PLASMONIC STRUCTURES IN PMMA RESIST

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Abstract

Some metal material can exhibit special physical phenomenon which is called plasmon resonance. This effect can be used in optical applications where designed structures, using this effect, have special function as optical filters, polarizers, holograms etc. This papers deals with preparation of plasmonic structures in poly(methyl methacrylate) (PMMA) resist which is the most common material used for e-beam processing. Designed structures were prepared by e-beam writer with Gaussian beam and accelerating voltage of 100 kV. These structures are usually prepared into negative tone resist hydrogen silsesquioxane (HSQ). We prepared these structures by unusual way into positive resist PMMA due to unavailability and cost of HSQ resist. By this way we are able to achieve high resolution of structures suitable for special optical application. Exposed structures were developed in isopropyl based developer. Final structures after development were coated by two metal layers (first one is Ag layer, second one is gold) by magnetron sputtering and vacuum evaporation. The quality of prepared plasmonic structures was examined by confocal laser scanning microscopy (CLSM) and scanning electron microscopy (SEM).

Keywords: Electron beam lithography, plasmonic structures, PMMA, metal coating

1. INTRODUCTION

The highest possible resolution for printed colour images is determined by the diffraction limit of visible light. To achieve this limit, it is required pitch of 250 nm between two pixels (half the wavelength assuming 500 nm as the mid-spectrum wavelength for visible light) and the fabrication of structural colour can have some limitations in scalability. Non-colourant method using plasmonic structures achieves bright-field colour prints with resolutions up to the optical diffraction limit. Colour information is encoded in the dimensional parameters of metal nanostructures, so that tuning their plasmon resonance determines the colours of the individual pixels as a result of the different diameters (*D*) and separations (*g*) of nanodisks (Fig. 1) [1]. These plasmonic structures prepared via e-beam lithography [2] or nanoimprint can be useful for security microimages, nano scale optical filters [3] and high-density encoded optical data storage.

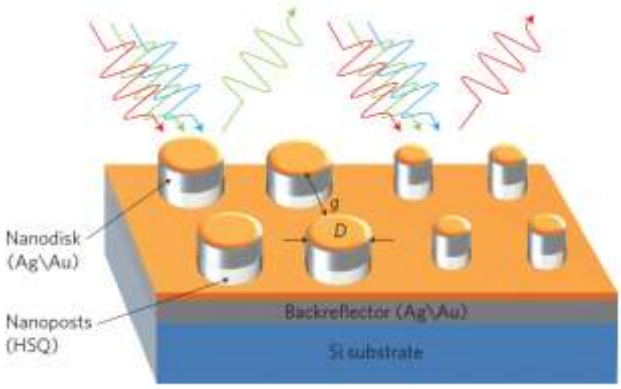

Fig. 1 Principle of plasmonic colours [1].

2. PROCESSING OF PLASMONIC STRUCTURES

2.1 Data design

Plasmonic structures were designed in software Layout Beamer. Plasmonic structures were in squares of matrix 10x10. The dimensions of individual squares were 12 um and separation gap of 5 um. Each square was filled in with round plasmonic nanodisks (Fig.2). The diameter of plasmonic nanodisks *D* was in range from 50 to 140 nm (step 10 nm). Separation gap *g* between plasmonic nanodisks was from 30 nm to 120 nm (step 10 nm). The least diameters and gaps were in the left bottom corner, diameters were increasing upwards and gaps to the right. The structures were designed to expose into positive tone resist PMMA, thus the surroundings of plasmonic nanodisks were exposed (detail in Fig.2).

