Optimization of silver for a 200 nm Fishnet grating fabricated by NIL

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Abstract

In this paper we show the fabrication of large area silver Fishnet gratings using Nanoimprint Lithography (NIL). The dimensions are designed such that the response of the Fishnet is within the visible. One main problem for such materials is the silver quality and its degradation by oxidation. We report on the fabrication of silver structures and its manipulation of grain size using plasma processes to reduce silver oxide and to improve the stability of the samples on air.

1. Introduction

Negative index materials (NIM) are characterized by designed structures that provide resonances for the electric and magnetic field such that negative refraction occurs [1]. A famous structure is the fishnet grating, which was shown to exhibit negative refraction [2], [3] and related structures fabricated using focus ion beam were recently shown to exhibit negative refraction within the visible regime [4].
It is of paramount importance to fabricate such structures with a fast and cost efficient technique suitable for industrial use. Nanoimprint Lithography (NIL) is such a promising technology, where large areas can be nano-structured within a few seconds. Here, we show the fabrication of single layer Fishnet made of silver aiming at the visible regime. Further we show annealing steps to influence the grain size and to reduce the AgO which is formed after taking out the samples from the evaporation chamber. This approach improves the silver properties like conductivity and roughness. In addition a plasma process is performed to passivate the silver surface and to increases the stability of silver on air and therefore increasing the life time of a negative index response of a silver fishnet.

2. Fabrication of silver NIM structures using NIL

The Fishnet structures with a period in the x-direction of 200 nm and in the y-direction of 220 nm and a line width of 70 nm and 90 nm, respectively, was fabricated using NIL and lift-off, similarly to the process reported in ref. [5]. Working stamps were used to replicate the features into a UV-NIL resist on top of a Borofloat or Silicon wafer [6]. The stamp contains 3 fields with a size of 7x7 mm² each. The results are protruding pillars (Figure 1). A reactive ion etching machine was used to remove the residual layer and the transfer layer below the UV-NIL resist. After developing the transfer layer re-

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cessed sidewalls were achieved. Then a layer system of 30 nm Ag / 30 nm MgO / 30 nm Ag was deposited ontop of the sample. After immersing the sample into a remover the lift-off takes place and the silver grating remains as shown in Figure 2.

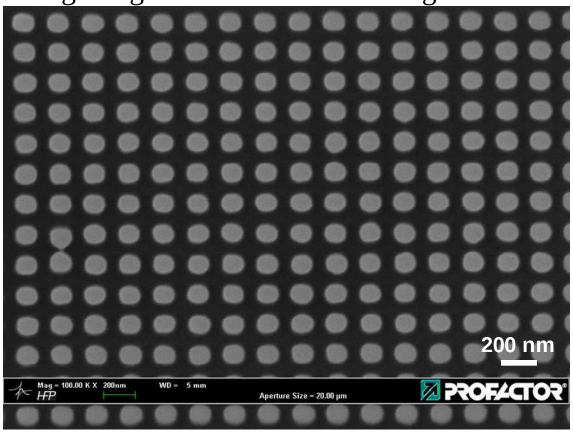


Figure 1:SEM picture of an imprint using working stamp with small Fishnet structure

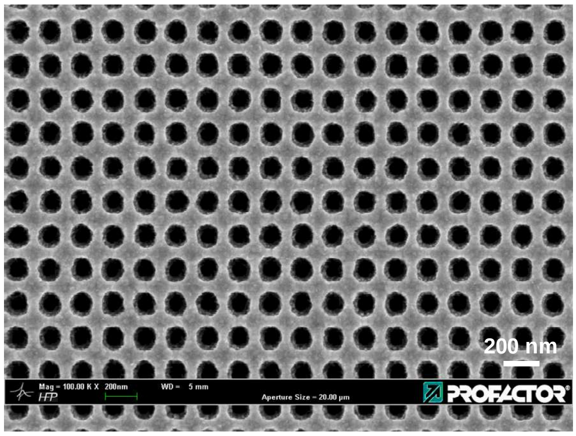
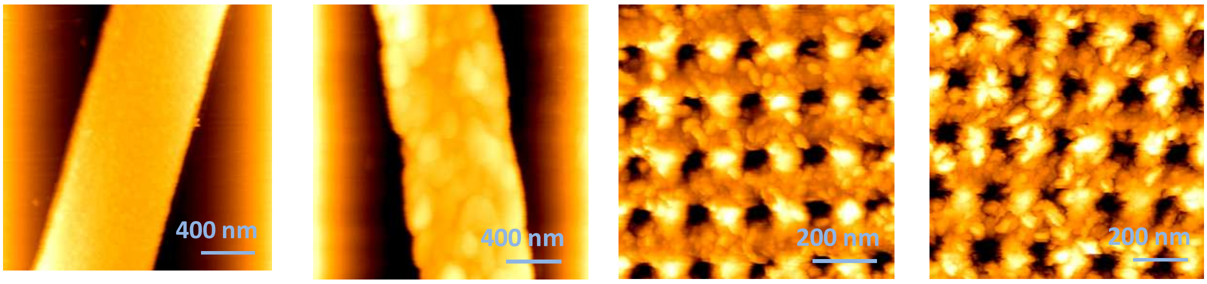


