New Fabrication for DSRRs Nanostructure in Optics

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ABSTRACT

The Deformed-Split-Ring Resonators (DSRRs) require metal nanostructure on high transmission material substrate for optical application. In this article, a simple method of fabricating three-dimensional polymer nanostructure that use an UV-curable polymer as the resist is discussed. Because UV cure imprinting has high resolution which is about 100nm and high transparency, it is ideally suited for photonic and meta-material optical device applications. The fabrication combines several mass production technologies. The first one is photolithography, such as a stepper UV exposure system can make the nano scale pattern in photoresist, the second is to change the photoresist sample to become the nanoimprint mould by precise electroforming, the third is to use UV cure imprinting to transfer the DSRRs pattern on the UV-curable polymer. Finally, it is also the most important process is that to coat metals and metal lift-off that coating Ag to become buffer layer by sputter, then coating Au into the nanostructure and lift off Ag by HNO_3. The DSRR structure is implemented in high transmission UV-curable polymer with Au.

Keywords: Metal lift off, Nanoimprint, Nanostructure, Left-handed metamaterial

1. INTRODUCTION

Research on left-handed materials (LHMs) has recently attracted the attention of numerous researchers of their wide range of unique properties in terms of electromagnetic propagation as shown in Ref. 1,2,3. With reference to the discussion of negative permeability material or LHM metallic structure, in 1968, Veselago disclosed a theory and pointed out that when transmitted through a substance with negative dielectric coefficient and negative permeability, an electromagnetic wave will display a distinctive and unusual quality. Moreover, in 1996, Pendry disclosed a system combining the split-ring resonators (SRRs) array with a metallic line array to enable an electromagnetic wave of a certain microwave band to simultaneously possess a negative dielectric coefficient and negative permeability. In 2000, Pendry also applied this theory to the analysis of optical lens resolution. Thus, if a metallic structure with LHM materials can be developed, the metallic structure will be capable of altering the non-penetrability of ordinary substances and modulating the direction of the wave-transmitting. Additionally, if the structure of LHM is formed on a large-scale silica substrate or other transparent substrate, the LHM can be introduced to produce a planar super-resolution optical lens. Accordingly, the requirements of delicate mechanical tolerance can be reduced, thus efficiency of assembly and production yield will be increased.

We also study a metallic-nanostructure composite, which comprises of Deformed-Split-Ring Resonators (DSRRs) and wires as shown in Ref. 4. The DSRR is designed for this project because it can minimize the size of the unit cell for fabrication, which is favorable for the implementation of LHM metamaterial in near infrared region and visible light region. The size of the unit cell has to be small than a wavelength, so the linewidth has to be smaller than 100nm in visible light region. Also the material is very important, because some properties have to be considered such as the light absorbability by substrate, the electric conductivity of metallic-nanostructure, and the adhesion of metallic material, etc. Therefore, nanolithography technology as shown in Ref. 5 and nanoimprint to implement DSRR for this fabrication has been developed in OES of ITRI. There are two main reasons to apply the method mentioned above in this project, one is that to achieve the linewidth of DSRR into nanoscale is difficult with the processes of lithography, coating metallic metal, lift off, electroform, and imprint in manufacture equipment of IC industry. The other reason is that the structure requires to be built on high transparency substrate such as quartz, silica, or polymer for optics applications.

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This paper offers a simple method of fabricating three-dimensional polymer nanostructure that using an UV-curable polymer as the resist. The UV-curable polymer is chosen because it has the characteristics of high resolution which is about 100nm and high transparency for DSRR in near infrared region and visible light region.

