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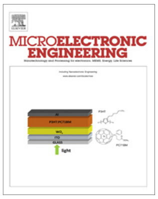

Subwavelength imaging of self-assembled triangular array through a silver superlens

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ABSTRACT

Superlens nanolithography is a promising technique for patterning nanoscale structures because of its ability to overcome the diffraction limit. In this paper, subwavelength imaging of triangular particle array through a silver superlens is investigated. The superlens structure was optimized by means of the transfer transmission matrix method. The triangular array was obtained by self-assembly of nanoscale polystyrene spheres (PSS) and was successfully replicated into the photoresist. Experimental results show that the superlens structure provides at least 50 nm resolution, about 1/7 of the incidence wavelength.

1. Introduction

The continuing size reduction of integrated circuits to nanometer-scale dimensions requires the development of new lithographic techniques. It becomes increasingly complex and costly to use the established method of optical projection lithography at the short optical wavelengths. Since 2000 when Pendry proposed the concept of superlens and noted that superlens can be used for subwavelength imaging [1], the superlens nanolithography has attracted wide attentions. As a near field imaging technique, it is a potential alternative to solve the problems encountered by traditional photolithography. Because the superlens structure substantially enhances the evanescent waves and collects both the propagating and evanescent waves, thus it is capable of achieving diffraction-free imaging [2–5]. In 2005, 60 nm resolution was achieved based on a metallic superlens structure by Zhang group [6–9]. Meanwhile, Blaikie et al. also demonstrated a sub-100 nm resolution [10,11]. In 2010 Fang group obtained a 1/12 wavelength resolution by reducing surface roughness of the metallic layer [12].

We noticed that almost all researchers used one dimension periodic gratings as masks in previous work. It was also demonstrated patterning such gratings through a metallic superlens structure possibly resulted in frequency-doubled images due to the interference of surface plasmons [13]. Up to now, few papers explore the superlens imaging of isolated structures which are also the basic structures in various lithographical applications. Below we investigate the ability of a superlens structure resolving a triangular particle array in which the particles can be regarded as isolated nanostructures.

2. Principle

Fig. 1 illustrates the schematic of our superlens imaging setup. The upper is the superlens structure which is a silver slab sandwiched by two Polymethyl Metacrylate (PMMA) layers. Due to its nanoscale thickness the superlens structure was designed to attach the mask. Use of soft PMMA material is a better choice than rigid material because it is easier to control the thickness and eliminate the uneven topography of the mask. The two PMMA spacers function as refractive index matching layers for wide surface plasmons (SPs) band excitation described below. Moreover, the bottom PMMA provides a way to avoid the contamination from photoresist [14]. The lower part is the recording photoresist on a silicon substrate. When a light is normally incident on the superlens structure, the mask will be imaged two times [1,13]. The first image is formed in the silver film and the second image on the photo-resist. Free electrons can accumulate on the silver surface because of the discontinuity of electric field. Under given conditions of the closely matching permittivity and perfect interface between the silver layer and the spacers, collective electron oscillations are generated known as SPs. The SP field is beneficial to transmit the propagating waves and amplify the evanescent waves onto the resist image plane, thus the imaging resolution is enhanced.

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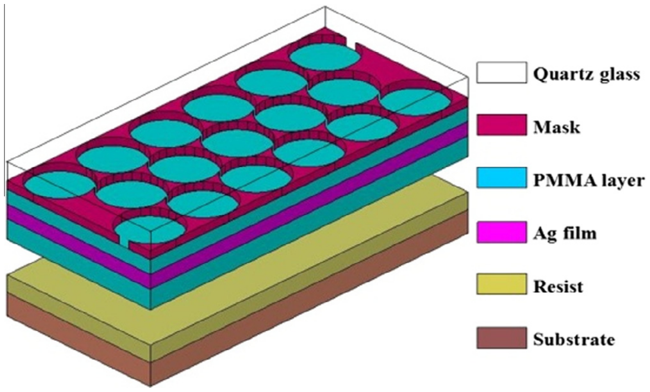

Fig. 1. Schematic of our superlens imaging setup.

3. Superlens structure design

In order to maximize the enhancement of evanescent waves for improvement of the imaging resolution, correct superlens structure size is very vital. The superlens structure consisting of PMMA/Ag/PMMA was optimized based on the transfer transmission matrix method. Numerical analysis of thickness dependent optical transfer functions is shown in Fig. 2. The incident wavelength is 365 nm.

