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Full Length Article

# Plasmonic direct writing lithography with a macroscopical contact probe

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ABSTRACT

In this work, we design a plasmonic direct writing lithography system with a macroscopical contact probe to achieve nanometer scale spots. The probe with bowtie-shaped aperture array adopts spring hinge and beam deflection method (BDM) to realize near-field lithography. Lithography results show that a macroscopical plasmonic contact probe can achieve a patterning resolution of around 75 nm at 365 nm wavelength, and demonstrate that the lithography system is promising for practical applications due to beyond the diffraction limit, low cost, and simplification of system configuration. CST calculations provide a guide for the design of recording structure and the arrangement of placing polarizer.

## 1. Introduction

With the development of semiconductor industry, the feature sizes of integrated circuit become smaller [1]. Lithography techniques have taken an important role in nanoscale manufacturing, therefore, need to be continuously improved to match space with demand. As alternatives to electron beam lithography, a series of low-cost lithography means including planar lens imaging nanolithography [2], imprinting lithography [3], Nanosphere lithography [4,5], near-field scanning lithography [6] have been explored. Benefiting from the nature of evanescent field, near-field scanning lithography has the potential to be a promising technique due to its low-cost, flexibility and high productivity. Recently, the near-field scanning lithography based on plasmonic nanofocusing probe has made great progress, which is also a kind of near-field direct-writing lithography. In this type of lithography, ridge nanoscale apertures of different shapes (C, bowtie) fabricated in metal film on probe tip have been shown to have a capability of creating an extremely small spot beyond the diffraction limit with enhanced intensity in the near field range [7–12]. Fig. 1 shows the schematic of a bowtie-shaped ridge aperture. Compared with regular apertures, the bowtie aperture has a much longer cutoff wavelength [13]. That is, all nanoscale metallic tips exist local electric field enhancement due to an electrostatic tip effect, and the stronger field enhancement and stricter confinement are achieved by motivating surface plasmons (SPs) through nanoaperture in noble metal film [14]. However, the significant decay of high spatial frequency element of an evanescent wave beyond the far field cutoff [15]. Thus these probes for nanolithgraphy must be in near field range with highly accurate distance between the probes and recording material, which inevitably causes a problem for distance control. To solve aforesaid problem, a few researches have been done. These have been implemented in different means including placing the mask on the photoresist surface, using air-pressure to levitate the mask to a 20 nm height [16], employing a closed-loop feedback mechanism, applying normal force to maintain contact, and using a high precision dynamic gap detection system named interferometric-spatial-phase-imaging (ISPI) to realize high quality parallel nanolithography [17]. However, the costs of aforementioned technologies are high due to complex dynamic system and stringent environment requirements. Later, Luo et al. presented an enhanced SPs nanolithography structure which combined the bowtie aperture with metal-insulator-metal (BMIM) structure, and experimental results show that the propagation length of transmission light enhanced is obviously prolonged [18,19]. In this case, we need to use adhesive tape to tear off the upper Ag film to ensure that photoresist (Pr) is reacted with the developer. Nevertheless, aforementioned process results in the residuary upper Ag film contaminating the target area, and therefore the residuary upper Ag film can affect the presentation of the experimental results.

Inspired by the researches mentioned above, we design a plasmonic direct writing lithography system based on a macroscopical contact probe with nanoscale bowtie-shaped apertures to obtain nanoscale patterns. In addition to reporting the focused spot size

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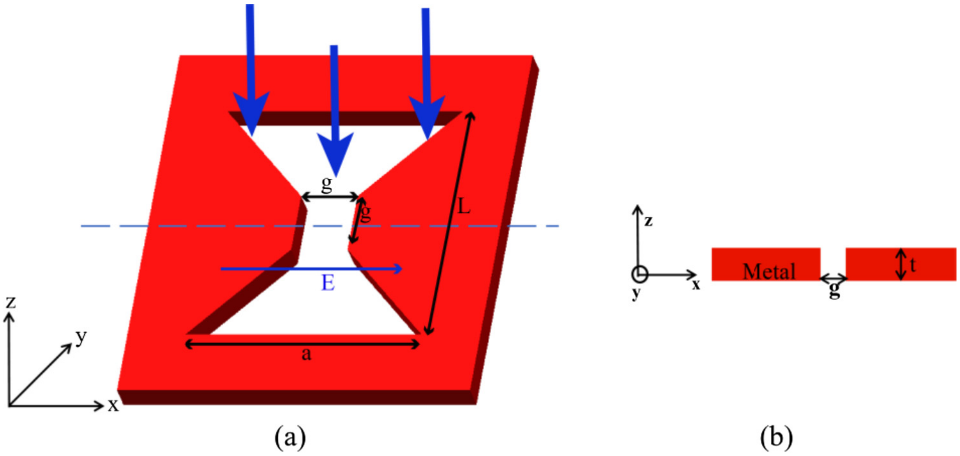