2. EXPERIMENTAL

The fabrication combines several mass production technologies: nanolithography, nanoimprint and metal lift off technology are able to fabricate the DSRR. The details of the fabrication are as follows:

2.1. Nanolithography Process

First, using e-beam lithography or photolithography such as stepper UV exposure system, we can make the nano scale pattern in photoresist. If the linewidth is set to be 200nm, we can use stepper UV exposure system to fabricate DSRR photoresist. The SEM photo is shown in figure 1. As we can observe the edge of the corner is not sharp, because the stepper exposure system has two parameters which have to be corrected as shown in Ref. 6. One is optical and process correction (OPC), the other is iso-dense bias. For the defects mentioned above, e-beam lithography is used. The advantage of using it is that it does not change shape and it has a high resolution which is smaller than 100nm.

Following we obtain the DSRR metallic material device using two ways. One is to use the coating metals and lift-off process to obtain the nano device directly, the other is to electroform the sample of photoresist to become the nanoimprint mould. The mould plays the same role as the photomask in photolithography.

As for lift-off process, the substrate is silicon wafer, there are two problems have to be solved, one is that the metallic material requires to be coated into resist nanostructure, we found the spin speed of sputter can control the coating. When spin speed slow to a certain extent and even stop, the metallic material can be coated into nanoscale hole, in another word, the spin speed reaches to another extent, it cannot be coated into nanostructure and only be coated on the surface. The spin speed is not fixed because it depends on the metallic material and the hole size of the structure.

The other problem is that if Au is chosen to be DSRR metallic material, the metal's adhesion on silicon has to be considered. Figure 2 shows the imperfect pattern of DSRR that uses sputter to coat Au on silicon wafer, and then remove the photoresist. It is imperfect because Au has not enough adhesion on silicon wafer. Due to the problems mentioned previously, we try to coat IZO and then coat Au, the adhesion increase much than only with Au is coated on silicon wafer. The lift-off process fabricates the DSRR that material is IZO and Au. The Pattern is shown in figure 3.

Another process is electroforming the photoresist sample to become the nanoimprint mould. The result of electroforming is Ni mould, it is shown in figure 4.

2.2. Nanoimprint Process

Then we used the Ni mould to imprint process. The UV-curable polymer smears on the Ni mould, and then with glass or plastic material to be as substrate to cover on UV-curable polymer. Smearing and pressing on UV-curable polymer, which is important step in nanoimprint process, leaves no air bubbles in polymer.

Another important step is the exposure of polymer. It normally takes precise time for exposing to cure polymer that is difficult to find time exposure precisely, because if the time exposure is insufficient or exceeded both of which will make the shape of DSRR changed. After exposing by the UV light, the UV-curable polymer will cure complete and transfer the DSRR pattern that the depth of imprinting is about 200nm. The depth corresponds to the thickness of DSRR nanostructure in Ni mould.

2.3. Metal Lift off Process

When we have the DSRR nanostructure on polymer that is shown in figure 5, the process has to proceed to coat the metallic material and polish polymer edge to become smooth such as cross-section of fiber or waveguide.

Due to the DSRR pattern has to be metallic material and only put into UV-curable polymer, so the metal lift off process is used to coat metallic material and remove redundant. To apply the metal lift off process for fabricating, Au and Ag are the main metal material to be used. Because Ag and Au have different characteristics, such as Ag can be easily lifted off by HNO_3, but Au not. First, we control spin speed of sputter to coat Ag, when spin speed reaches to a certain extent, Ag will not be coated into DSRR nanostructure, and instead Ag will become a buffer layer on UV-curable polymer surface with the thickness about 20nm. Second Au will be coated as the section described previously. The Au can be coated into DSRR nanostructure with the thickness about 100nm. After metal lift off process, Ag will be removed by HNO_3 and the DSRR Au pattern will be implemented, the output element is shown in figure 6. Finally, we polish the sample edge to prepare for measurement.

So, in this paper, we finally provide two DSRR nanostructures that the diagram is shown in figure 7. One is metallic material that combine IZO and Au on silicon wafer, the other is metallic material that to be covered in UV-curable polymer. And the DSRR sample will be measured for the properties of the effective negative permeability. The experiment frame is shown in figure 8.

