Optical and Plasmonic Devices Realized by UV-LED-Based Projection Photolithography

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***Abstract*— A simple and cost-effective UV-LED-based microscope projection lithography technique for the manufacturing of optical and plasmonic devices as well as their functionalities is demonstrated.**

***Keywords*— plasmonic; optical fabrication; photolithography; projection lithography**

I. Introduction

Miniaturization and integration are important and demanded for the advancement of photonic, optoelectronics and micro- or nanoelectromechanics devices. To meet these demands, manufacturing technologies enabling high-resolution and highly reproducible optical structuring at the micro- and nanoscales are required. So far, various technologies have been developed and extensively used for micro- and nanofabrication. Direct laser writing-based two-photon lithography [1–5], electron beam lithography [6–8] and focused ion beam lithography [9–11] implement fabrication through direct writing processes. They do not require masks, but the fabrication processes are rather slow and the fabrication system are costly. Nanoimprint lithography [12–14] is capable of achieving high throughput on the other side. However, a high-resolution mask, which is usually produced via electron beam lithography, is needed for this process..

In this work, we developed a simple and low-cost UV-LED-based lithography system toward rapid high-quality micro- and nanofabrication. The structuring can be implemented within seconds based on a standard microscope projection photolithography (MPP) process. With the developed approach, various optical and plasmonic structures, i.e. straight waveguides, microring resonators and plasmonic crossed waveguides, were successfully produced. Furthermore, their functionalities, i.e. light guiding, optical coupling and switching, were studied and characterized. The demonstrated results show that this simple, low-cost and highly efficient approach is capable of performing high-resolution structuring for nanophotonics, optoelectronic and micro- and nanoelectromechanics applications.

II. Results and Discussion

The proposed UV-LED-based projection photolithography system was established using standard components which are commercially available. A detailed introduction of the setup can be found in [15, 16]. An organic-inorganic hybrid photopolymer [17] was used for the fabrication of structures demonstrated in this work.

A. Optical waveguides

Optical waveguides with microscale dimension were first fabricated using the developed system. Fig. 1a is the SEM image of an array of waveguides with a designed width of 8 µm. A good structure uniformity can be seen. A 3D microscope image and the profile of the obtained waveguides are shown in Fig. 1b and 1c, respectively. The waveguide has a measured width of approx. 8 µm and height of approx. 4 µm. The image in Fig. 1c exhibits almost a vertical profile of the waveguide. This indicates the that MPP is capable of achieving high-quality structure formation. To investigate the functionality of the produced structures, a HeNe laser with the wavelength of 633 nm was coupled into the waveguide. A microscope image showing the light guiding in the waveguide is illustrated in Fig. 1d. These results demonstrate the functionality of the obtained waveguides, as well as the capability of the proposed approach in micro- and nanofabrication.

B. Microrings

Microring resonators were also designed and produced using MPP. Fig. 2 shows a SEM image of a microring with a diameter of 100 µm and a linewidth of approx. 4.3 µm. The obtained microring exhibits high smoothness and good structure formation. A characterization experiment was performed to inspect its functionality. To enable the coupling

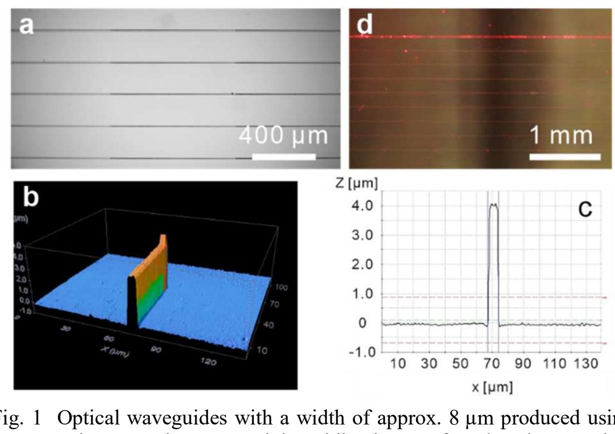

Fig. 1 Optical waveguides with a width of approx. 8 µm produced using MPP. **a** Microscope images. **b** Light guiding image of produced waveguide. **c** Confocal microscope image of a waveguide. **d** Profile of the waveguide.

