Fabrication of subwavelength-structured hollow waveguide array by two-photon polymerization

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The fabrication of a metallic subwavelength hollow waveguide array is discussed. We produce a negative sample of the structure using two-photon polymerization and a subsequent sputtering process to fabraicate the metallic hollow waveguide array. A linewidth of $d = 0,28\,\mu\mathrm{m}$ and an aspect ratio of $r_\mathrm{a} = 8$ is achieved by two-photon polymerization in a positive tone photoresist.

1 Introduction

The ongoing trend to miniaturization of electronic and optical devices encourages the development of fabrication technologies on a nanometer scale. In particular, optical structures with subwavelength dimensions attract much interest in current research activities, e.g., in the field of plasmonics [1] and metamaterials [2]. Here we report on the fabrication of a subwavelength hollow waveguide array which acts as a polarization converting element for an incident light wave of $\lambda = 1064\,\mathrm{nm}$ [3]. The geometry of the structure is illustrated in figure 1.

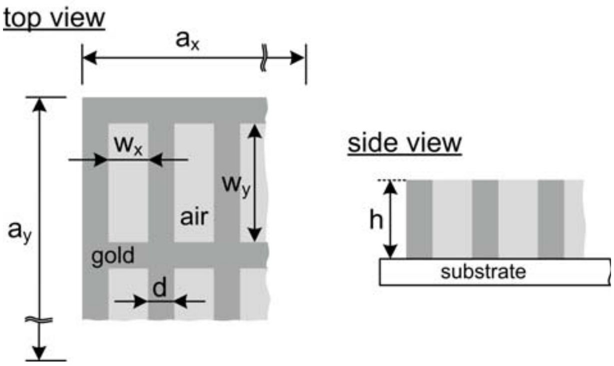

Fig. 1 *Subwavelength hollow waveguide array*

The subwavelength hollow waveguide array consists of a metallic frame (gold) filled with air. The linewidth of the frame is $d = 0,28\,\mu\mathrm{m}$ with a height of $h = 2\,\mu\mathrm{m}$ and therefore an aspect ratio of $r_\mathrm{a} = 6.6$. The dimensions of the air windows are $w_x = 0,64\,\mu\mathrm{m}$ and $w_y = 1\,\mu\mathrm{m}$. The overall dimensions of the array are $a_x = 800\,\mu\mathrm{m}$ and $a_y = 800\,\mu\mathrm{m}$. In this contribution, we report on the successful fabrication of the subwavelength element using two-photon polymerization and a subsequent sputtering process. The two-photon polymerization is used to generate the negative of the subwavelength element into a positive tone photoresist. After developing the resist, gold is sputtered into the lithographically opened areas to fabricate the metallic frame. The structures are characterized with an atomic force microscope (AFM) and a laser scanning microscope (LSM).

2 Fabrication

The fabrication steps are listed in table 1 and are specified in detail:

	Fabrication steps
1.	Substrate preparation
2.	Spin coating
3.	Soft bake
4.	Exposure
5.	Post exposure bake
6.	Development
7.	Metallization
8.	Lift-off

Tab. 1 *Fabrication steps*

1. Substrate preparation: The substrate (microscopic cover glass, BK7) is placed on a heating plate at 120 °C for 10 min to improve the adhesion between photoresist and substrate.
2. Spin coating: A thin primer layer (Ti prime) is applied to improve the resist adhesion on the glass substrate. Followed by spin coating the photoresist (AZ 3027).
3. Softbake: The coated photoresist is placed on a heating plate at 95 °C for 6 min.
4. Exposure: The exposure is performed by a 3D laser lithography system (Nanoscribe Professional GT). To reach a line width of $d = 0,28\,\mu\mathrm{m}$, an ultra short pulse laser is focused into the photoresist and the two-photon polymerization is generated only in the focal volume of the microscope objective. For the polymerization we use a writing speed of $v = 5\,\mathrm{mm/s}$ and a laser power of $P = 6,8\,\mathrm{mW}$. The structure is build by a layer-by-layer process.
5. Post exposure bake: After exposure, and a waiting time of 10 min at room temperature, the sample is placed on a heating plate at 110 °C for 2 min.
6. Development: The exposed structure is placed into a

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developer bath (AZ 726 MIF) for 1 minute followed by a washing step in deionized water to stop the development. We obtain the negative of the hollow waveguide array in the photoresist.