3. CONCLUSIONS

This study for the DSRR is about the implementation of LHM metamaterial in near infrared region and visible light region which can be fabricated. We provide several fabrications for DSRR such as the nanolithography, nanoimprint and metal lift off are used. In this paper, two DSRR nanostructures are used for the future application in Optics, one is to use metallic material that combine IZO and Au on silicon wafer, the other is metallic material that to be covered in UV-curable polymer. In the Future, with the development of nanotechnology such as e-beam lithography, the linewidth of DSRR can be implemented into small size which is even smaller than 50nm, with this more optics applications can be used.

4. REFERENCES

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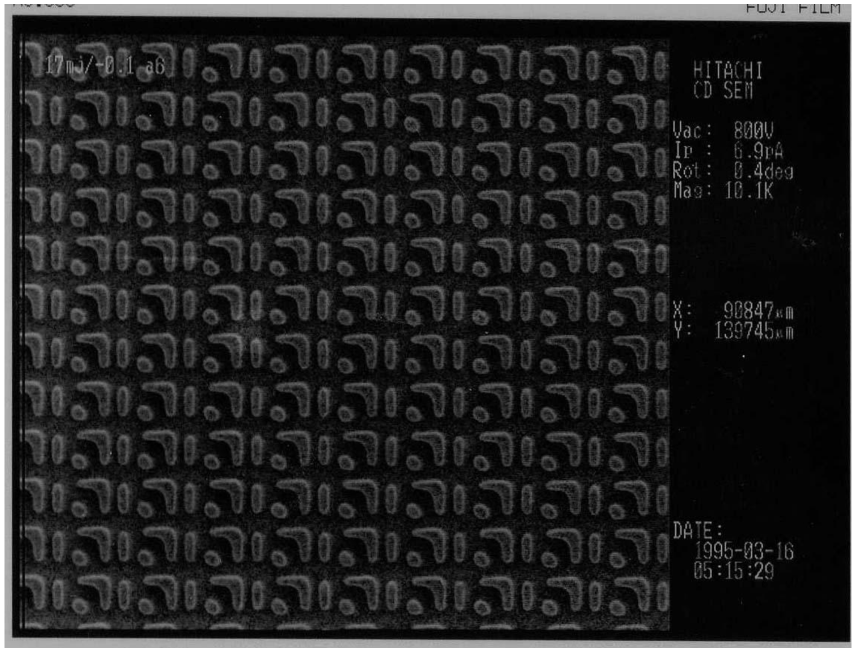

Figure 1. Photoresist linewidth of DSRRs and wires is 200nm by Photolithography

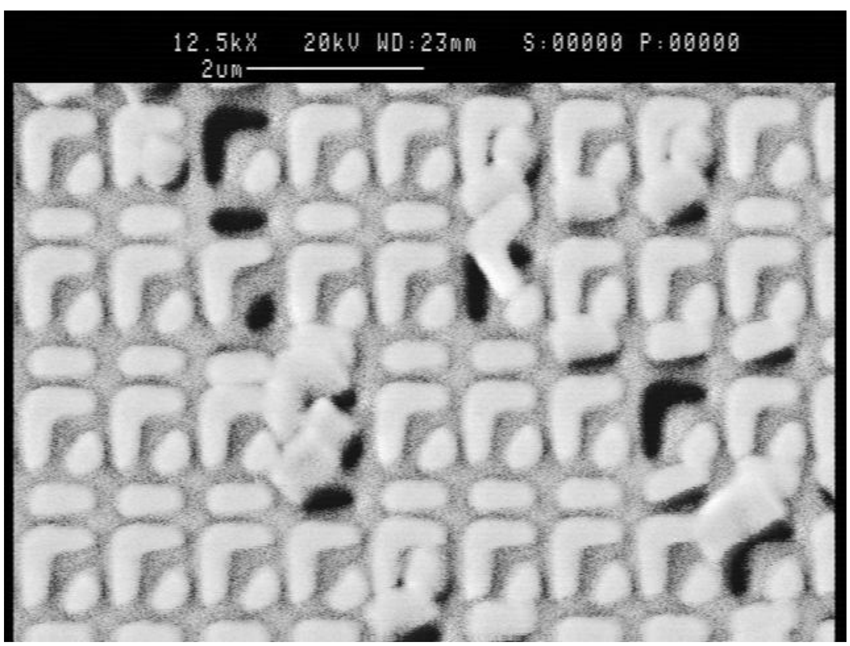

Figure 2. Imperfect pattern of DSRRs and wires because Au has not enough adhesion on silicon wafer.

