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Fabrication of nano-and micro-structured surface using spatial beat of evanescent wave interference lithography

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Abstract

In the last few decade nano- and micro-structured surfaces have been attracting great attention in various fields represented by biomimetics. Because it becomes clear that multi-scale structures have multiple functions such as several hundred nm for antireflection and several tens of µm for superhydrophobic. In this paper, we present a fabrication method for nano- and micro-structured surface using the spatial beat of evanescent wave interference lithography. The spatial beat of evanescent wave interference modulate visibility of interference fringes with micrometer period. Furthermore, unlike ordinary propagation light, the attenuation height is also modulated by the exponential decay of the evanescent wave. A four-beam evanescent wave interference lithography system was set up to demonstrate this method. As a result, we could successfully fabricate multi-scale structured surface combining nano-sized 1D gratings with the pitch of 450 nm aligned in a 2D elliptical dot patterns of several tens of microns. The results indicate multi-scale structures can be fabricated by this method.

Keyword: Interference lithography, Evanescent wave, Nano-structure

1. Introduction

In the last few decade nano- and micro-structured surfaces have been attracting great attention in various fields represented by biomimetics[1]. Because multi-scale structures have multiple functions such as several hundred nm for antireflection and several tens of µm for superhydrophobic. In particular, interference lithography is one of the effective and widely used techniques to fabricate periodic structures. It is also possible to fabricate a dual-scale structure with an asymmetrically incident multi-beam[2]. However, as long as propagation light in the air is used, fabrication of fine structures less than half of the wavelength is impossible in principle[3]. Then it was reported that the processing resolution was improved by using evanescent wave instead of propagation light[4].

In this paper, we presented the fabrication method for nano- and micro-structured surface using the special beat of evanescent wave interference lithography (EWIL). The spatial beat of evanescent wave interference modulates visibility of interference fringes with a micro-order period. To demonstrate this method a four-beam EWIL system was set up.

2. Evanescent wave interference lithography

2.1. Evanescent wave interference lithography

When the light incident to low refractive index matter beyond critical angle from a higher one, the light is totally reflected. However, in the lower index media, some of the electromagnetic fields exist and exponentially decay from the boundary which is evanescent wave. In general, electromagnetic fields of the n_{th} evanescent wave is expressed as

$$E_n(\boldsymbol{r},\ z,\ t) = A_n \exp(-i\omega t)\exp(i\boldsymbol{k}\cdot\boldsymbol{r})\exp(-\beta\, z).$$
$$(\boldsymbol{k} = \frac{2\pi}{\lambda} n_1 \sin\theta\,(-\cos\phi_n, -\sin\phi_n), \beta = \frac{2\pi}{\lambda}\sqrt{n_1^2\sin^2\theta - n_2^2}) \quad (1)$$

In this expression, subscript n means n_{th} wave. A_n is an amplitude of the electromagnetic field. n_1, n_2 is the refractive index of the medium. As for EWIL, lower media is generally photoresist and higher media is immersion oil or substrate. Incident angle and wavelength was expressed θ, λ . Angular frequency is expressed by ω. The azimuth angle of Φ_n is an angle in the xy plane from the x-axis positive direction. The polarizations of beams were ignored and all intensity distribution was calculated by eq(1). Because polarization only affects the contrast of interference pattern and we focused to analyze the shape and pitch of interference.

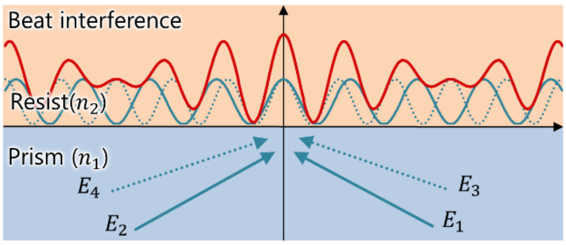

Figure 1. Schematic of spatial beat of evanescent wave interference

2.2. Spatial beat of interference

Figure 2 shows a schematic of the spatial beat of two interference fringes by the incident of four evanescent waves. In this situation, slightly different fringe pitchs provide spatial beat of interference. The pitch of spatial beat d_{beat} is expressed as $d_{beat}=2d_1d_2/|d_1-d_2|$ by each pitch $d_{1,2}$. Controlling each pitch allows us to design the spatial frequency of beat.

Next the intensity distributions of four-beam interference calculated by eq.(1) are shown in fig. 2. Refractive index n_1, n_2 are 1.78, 1.5 respectively. Here calculated fringe pitch of $E_{1,2}$ and $E_{3,4}$ are $d_{1,2}$=160, 140 nm. As a result pitch of spatial beat d_{beat} is 2.24 µm. Figure 2(a) shows the result of two-evanescent wave interference. Next fig.2(b) shows interference of four evanescent waves. Both fringe pitch of fig.2(a) and (b) is 160 nm. Because amplitude $A_{1,2}$ is over two times larger than $A_{3,4}$. In fig.2(b) the intensity modulation caused by spatial beat can be confirmed with the period of d_{beat}=2.24 µm. Therefore using this modulated periodic pattern, fabrication of nano- and micro-structured surface was expected.