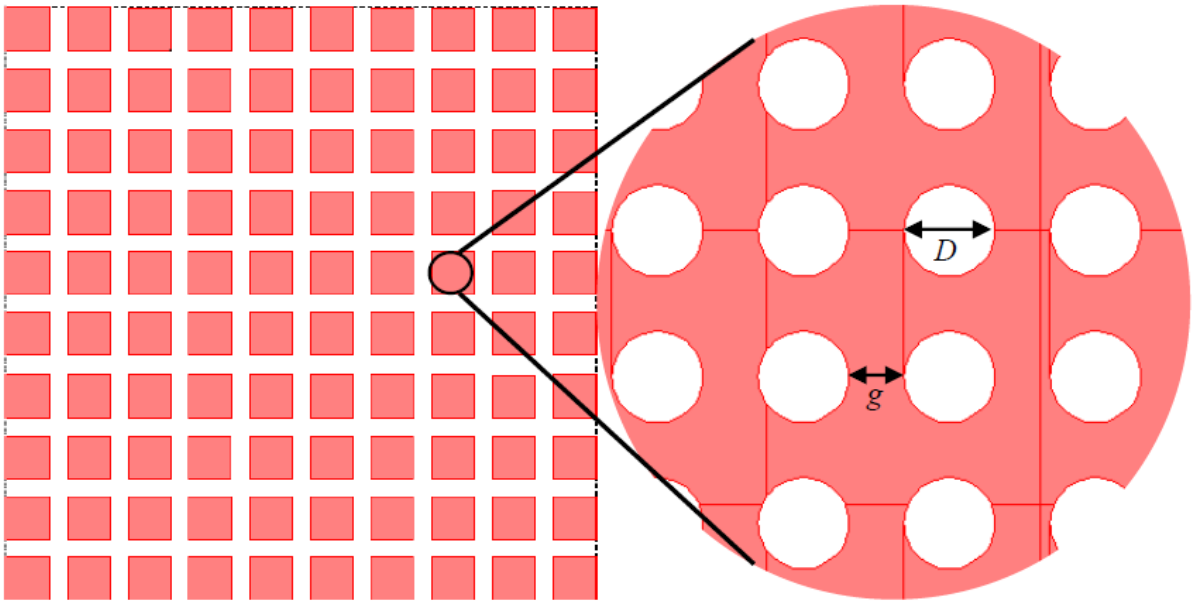

Fig. 2 Layout of designed structers and detail of plasmonic nanodisks with exposed surroundings.

2.2 E-beam patterning, development and metal coating

Exposure was carried out on e-beam writer system Vistec EBPG5000+ ES using acceleration voltage of 100 kV and Gaussian beam, exposure parameters were following: beam current of 500 pA, Beam Step Size (BSS) 2.5 nm, exposure dose were set from 400 to 560 $\mu C.cm^{-2}$ for each individual matrix layout (see Fig. 2). No proximity effect correction [4] was applied. As a resist we used positive tone PMMA 950K of thickness = 85 nm spin-coated on Si wafer. Prior to exposure the resist was baked for 9 minutes at 150 °C. After exposure, alcohol based developer was used for 60 s at 21 °C in the developing process. After development process the sample was coated by silver layer with thickness of 15 nm and then gold layer of 5 nm thick. Sample metal coating was carried out by magnetron sputtering [5].

3. RESULTS

First, sample coated by silver layer and gold layer were observed by confocal laser scanning microscopy (CLSM). The most impressive colour sensation was visible for plasmonic structures exposed by dose of 520 $\mu C.cm^{-2}$. In comparison with results from [1], it is obvious that our colours were less bright and colour shift from left edge (Fig.3).

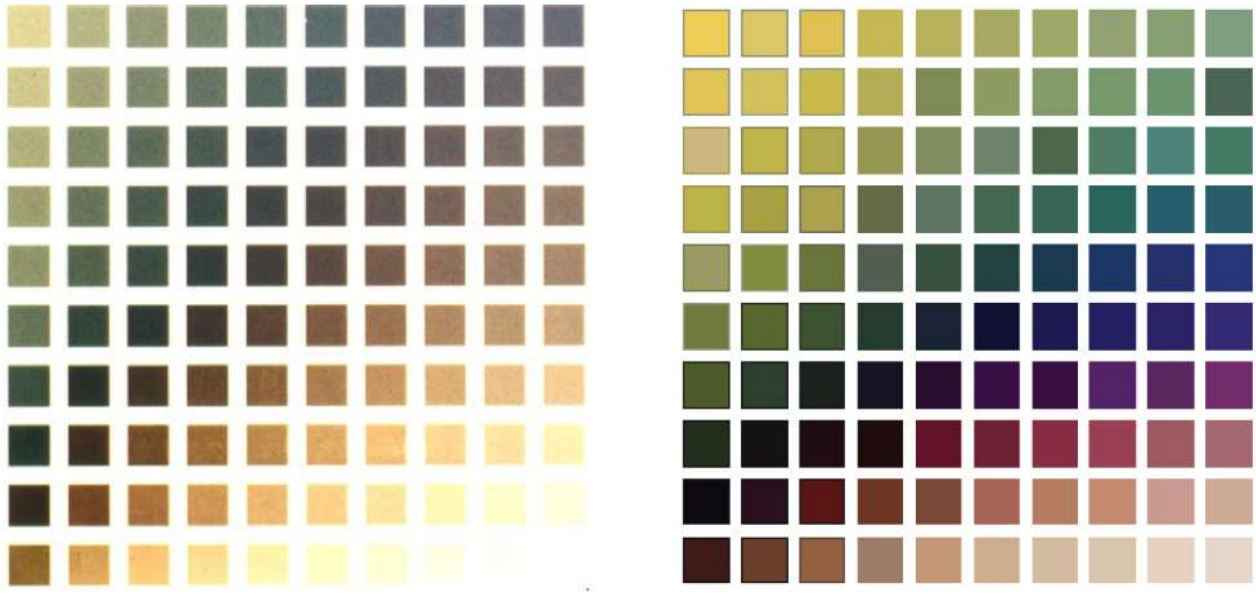

Fig. 3 Comparision of plasmonic structures: right - exposed on PMMA; dose of 520 μC.cm^{-2}, left - from [1].

