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Photolithography using lateral surface of nanofibers

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ABSTRACT

To enhance the resolution of photolithography, we demonstrate a technique that confines the exposure area by using lateral surface of nanofibers. Due to evanescent wave and optical tunneling effect, the interaction area of optical energy and the photoresist layer is confined into sub-wavelength dimension. Illuminated by a He–Cd laser device with a 442 nm wavelength, exposed lines with sub-wavelength width were obtained by using a nanofiber with a 247 nm diameter. Furthermore, curve lines and annular lines were obtained by manipulating the shape of nanofibers on the photoresist layer.

1. Introduction

Although electron-beam lithography and atomic force microscope (AFM) etching have obtained resolution beyond 50 nm [1–3], they could not satisfy mass production of nano-components. Enhancing the resolution of photolithography to sub-wavelength dimension is urgent for fabricating nano-sensors, nano-detectors and so on. Recently, exposed lines with 350-nm-resolution were obtained by using the tip of a nanofiber as an exposure source [4]. Unfortunately, light divergence and diffraction limit impede further improvement of resolution. The purpose of this paper is to enhance the resolution of photolithography by narrowing down the interaction area of optical energy and the photoresist layer.

Evanescent wave confined in sub-wavelength scale has brought about a lot of application, such as Scanning Near Fields Optical Microscope (SNOM), optical micromanipulation and so on [5–10]. Besides, based on the frustrated total internal reflection, a kind of optical tunneling effect, Photon Scanning Tunneling Microscope (PSTM) could form images with $\lambda/10$ lateral resolution [11–16].

Silica nanofibers with diameters ranging from 50 to several hundred nanometers were fabricated successfully. With the decrease of the nanofiber diameter, the proportion of optical fields propagating as evanescent wave increases dramatically [17–19]. Actually, nanofibers have brought about a lot of applications, such as nano-lasers, nano-interferometers and so on [20–23].

In this paper, the simulations demonstrated that nanofibers confine the interaction area of optical energy and the photoresist layer in sub-wavelength dimension so that the linewidth of the light spot in the photoresist layer decreases to 200 nm. Experimentally, using a 247-nm-diameter nanofiber, exposed lines with 75, 160 and 238 nm width were achieved under the illumination of different powers. This basic research provides a novel method for photolithography.

2. Principles and simulations

2.1. The principle of photolithography using lateral surface of nanofibers

The model of photolithography using lateral surface of nanofibers is illustrated in Fig. 1(a): a nanofiber's lateral surface intimately contacts the photoresist layer ($0 \le x \le 0.1, -0.4 \le y \le 0.4, 0 \le z \le 3.1$) which is coated on a silicon wafer ($0.1 \le x \le 0.35, -0.4 \le y \le 0.4, 0 \le z \le 3.1$). The principle of the exposure could be explained by analyzing the *XY* plane of the model. As shown in Fig. 1(b), because the refractive index of the photoresist layer is larger than that of the nanofiber, optical energy could be transmitted from the nanofiber into the photoresist layer at the connected point ($x=0$, $y=0$). However, at the disconnected region, optical energy could not be transmitted into the photoresist layer unless the optical tunneling effect occurs. Actually, the optical tunneling effect generates a transparent aperture in the air (blue region). As shown in Fig. 1(b), inside the critical plane which is defined as $y=a (a\neq0)$,

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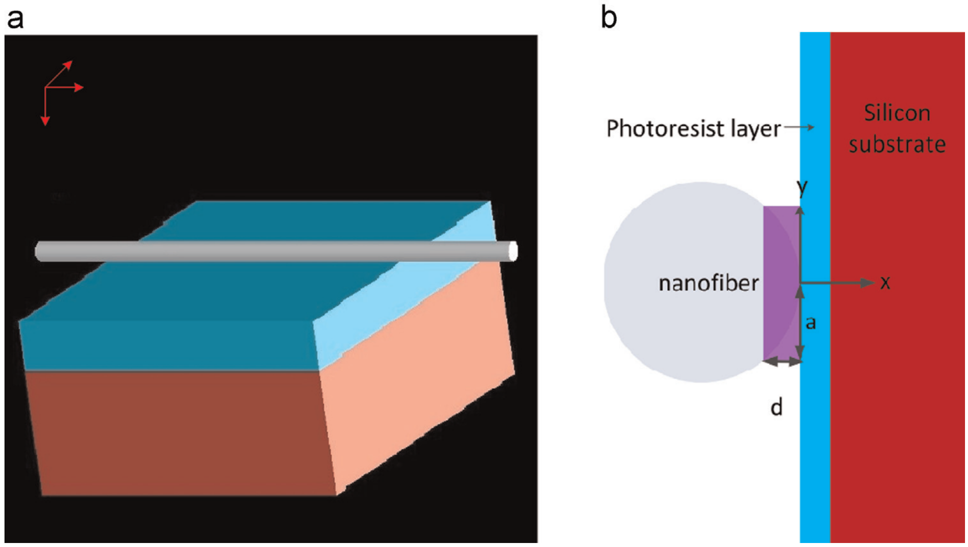

Fig. 1. (a) The model of photolithography using lateral surface of nanofibers and (b) the *XY* plane of the model. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

the evanescent wave is intense enough so that optical energy could penetrate the air and expose the photoresist layer, but optical energy could not penetrate the air if $y > a$. Consequently, the dimension of the transparent aperture is confined to 2a and lower power brings out narrower optical channel.