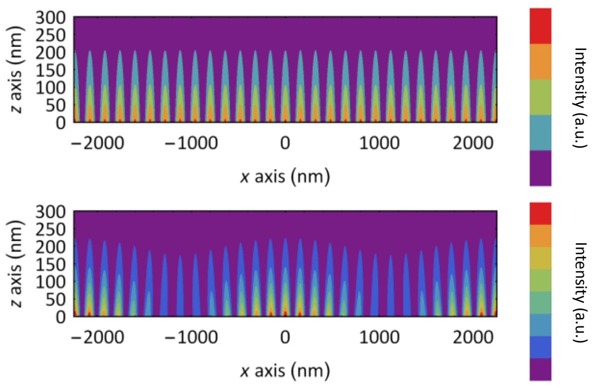

Figure 2 Calculated intensity distribution
(a)Two-beam interference (A_1,A_2,A_3,A_4)=(1,1,0,0)
(b)Four-beam interference (A_1,A_2,A_3,A_4)=(1,1,0.4,0.4)

3. Fabrication experiments

3.1. Experimental method

Fabrication experiment was conducted to demonstrate the concept ot this method. Figure 3 shows the four-beam EWIL system. The light source was a diode laser with the wavelength of 488 nm. Exposure energy was controlled by a halfwave plate and polarizer. The laser was divided into 4 beams by two beam splitter and all beam is P polarized light. The incident angle of each beam was adjusted by mirrors and it incidents to cubic glass prism with the refractive index of 1.78. Positive tone photoresist (AZ 1350) was spin-coated on the glass substrate to a thickness of 500 nm at 6000 rpm. After that substrate was baked at 130 °C for 6 min. To expose the resist to evanescent wave coated substrate was placed at the top of the prism and the gap betweenthe resist surface and prism was filled with index matching liquid. Intensity and incident angle of each beam was described in table 1. Exposure was performed for 1.2 s. Thereafter reisist was developed by AZ developer 1:1 for 30 s at 23 °C.

Table 1 Incident conditions of 4 beams

	E_1	E_2	E_3	E_4
Intensity (mW)	2.8	2.8	2.1	2.1
Incident angle (°)	80	80	78	78
Azimuth angle (°)	18	-18	17.6	-17.6

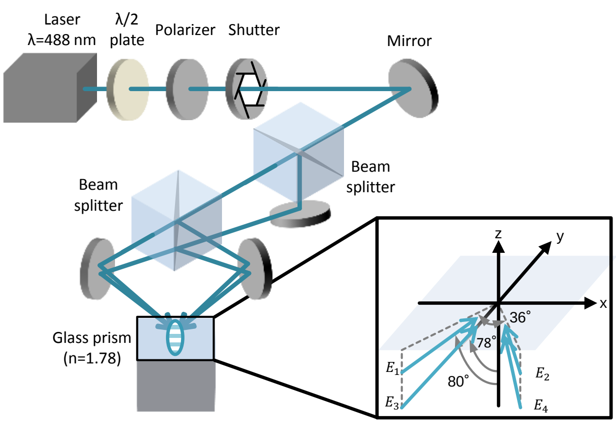

Figure 3 Setup of fabrication experiment

3.2. Experimental result and discussion

Figure 4 shows the calculated intensity distribution of z=0. The small pitch is 450 nm and interference fringe modulated as eliptical dot pattern with the period of 23.4 and 26 µm by the spatial beat. The fabricated structures are shown in Fig. 5 which is observed by a microscope with epi-illumination. Although the fabricated pattern is slightly distorted compared with fig.4(a), elliptical dot patterns showed good agreement with the calculated results. Figure 5(b) shows the magnified image and nano-sized grating structure was clearly observed with the pitch of 450 nm. Antireflection effect of nano-grating made elliptical patterns look dark. It is known that these subwavelength grating works as a waveplate due to form birefringence. Therefore this fabricated shapes can be a micro-waveplate array. Furthermore, fabrication of multi-scale and pattern structure was successfully achieved.

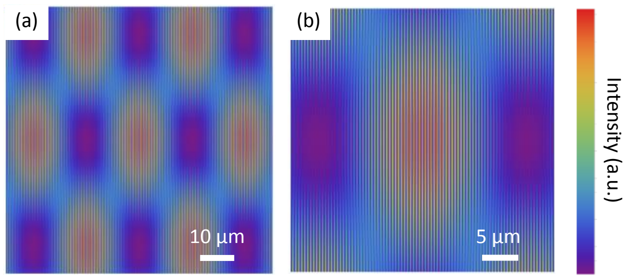

Figure 4 Calculated intensity distributions (z=0)
(a)large area image (b)magnified image

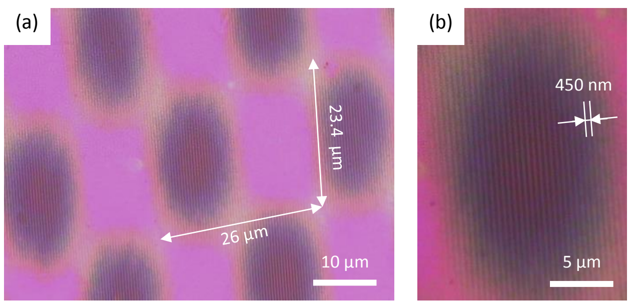

Figure 5 Microscopy image of fabricated structure
(a) large area image (x20) (b) magnified image (x100)

4. Conclusion

We have presented the fabrication of nano- and micro-structured surface by using the spatial beat of EWIL. According to the calculated results, nano-sized grating structures of the modulated height due to spatial beat can be expected. Experimental results show good agreement with the calculated results which has nano-grating with 450 nm pitch and 2D beat pattern of several tens of microns. This technique can be applied to a fabrication of multi-functional devices.

Acknowledgment

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