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Direct Laser Writing of micro-structures in vector mode for chemical sensors

Milija Sarajlić, Milče M. Smiljanić, Žarko Lazić, Katarina Cvetanović-Zobenica, Danijela Randjelović and Dana Vasiljević-Radović

***Abstract*—Chemical sensors are the key part of the sensing platforms. They have different operating principles, but most of them are based on microstructures formed on the surface of the chip. In this paper we present technique for obtaining micro sized structures for the use in two different types of the chemical sensors. One type of the sensor is based on the electrical conductivity alteration in Au thin-film while the other is based on the optical properties of periodic metallic structures utilizing plasmonic effects. Technique presented here is based on the laser writing on the photosensitive material in "vector mode" where only continuous lines could be directly written. Width of the written lines is modified by alternating technique parameters. Narrowest obtained lines have width of about 1 μm with clearance of about 3 μm.**

***Index Terms*—Chemical Sensors; MEMS; Photolithography; Laser Writer.**

I. INTRODUCTION

IN the recent years chemical sensors receive more and more attention from the scientific community due to the increased awareness on air pollution and environmental protection. One of the obvious ways of controlling pollution is development of small and portable chemical sensors specially targeted to major pollutants in the environment. These sensors include micro fabricated chips with sensitive structures on the surface. There is a number of producers and different versions of chemical sensors for sensing various pollutants [1].

In 2012 at ICTM, Belgrade, Serbia, Center for Microelectronic Technologies, we fabricated and tested mercury (Hg) vapor sensor [2, 3]. The sensor is based on the resistivity alteration due to the mercury vapor adsorption. For this particular design it is shown that it can sense very low mercury concentrations, below 1 μg/m^3 [3], as well as it is possible to make continuous concentration monitoring [2]. In addition to this we also fabricated a plasmonic structure which can be utilized as a platform for chemical sensing due to the altered optical response in the case of vapor adsorption [4, 5]. Key aspect of these structures in both cases is controlled micro fabrication on the order of micrometer in 2D plane.

Mercury sensor [2, 3] was patterned by optical proximity mask in the process of standard optical photolithography. Smallest obtained dimension of the sensitive element was 20 μm for the meander width and 20 μm for the clearance between meander stripes. Developing new photolithographic technique using Laser Writer (LW405, MicroTech, Italy) we hope to obtain meander structure with the line width and clearance below 2 μm.

Plasmonic structures [4, 5] are fabricated by direct laser writing on the Laser Writer in the raster mode where the machine is scanning the full surface of the chip and exposing photoresist according to the already designed pattern. The full surface was swept by the laser head in which exposed stripes were 100 μm wide. Due to the overlap between adjacent stripes the surface on the strip junction is overexposed which makes the structures to appear smaller than designed. One way for overcoming this effect is using the same machine in the vector mode (direct writing).

II. MANUFACTURING PROCEDURE

We use silicon (Si) 3 in, double polished wafer 400 μm thick, 3-5 Ωcm resistance, n-type, orientation <100>. On the surface of Si a layer of SiO_2 is made by wet thermal oxidation on temperature 1100 °C, duration 1 hour with oxygen flow 2 liter/h. Measured thickness of SiO_2 is (460±10) nm. Thickness of SiO_2 does play a role during laser writing. Here it is designed to act as an anti-reflexive coating thus reducing the intensity of the reflected light on 405 nm from the Laser Writer. Subsequently, Si wafer is coated with photoresist (AZ1505) on the spinner with initial speed 500 rpm and later 4000 rpm for 30 s. Photoresist is baked for 50 s on 115 °C. Obtained photoresist thickness is 0.5 μm. We draw a pattern using CleWin software package producing CIF (Caltech Interchange Format) format file. This file is than converted to native Laser Writer machine format LDF. Parameters of the Laser Writer were: Gain 1, Lens 5, D-Step NA, Filter 1. Process parameters during laser writing are summarized in Tab. 1. Detail of the loaded pattern is presented in Fig. 1 (inset). It consists out of two crossed meanders 60 μm wide and 36 μm high. Together they form a matrix of intersected