2.2. The simulated results of photolithography model

To investigate the transmission of optical energy, the model is simulated with the Lumerical FDTD Solutions. The simulations are set with the following parameters: the refractive indices of

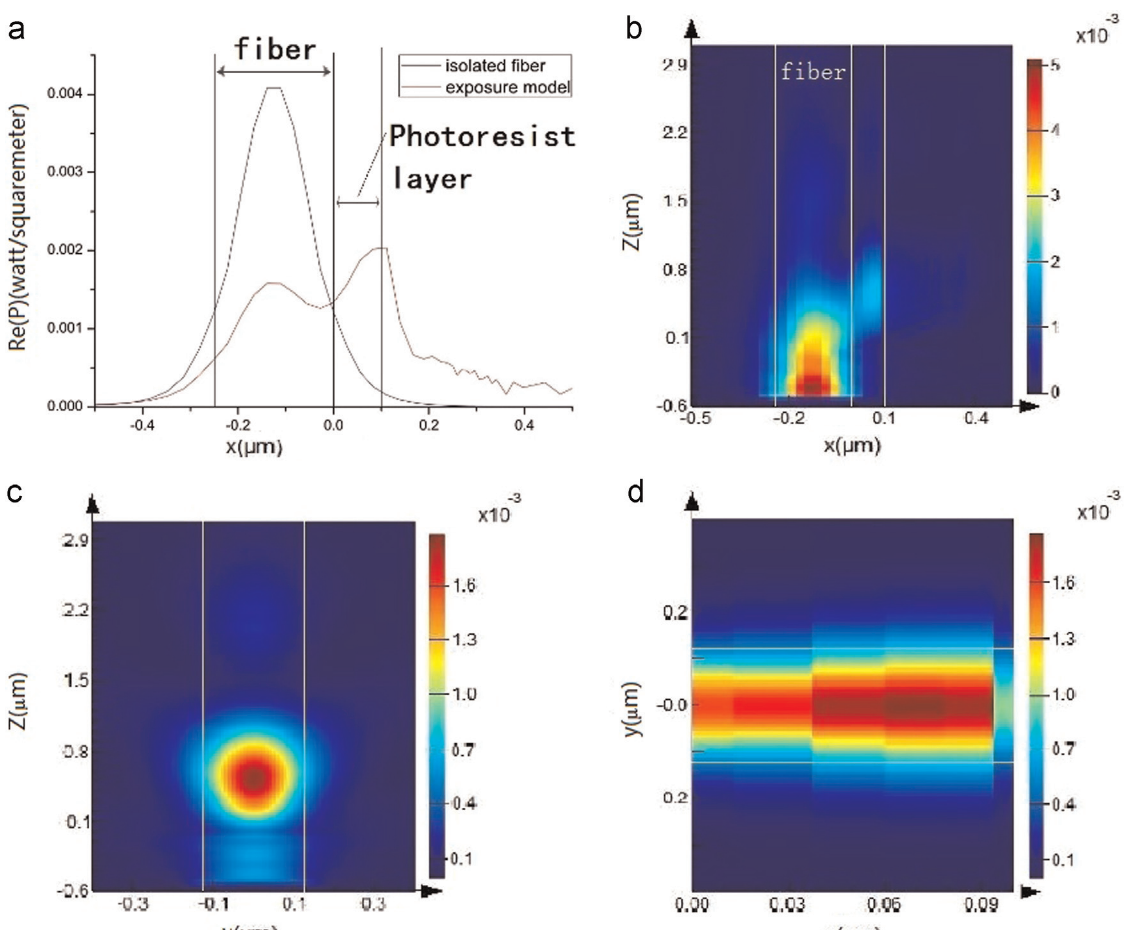

Fig. 2. (a) Poynting vector in the *X*-direction. of an isolated 250-nm-diameter. nanofiber (blue line) and the exposure model (red line). (b) Poynting vector in the XZ(y=0) plane of the model. (c) Poynting vector in the *YZ* (x=0.05) plane of the photoresist layer. (d) Poynting vector in the *XY* (z=0.555224) plane of the photoresist layer. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)