Thereafter the sample was observed by scanning electron microscope (SEM). The roundness of exposed structures was evaluated. SEM image of exposed plasmonic structures showed that they are very close in shapes to the designed structures in Layout Beamer software (as compared in Fig. 4).

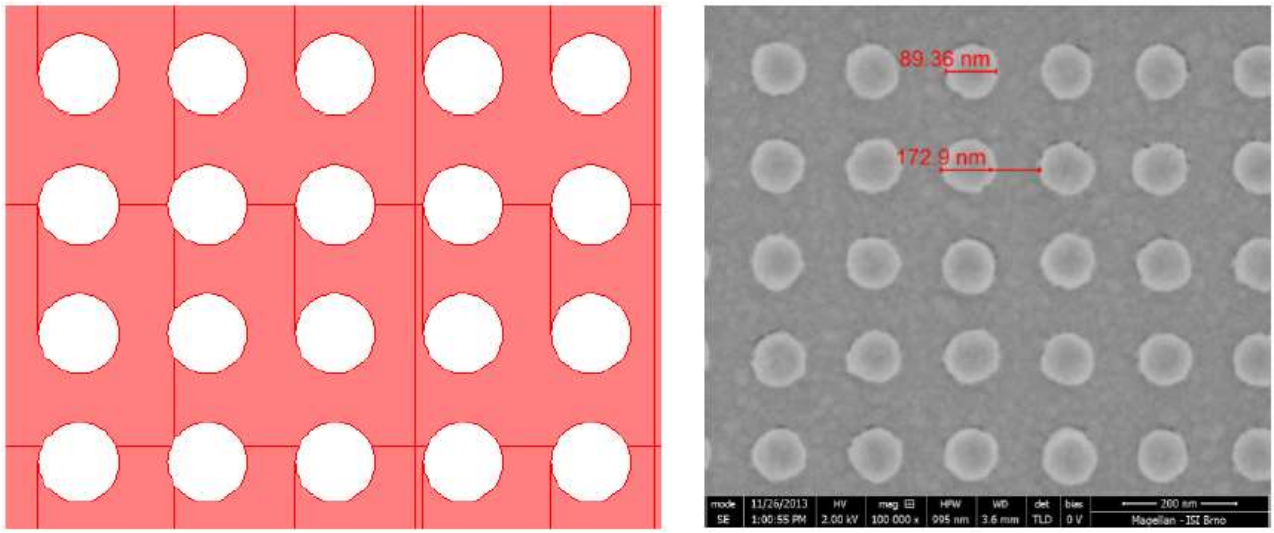

Fig. 4 Shape comparision of designed and exposed plasmonic structure.

The matrix exposed by dose of 520 μC.cm^{-2} was selected on the basis of the best colour sensation. The diameters of individual plasmonic nanodisks in squares on the main diagonal in this matrix were measured by SEM. Measured deviations of diameters exposed plasmonic nanodisks from the designed are very small as obvious in fig. 5. Deviation from designed pattern could be one reason for colour shift from original image from [1]. The matrix exposed by dose of 520 μC.cm $^{-2}$ was also observed by SEM under angle of 30° (fig. 6). It is evidently that metal layer was also deposited on sides of individual plasmonic nanodisks due to omnidirectional magnetron sputtering. It could be the reason for worse colour sensation of exposed structures.