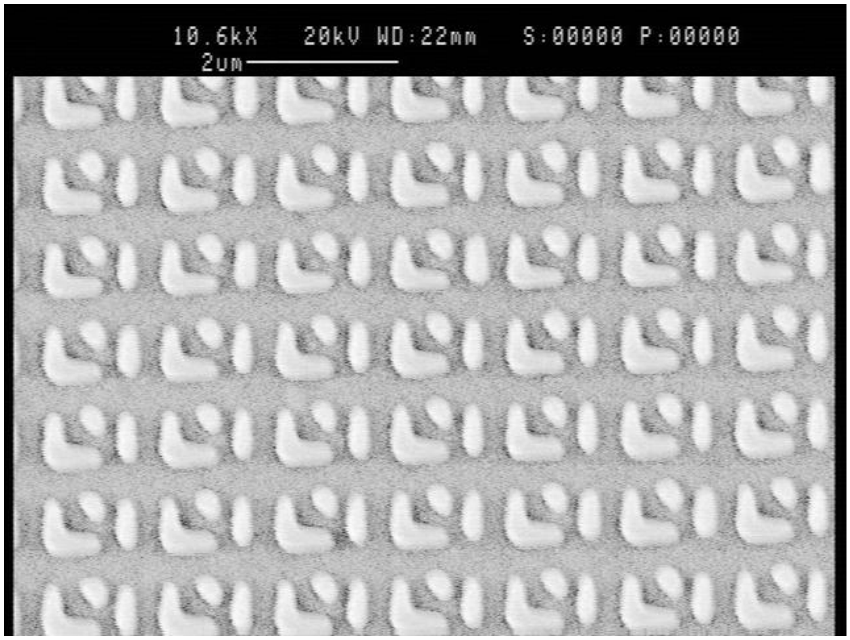

Figure 3. The DSRRs and wires pattern coated IZO and Au.

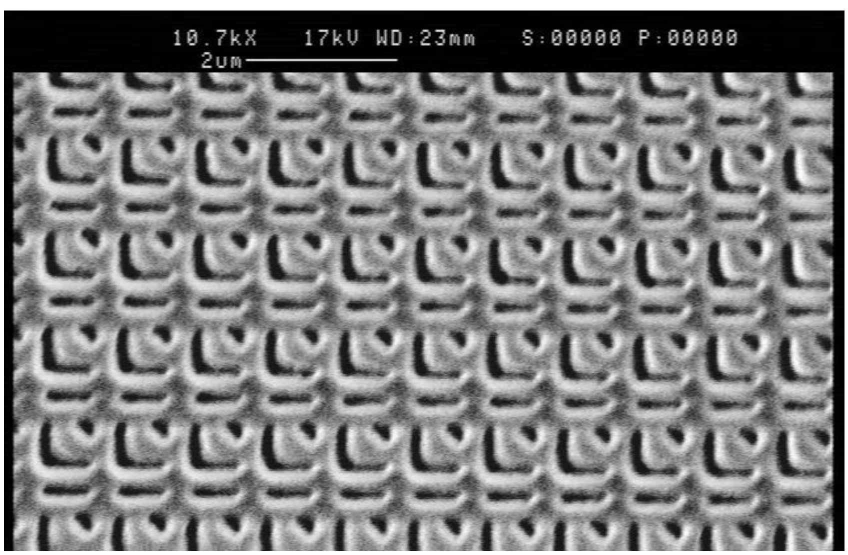

Figure 4. The DSRRs and wires pattern of Ni mould.