**Fig. 1.** Schematic of bowtie-shaped ridge aperture which is defined by the outline lengths $a$ = 200 nm and $L$ = 200 nm, the gap size $g$ = 30 nm and the thickness $t$ = 30 nm. (a) Autostereogram. (b) Cross sectional view at the location of the dashed line.

related to recording material and polarization orientation, we also clearly describe the manufacture process of macroscopical contact probe. We present that the lithography system employs beam deflection method (BDM) and the spring hinge to realize parallel contact lithography. In the exposure experiments, we demonstrate plasmonic direct writing lithography with different expose time and polarization orientation.

## 2. Numerical simulations

To illustrate the advantages of BIM structure, we use finite integration time domain algorithm (CST Microwave Studio) to numerically calculate bowtie with insulator (BI) and BIM structure, respectively. The grid size is adaptive with a smallest grid size of 5 nm in critical areas to resolve the near field below the aperture. Electric boundary condition apply in x direction, magnetic boundary condition apply in y direction, and open boundary condition apply in z direction. Fig. 2 shows the configuration of BI and BIM structure. It is all known that the choice of the metal film for fabricating bowtie apertures is important from the standpoint of aperture performance [20]. In this work, we choose Cr as the mask material due to its hard texture, stable properties and small friction coefficient. The thickness of Cr is set to 30 nm due to the technology limitation of the focused ion beam (FIB). The frequency dependent dielectric function of Cr are described by the Drude model [21]. The light is normally incident with a plan wave (365 nm wavelength) that is linearly polarized in the x-direction. In order to restore the actual situation, Cr and Pr recording structure are separated by 5 nm air gap in two structures. For BI structure, 30 nm single Pr layer is firsthand coated on the quartz substrate. Since Ag has property of evanescent amplification, we usually choose Ag to serves as the material of waveguide in experimental work [22]. For the BIM structure, 50 nm Ag layer first is coated on the quartz substrate, then aforesaid Ag film is clad in 30 nm Pr layer, which of two materials layers constitute the recording structure.

As shown in Fig. 1, the geometry of bowtie is defined by the thickness of the metal $t$, the outline length $a$ and $L$, and the gap size $g$, which are set to be 30 nm, 200 nm, 200 nm and 30 nm, respectively. When the bowtie aperture is illuminated with incident light, surface plasmon polaritons (SPPs) are excited, the field intensity is confined in bowtie gap. Fig. 3(a) and (b) shows the normalized electric field distribution of x-z plane of BI and BIM structure, respectively. Clearly, the electric field is enhanced near both the entrance and the exit of the bowtie aperture, but BIM structure produces a directional field beaming in the propagation direction and obviously prolongs the propagation length of transmission light compared to BI structure. Fig. 3(c) and (d) presents the normalized electric field distribution of x-y plane at 20 nm below the exit of the aperture in BI and BIM structure, respectively. The full width at half maximum (FWHM) of the electric field is called spot size. For the BI structure, the spot size is 130 nm and 88 nm

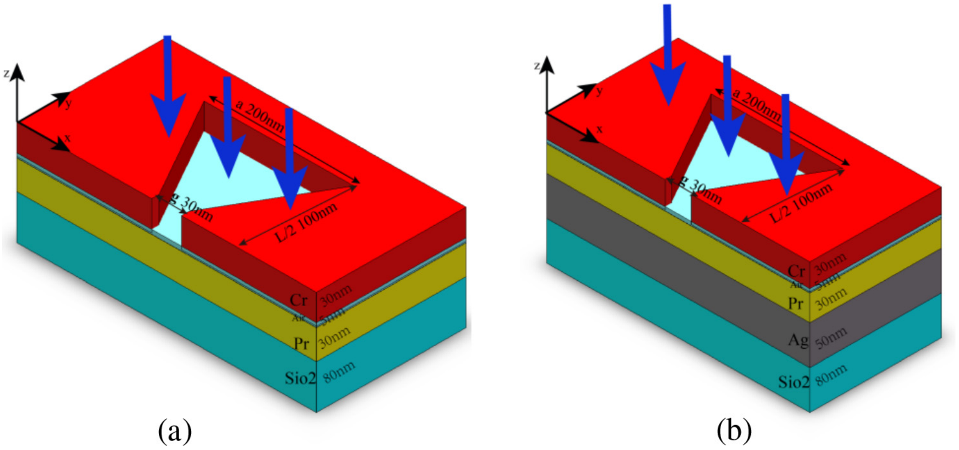

**Fig. 2.** Schematic configurations of (a) BI and (b) BIM structure.