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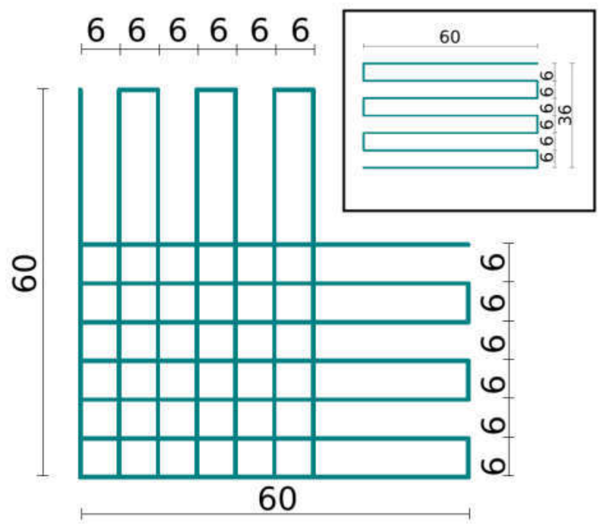

Fig. 1. Detail of the structure to be patterned by Laser Writer. Structure is composed out of the two crossed meanders. One of the meanders is shown in the inset. All units are in micrometers.

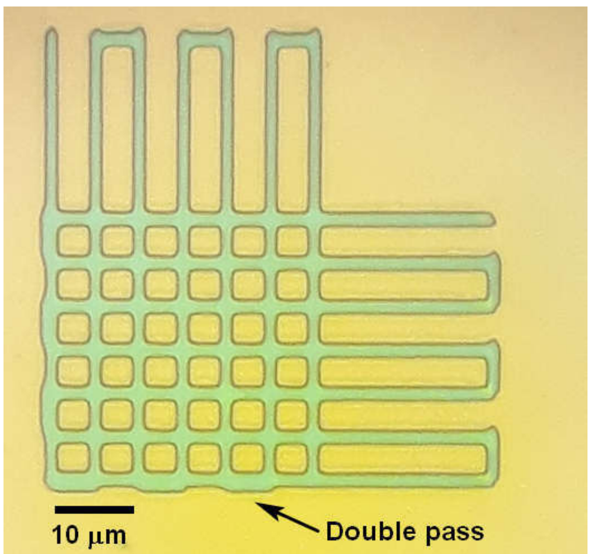

Fig. 2. Optical microscopy of the finished structure. Width of the lines is estimated on 1.5 µm. Parts of the outer lines appear thicker as a consequence of the double laser pass during writing. Top of the lines has additional protrusions.

lines. Lines are spaced 6 µm apart from each other. Thickness of the line in the design does not influence fabricated line thickness. Thickness depends on the broadening of the laser spot width in photoresist. Rated laser spot size is 0.8 µm on the Lens 5 but expected line width is around 1 µm. Laser Writer machine counted in total 250 elements to be drawn. It took around 5 min for the laser writing to complete. In this sequence we performed laser writing three times on three different places on the wafer with three different focus procedures, namely: machine will set the focus automatically and it will stay fixed during laser writing, machine will set the focus automatically but it will make adjustments during laser writing (so called Track Rings feature), focus is set manually and it will be fixed during laser writing. It turned out that manual focus setting gave the best result. Here it should be noted that the patterned area was relatively small thus focus discrepancies are expected not to be severe.

After patterning is finished, photoresist on the Si surface is developed using AZ725MIF developer at temperature of 23 ^{o}C for 20 s. Photoresist is then baked at 100 ^{o}C for 5 min which makes the end of the fabrication procedure.

TABLE I
PROCESS PARAMETERS DURING LASER WRITING

Substrate:	
Material	Si
Diameter	3 in
Thickness	400 µm
Photoresist:	
Type	AZ1505 (positive)
Thickness	0.5 µm
Machine parameters:	
Filter	1%
Lens	5
Gain	1
Developer:	
Type	AZ725MIF
Time	20 s
Temperature	23 ^{o}C

III. RESULTS AND DISCUSSION

Wafer is examined on an optical microscope and one detail of the patterned structure is shown in Fig. 2. This structure is designed as an overlap of two identical patterns rotated 90 deg in respect one to another, Fig. 1 inset. It is in total forming a matrix of squares with 6 µm period as it was designed. The width of the etched line is estimated on 1.5 µm. This is broadening from the rated laser beam width of 0.8 µm. We believe that broadening comes from the increased light energy deposited in photoresist.