In Fig. 2(a), the Ag thickness varied from 10 to 40 nm in 10 nm step with two PMMA layers thickness of 20 and 15 nm, respectively. It is observed that the thinner Ag layer, 10 nm, shows higher but narrow enhancement bands and thicker layers of 40 nm show smaller enhancements. Around 30 nm Ag layer gives the optimum transfer function. Fig. 2(b) describes thickness-dependent transmission for different particular wavenumbers with varying Ag thickness from 20 to 70 nm. Improper thickness often leads to diminishing the enhancement resulting in a diffraction-limited image [15,16]. High wavenumber requires small Ag thickness. In order to obtain high wavenumber, 35 nm Ag thickness is selected for maximum field enhancement. In Fig. 2(c), the first PMMA thickness varied from 10 to 40 nm, while the Ag/PMMA thicknesses were fixed at 35/15 nm. As expected, thinner PMMA shows larger enhancements. In Fig. 2(d), the second PMMA thickness varied from 10 to 40 nm, while PMMA/Ag thicknesses were fixed at 20/35 nm. Similar to the first PMMA thickness, the second thinner PMMA also shows larger enhancements. The first PMMA thickness is chosen to 20 nm instead of 10 nm for easy spinning and removal of particle topography. The 15 nm second PMMA layer is chosen for the reason to match the second focal plane. As a result, the optimized structure is 20 nm PMMA/35 nm Ag/15 nm PMMA.

4. Experiments

4.1. Fabrication of triangular array by self-assembly of PSS

Silicon substrates (diameter: 8 cm) and K9 quartz glass (diameter: 2.5 cm) substrates were soaked thoroughly in a freshly

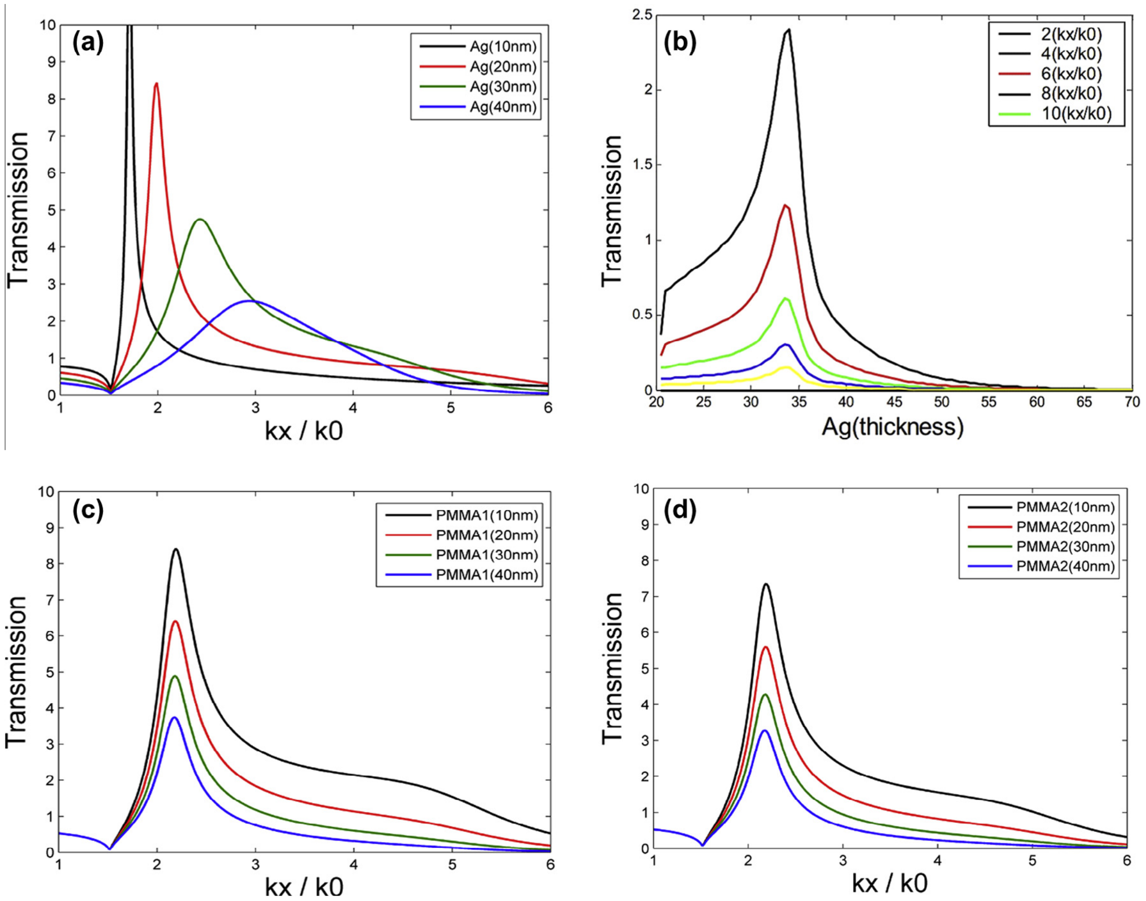

Fig. 2. The transmission of various superlens structures. (a) The two PMMA layers thicknesses were fixed at 20 and 15 nm respectively, and Ag layer thickness varied from 10 to 40 nm in 10 nm step. (b) Transmission for different wavenumbers with varying Ag thickness from 20 to 70 nm. (c) Ag/PMMA thicknesses were fixed at 35/15 nm, and the first PMMA layer thickness varied from 10 to 40 nm in 10 nm step. (d) PMMA /Ag thicknesses were fixed at 20/35 nm, and the second PMMA layer thickness varied from 10 to 40 nm in 10 nm step.