Figure 2: SEM figure of Fishnet grating fabricated by NIL

3. Annealing and passivation of silver

After taking out the samples from the evaporation chamber and performing lift-off, the Ag oxidizes immediately, such that the conductivity of the silver was reduced and a negative index response within the visible regime was hardly achievable. Additionally, the grain size of the silver plays an important role in the strength of plasmonic peaks, as shown recently for gold antennas [7]. We applied a soft H_2 plasma treatment to reduce the silver oxide (AgO), to increase the grain size (compare Figure 3 (a) and (b) and (c) and (d)) and to passivate the silver surface in order to increase the stability of the optical properties of the silver fishnet on air.



(a) **(b)** **(c)** **(d)**

Figure 3: Silver line and space grating and silver fishnet fabricated using NIL (a), (c). Silver line (b) and silver fishnet (d) after annealing. The grain size is increased and AgO is reduced which leads to a higher conductivity and an enhancement of the Plasmon peaks in silver.

3. Optical properties

The silver fishnet was measured using ellipsometry. The ellipsometric parameters which are measured - complex ratio r_p/r_s - contains the phase difference $\Delta = \Delta_p - \Delta_s$ as well as the amplitude information Ψ of the optical response $\rho = \frac{r_p}{r_s} = \left|\frac{r_p}{r_s}\right| e^{-i(\Delta_p - \Delta_s)} = \tan(\Psi)\, e^{-i\Delta}$. The difference of silver after evaporation (oxidized) and annealed silver can be seen in the resonance strength of ψ (Figure 4). Therefore the value of psi at the plasmonic peak e.g. around 3.9 eV can be used to monitor the silver properties. We measured the plasma processed fishnet sample over time and monitored the value for psi at around 3.9 eV, which clearly shows that the plasma passivation of the silver prevents its fast re-oxidation. The stability of the sample is enhanced and values are improved measured up to 30 days (Figure 5).

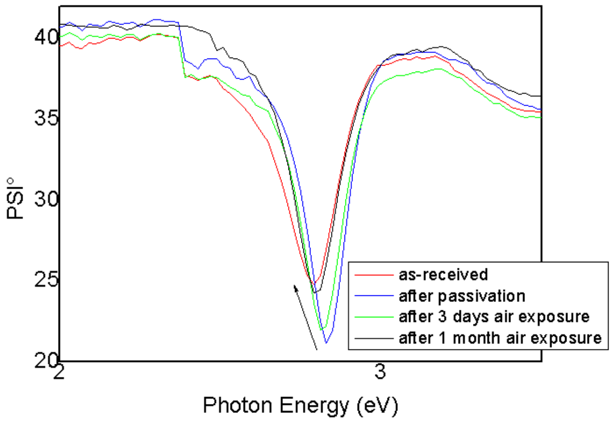


Figure 4: Comparison of ellipsometry measurement of Fishnet silver sample after lift-off “as-received” and after passivation. Due to the difference of the peak minimum in ψ (plasmon peak) the quality of the silver can be monitored.

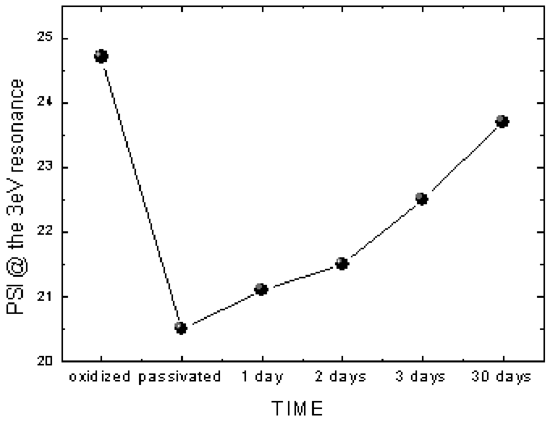


Figure 5: Measured ψ at 3.9 eV for silver fishnet shown in figure 3 (e). The value after deposition is decreased during sample annealing and passivation. The stability of the silver sample is enhanced.

4.Conclusion

In this work we demonstrated the fabrication of a fishnet structure with line width down to 70 nm using NIL. The structures were designed to exhibit negative refraction within the visible regime. To improve the silver properties the samples were processed by a hydrogen plasma to reduce the silver oxide and simultaneously passivate the silver surface and grain boundaries such that the stability of the silver properties against re-oxidation is improved.

5. Acknowledgement

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