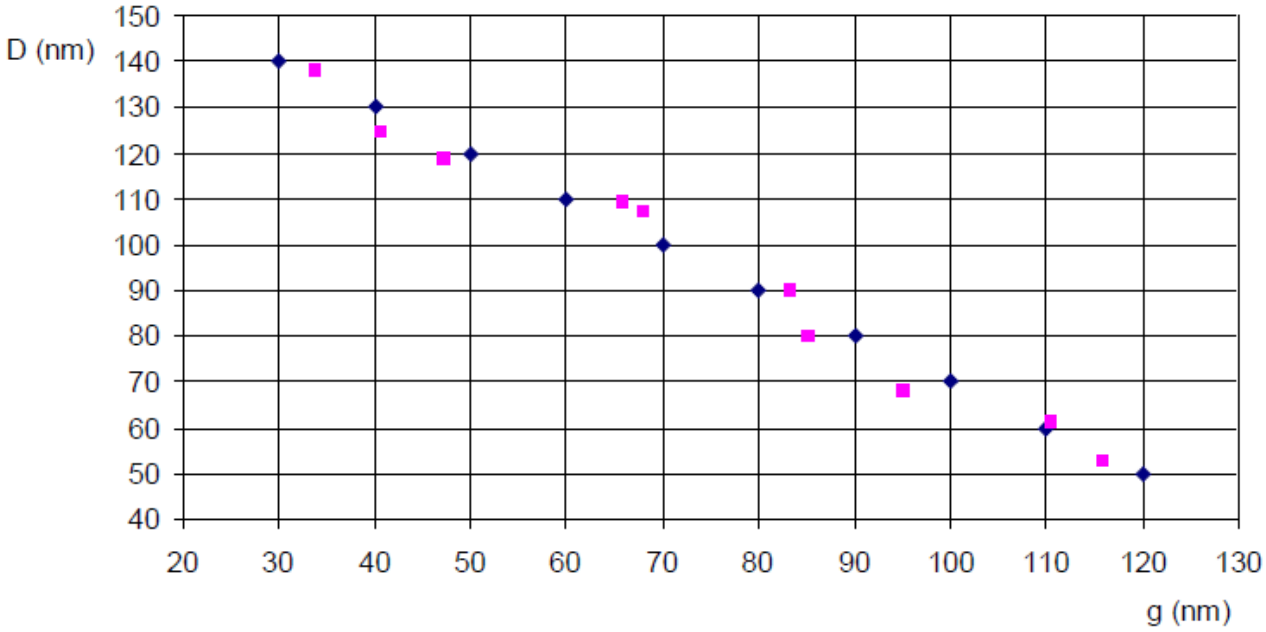

Fig. 5 Diameters of plasmonic nanodisks *D* on separation distance *g* on the main diagonal of matrix: exposure dose of 520 μC.cm^{-2} (blue rhombus label – designed, magenta square label – measured by SEM).

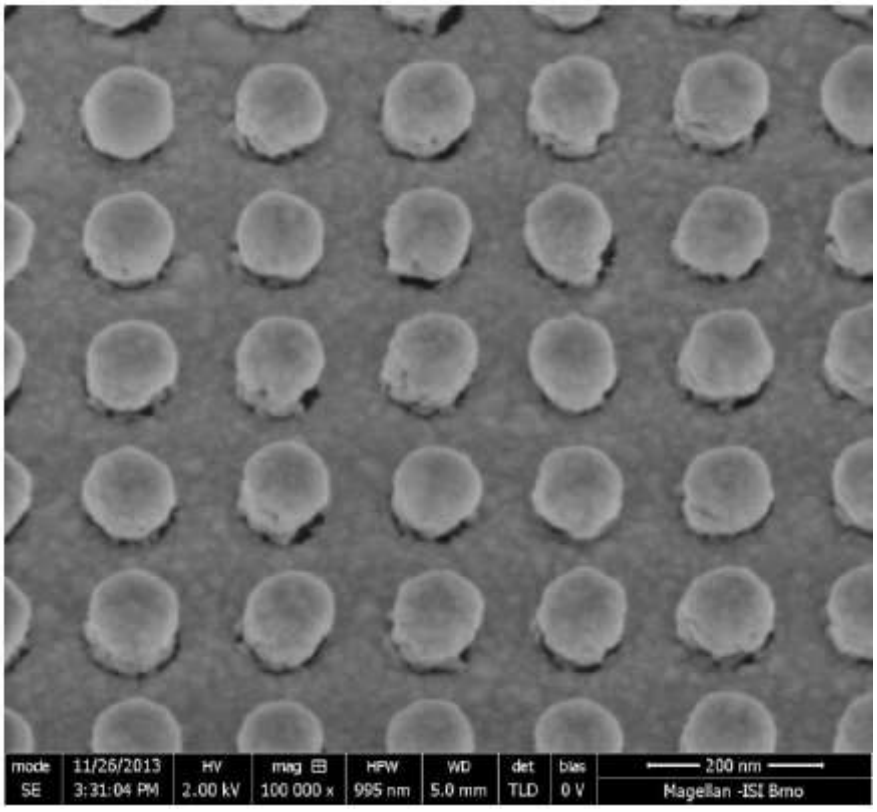

Fig. 6 SEM image of plasmonic nanodisks under 30°

CONCLUSION

We successfully prepared plasmonic nanodisks on positive tone resist PMMA which is much cheaper and common resist. This is considerable advantage in comparison with plasmonic nanodisks prepared in expensive and rare HSQ resist. The results show that PMMA resist is suitable for patterning small structures in high resolution. Other way of metal coating could improve sample colours due to edge non-coverage of plasmonic nanodisks. The main disadvantage is duration of selected writing strategy because the exposure of one square millimeter lasted approximately 6.5 hours. Fortunately we are currently able to decrease writing time of square millimeter to 3 minutes by changing writing strategy which is very promising for further experiments.

ACKNOWLEDGMENTS

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