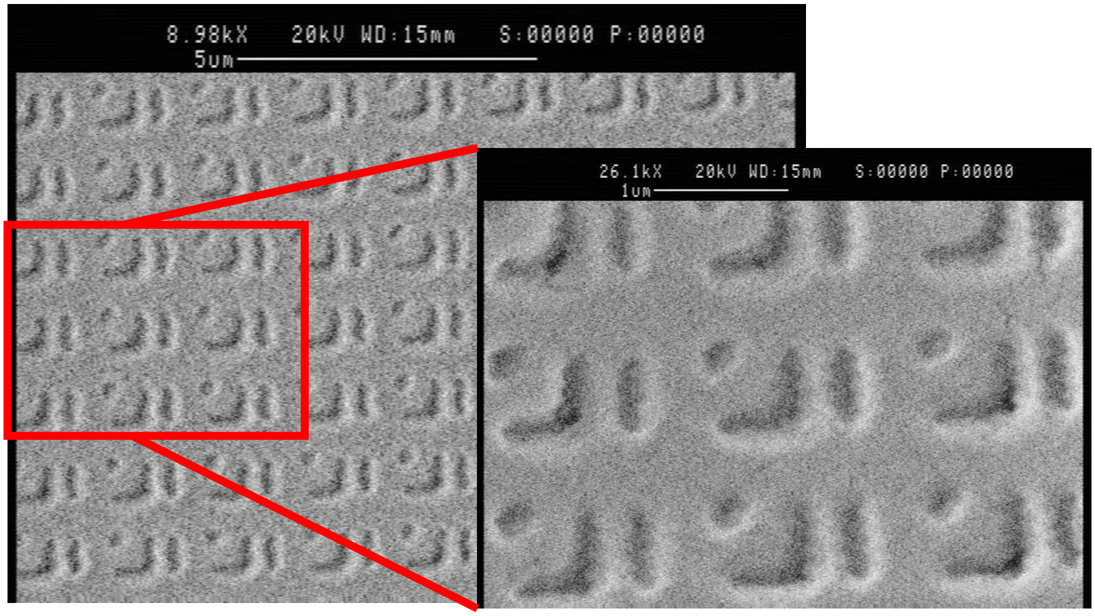

Figure 5. UV-curable polymer has DSRRs and wires pattern with the depth approximates to 200nm.

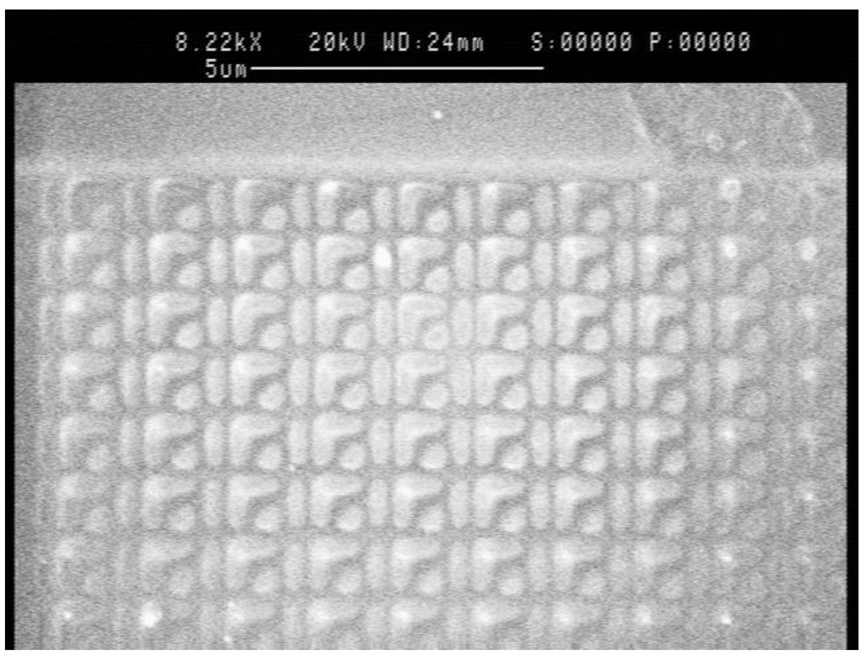

Figure 6. The DSRRs and wires pattern has to be Au and only put into UV-curable polymer.