Islands of the photoresist which remain between etched lines have a square shape with dimensions estimated on 4.5 µm × 4.5 µm and slightly rounded corners. The pitch between the islands is 6 µm. Nevertheless, this structure can be used as a pattern for formation of 2D plasmonic crystals. After deposition of the metal layer this can serve as a plasmonic chemical sensor.

In the future work we will consider methods for reducing the light intensity deposited in photoresist. One way of doing it is making an anti-reflexive coating on the surface of Si thus reducing the intensity of the reflected laser light. Corners of the upper part of the structure show typical overexposure pattern. This will be the subject of the further research and optimization.

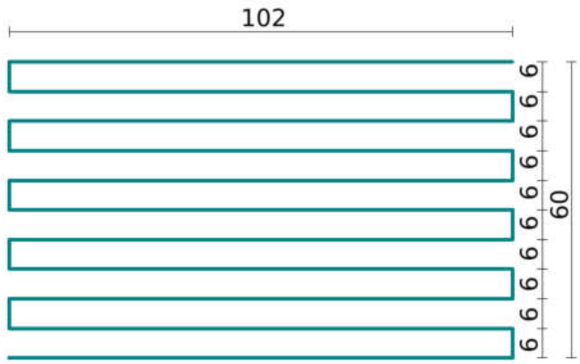

Fig. 3. Meander to be patterned. All units are in micrometers.

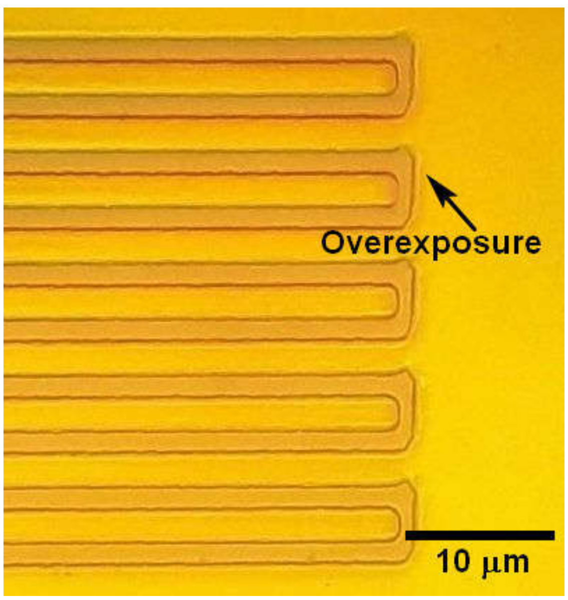

Fig. 4. Detail of the patterned meander. Corners of the lines on the upper right side are overexposed.

Another structure tested is meander as shown in Fig. 3. Meander structure like this is a building block for chemical sensors based on conductivity alteration. Fig. 4 gives optical microscopy of the developed structure. Visible lines are where the photoresist is removed. Width of the lines is estimated on 1.5 µm but the structure shows pronounced overexposure structures on the upper right corners. More study will be needed to explain this effect.

In order to get more quantitative insight into details of the fabricated structures we performed Atomic Force Microscopy (AFM) measurements. Fig. 5 gives 2D image of the structure detail from Fig. 2 with the profile line plotted red and shown in Fig. 6. The thickness of the photoresist is around 0.5 µm, and the surface roughness inside of the lines and on the top of the photoresist is visible in Fig. 6. Important information obtained from the AFM scans is the slope of the vertical walls in photoresist. The slope plays an important role in the case of possible subsequent lift-off technology. The steeper the vertical walls, the better quality of the lift-off technology. For

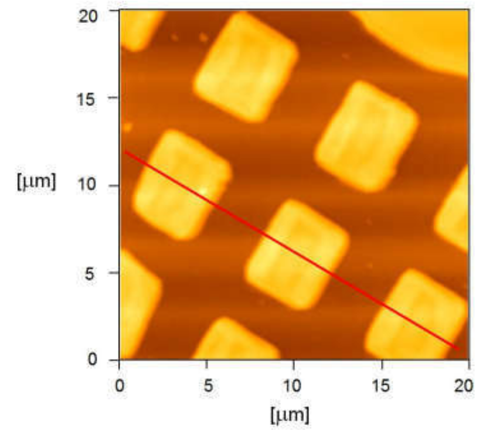

Fig. 5. 2D AFM image with the profile line depicted red.

