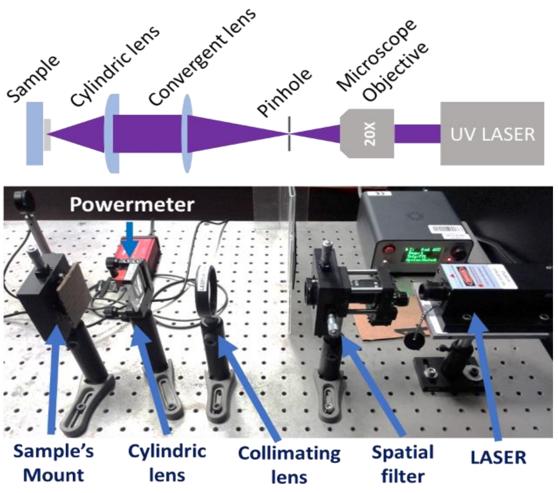

Figure 1 Schematic of the experimental photolithography system (top) and image of the experimental setup (bottom)

Once the samples were prepared, they were exposed to the UV light by making use of the experimental setup shown in Figure 1. The system consists of a UV laser operating at a wavelength of 405 nm and a maximum optical power of 50 mW. The laser beam is spatially filtered with an infinity corrected microscope objective (20X, NA=0.40) and a pinhole of 2 µm diameter.

The beam is collimated with a convergent lens of focal distance 75 mm and 2” diameter, and then focused with a cylindrical lens of 25 mm focal distance. This lens generates a line of light that was focused on the surface of the prepared sample.

To measure the optical power of light impinging the sample, we used an optical power meter (Thorlabs PM100USB with S120C detector). At the bottom of Figure 1, is shown a picture of the actual experimental setup. We must notice that the mount of the sample should be placed as precise as possible at the focal distance of the cylindrical lens to reduce the size of the line illuminating the sample.

After UV-light exposure, the sample was hard baked at 100°C for 1 minute, and then developed by washing it in cold developer (at 4° C) for 1 minute. The development process was stopped with distilled water, and the sample was finally dried with pressurized air. We must remark that all the fabrication process was performed in a dark room illuminated with near infrared light to avoid photoresist over exposure.

Results

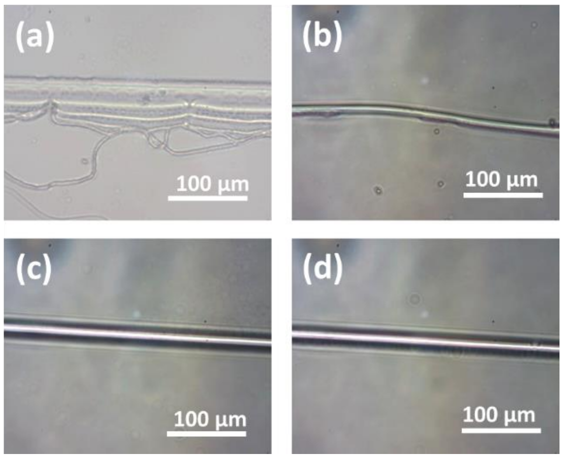

Figure 2 Optical microscope images of different samples as a function of the optical energy (optical power per unit time) (a) E=450 mJ, (b) E=2400 mJ, (c) E=1560 mJ and (d) E=1750 mJ.

In Figure 2 are show the images obtained with an optical microscope of some fabricated samples. In these images can be observed a qualitative dependence of the shape of the printed pattern as a function of the optical energy (optical power per exposure time) at which the samples were exposed.

In Figure 2a can be observed that the printed line is not well defined because the optical energy (*E*=450 mJ) was too low, meaning that the sample was underexposed. By the other hand, when the optical energy was too high (*E*=2400 mJ), the sample was overexposed, reducing the size of the pattern as well as the adhesion of the photoresist to the substrate, leading to a deformation of the pattern (Figure 2b). When the optical energy of impinging light was between *E*=1400 mJ and *E*=2000 mJ, the line patterns where well defined, with good adhesion, low lateral roughness and almost without deformation.

To complete the characterization of the samples, we measured the topography and transverse profile of the patterns with an atomic force microscope (AFM).

In Figure 3a is shown the topography of a 100 µm x 100 µm region of a sample exposed to an optical energy of E=1600 mJ (40 mW for 40 seconds). From this image, the average height of the pattern was about 2.1 µm respect to the surface of the substrate. The black arrow line indicates a region where the transverse profile of the pattern was measured (Figure 3b). From this profile, the width of the pattern was about 28.5 µm, being confirmed a low lateral roughness of the photoresist.

The results in Table 1 summarize the widths of different samples exposed at different optical energies, being indicated the optical power and exposure time as well.

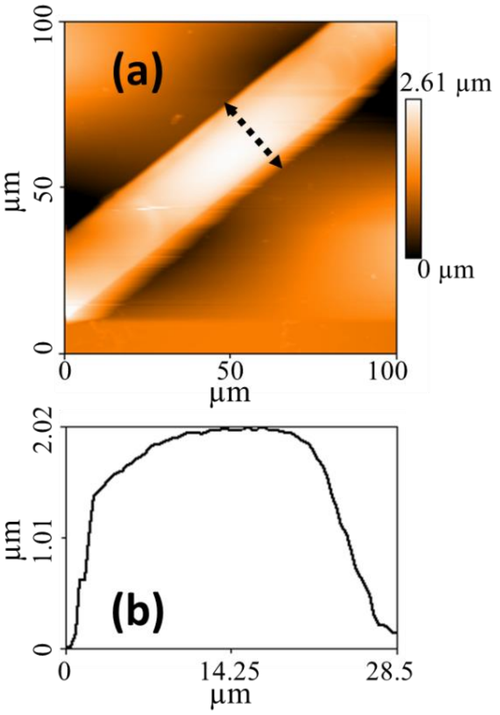

Figure 3 (a) AFM image of the topography of the line patterned on the SU-8 photoresist exposed at E=1600 mJ. The black-dotted arrow line indicates the region where the profile (b) was measured, which reveals that the width of the structure was about 28.5 µm

Optical Power (mW)	Exposure time (s)	Optical energy (mJ)	Width (µm)
40	35	1400	29.9
40	40	1600	28.5
40	45	1800	29.2
40	50	2000	23.8

Table 1 Width of the lines patterned on the SU-8 photoresist as a function of the optical power and exposure time (optical energy)

Conclusions

In conclusion, through the methodology developed for a simple non-commercial, simple and low-cost photolithography system, we were able to fabricate patterns on negative SU-8 photoresist of 2 µm thickness, being obtained an average resolution of the patterns around 28 µm. This resolution can be further improved by using lenses with larger numerical aperture and having a more precise control of the position of the sample relative to the focal plane of the cylindrical lens, such that the waist of the beam is focused as close as possible to the surface of the sample. Due to the aspect ratio between the width and height of the printed lines, is possible to use them as masks for the fabrication of multilayered plasmonic waveguides.

The low cost of the proposed system and easiness of the methodology bring us a first approach for the development of a platform to fabricate integrated metaphotonic devices that can be applied in different research areas, such as lab-on-a-chip biosensing or optical communications, outstanding areas that are in continuous progress.

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