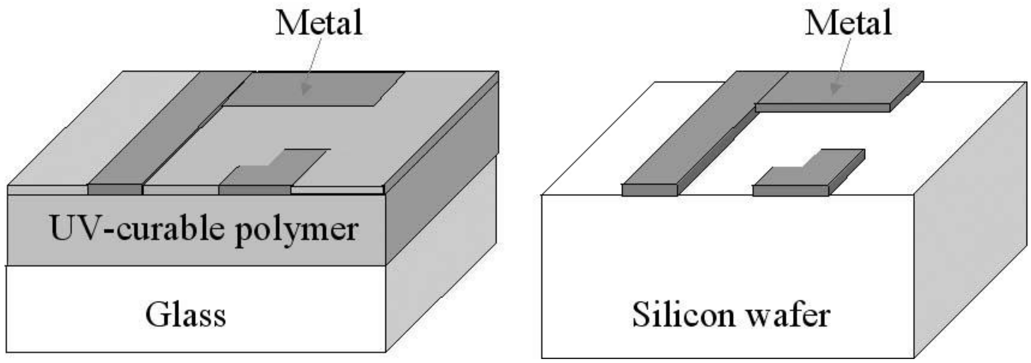

Figure 7. It has two DSRR nanostructures that can be used for the future application in Optics.

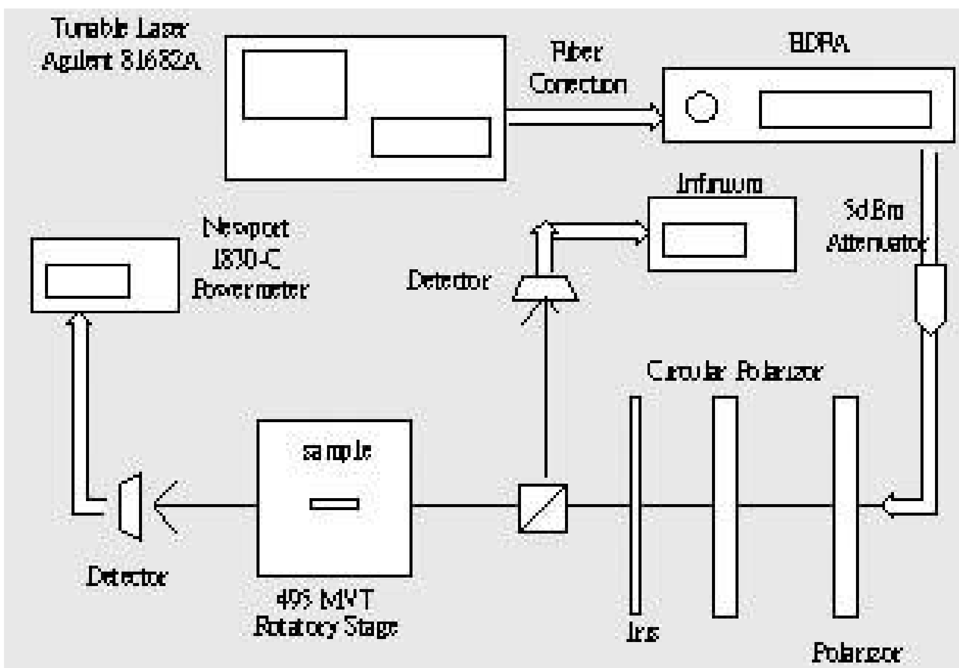

Figure 8. The experiment frame shows the DSRR sample will be measured for the properties of the effective negative permeability.