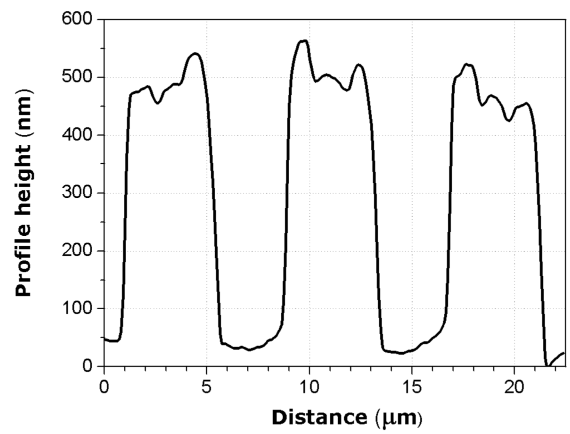

Fig. 6. Profile on the characteristic line marked red in Fig. 5.

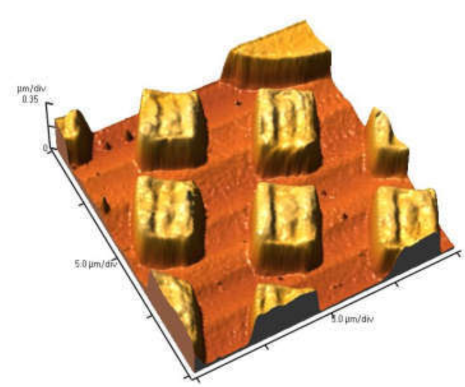

Fig. 7. 3D AFM image of the structure detail.

the sake of better visualization a 3D image of the same structure detail is given in Fig. 7.

IV. SENSOR PROPOSAL

With the technology to fabricate such structures we propose sensor structure similar to the one fabricated in Ref. [2, 3]. Fig. 8 gives schematic of the proposed structure. All units are

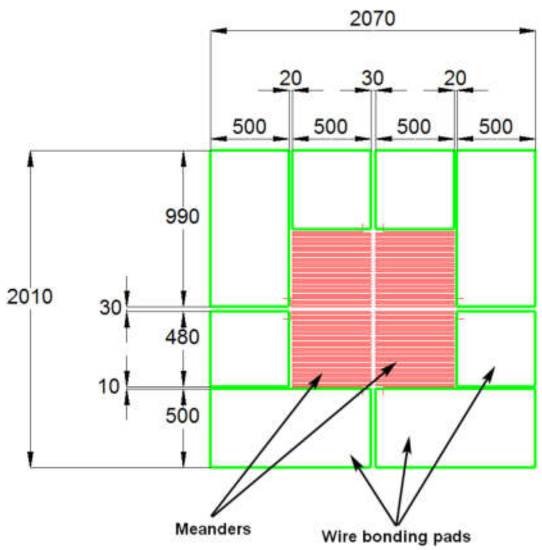

Fig. 8. Proposed sensor structure envisioned to be made with the direct laser writing technology. All units are in micrometers.

in micrometers. The proposed sensor consists out of four meanders and eight wire bonding pads. Each meander has two wire bonding pads which gives more flexibility in the choice of meander interconnections. In this way, each meander can be operated independently or they could be connected in the Wheatstone bridge configuration. In respect to the design shown in [2, 3] here is no separate heater designed. Heater is not necessary since each meander can act as a heater if sufficiently high current is applied.

V. Conclusion

This research shows feasibility of the laser writing in vector mode for applications with chemical sensors. We showed that by direct laser writing it was possible to produce the structure for chemical sensors based on electric potential alterations (meander) and sensors based on alteration of optical properties (plasmonic structures). Future work will encompass optimization of the process of optical lithography and implementation of the obtained structures to the real chemical sensors.

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