7. Metallization: Sputtering of a 10 nm chrome layer which serves as an adhesive layer for the subsequent gold deposition. After sputtering the adhesive layer the negative sample is sputtered with $h = 2\,\mu\mathrm{m}$ of gold.

8. Lift-off: The metallized structure is placed into an ultra sonic bath of Technistrip P1316 at 60 °C for 7 min. The remaining photo-polymer is removed and we obtain the metallic subwavelength hollow waveguide array.

3 Measurements

Figure 2 shows an AFM measurement of the photo-polymeric structure, clearly resolving the negative shape of the subwavelength hollow waveguide array. The free-standing areas correspond to the air windows of the sample. The unsymmetric rounding of the free-standing areas results from the shape of the cantilever as well as the scanning direction of the atomic force microscope indicating a symmetric shape. With the two-photon polymerization process, we have achieved a linewidth of $d = 0,28\,\mu\mathrm{m}$ with a height of $h = 2,25\,\mu\mathrm{m}$.

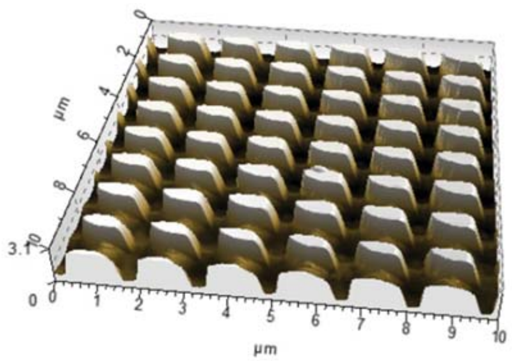

Fig. 2 *Photo-polymeric structure*

Next we have performed the metallization and the grooves are filled with gold. After the lift-off step to remove the remainig photoresist we get the final structure. Figure 3 shows a laser scanning microscope image after the lift-off step, hightlighting the metallic frame and the air windows of the hollow waveguide array. We have achieved a linewidth of $d = 0,28\,\mu\mathrm{m}$ and a height of $h = 0,32\,\mu\mathrm{m}$. Here we have observed a strong overgrow of the grooves before they are completely filled with gold up to the desired height. The sputtering technique is an undirected process and the deposition of the metal on the photopolymeric structure appears also on the sidewalls. A futher optimization of the process parameters may lead to a more directed deposition. Alternatively an another metallization technology, e.g., to electroplating has been chosen to achieve the desired height of the metallic structure.

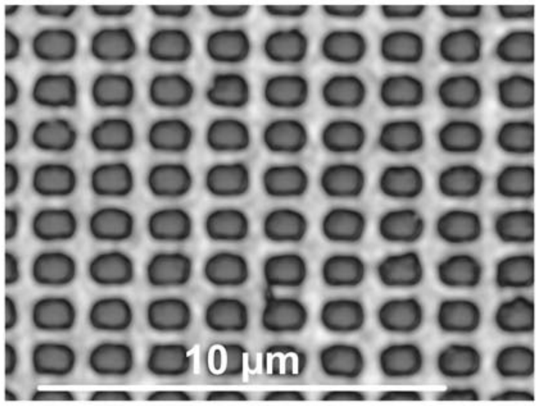

Fig. 3 *Metallic subwavelength hollow waveguide array*

4 Conclusion

We have demonstrate the successful fabrication of a subwavelength hollow waveguide array using two-photon polymerization and sputtering. For the hollow waveguide array an aspect ratio of $r_{\mathrm{a}} = 8$ has been achieved. The structure have been metallized using sputtering technique resulting in a maximum height of $h = 0,32\,\mu\mathrm{m}$ and a linewidth of $d = 0,28\,\mu\mathrm{m}$. In general, the successful implemtation of the complete fabrication process highlights the potential of two-photon polymerization to generate photonic micro- and nanostructures with a flexible three-dimensional shape without the need of any masks or master stamps.

References

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