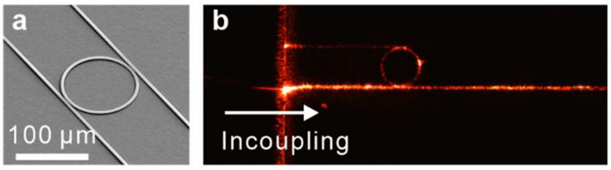

Fig. 2 SEM image of a microring (**a**) and microscope image showing the light propagation in the structure when coupled to a laser beam (**b**).

of light into a waveguide, the sample was cleaved to enable the light coupling into the waveguide through the cross section. Here, a laser beam at 633 nm was coupled into the cleaved bus waveguide, the coupling of light into and out of the ring resonator was observed using a CCD camera. Fig. 2b is the image showing the coupling performance. It can be seen that light coupled into the bus waveguide was successfully coupled into the resonator. Output signal on the other bus waveguide is also visible. The observed light propagation indicates that the produced structure is functional. A detailed performance investigation will be further performed.

C. Plasmonic crossed waveguides

To explore the capability of the proposed approach in the fabrication of elements for nanophotonics application, crossed waveguides with feature sizes at the submicron scale for optical switching were designed and manufactured. Fig. 3a is the SEM image of three crossed waveguides with the widths of 300 nm, 400 nm and 500 nm, respectively. A smoothness and good formation of the structures can be seen.

The obtained crossed waveguides were characterized using a leakage radiation microscopy [18–20], in which surface plasmon polaritons (SPPs) can be excited when a focused laser beam hits onto a surface defect. A laser source with a wavelength of 800 nm was used in this setup (more information can be found in [20]). As the optical switching performance is realized based on interference, two excitation laser beams are required for the experimental investigation. To achieve this, a beam splitter was employed to generate two identical excitation beams. These two beams were focused onto the end of two crossed waveguides, respectively, to excite SPPs propagating in the waveguides. The phase difference of the two beams can be tuned by controlling their optical path difference to the sample surface. The output signal from the middle waveguide that starts from the junction of the two crossed waveguides was observed and used for the evaluation of optical switching effect. Fig.3b and 3c are images showing the status of “on” and “off”, respectively, realized on the crossed waveguide with the width of 500 nm. When the two laser beams have a phase difference of 0 (in phase), the two excited SPP waves encounter at the junction and generate constructive interference. Therefore, light propagating through the middle waveguide with an output signal (status “on”) is seen. A status of “off” is resulted when the two excitation laser beams have a phase difference of π (out of phase). In this case, no output signal is delivered from the middle waveguide due to the destructive interference of the excitation beams when encountered.

III. CONCLUSION

In this work, a UV-LED-based microscope projection lithography technique was developed toward low-cost and

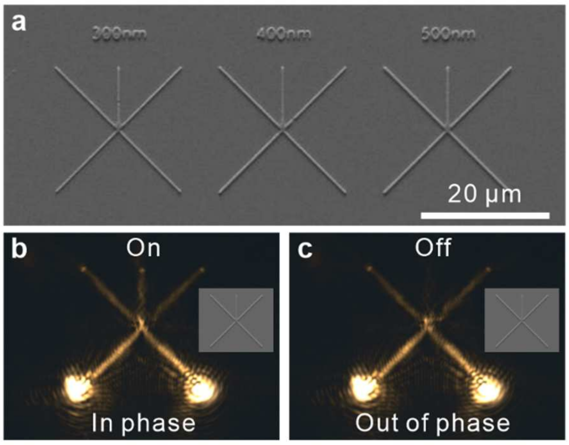

Fig. 3 **a** SEM image of plasmonic crossed waveguides. **b-c** Leakage radiation microscopy images showing the status of “on” (b) and “off” (c) on the crossed waveguide with a width of 500 nm.

rapid optics manufacturing. Various optical and plasmonic devices, including optical waveguides, microrings and plasmonic crossed waveguides, were fabricated and characterized in terms of their functionalities. The results demonstrate the capabilities of this low-cost technique in highly efficient and geometrically flexible micro- and nanofabrication. It offers an alternative approach for the production of optical elements and devices for applications in fields, i.e. sensing and monitoring, data communication, among others [21–24].

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