248 nm imaging photolithography assisted by surface plasmon polariton interference*

TIAN Man-man (田曼曼)[1], **MI Jia-jia** (米佳佳)[1], **SHI Jian-ping** (石建平)[1]**, **WEI Nan-nan** (魏楠楠)[1], **ZHAN Ling-li** (詹伶俐)[1], **HUANG Wan-xia** (黄万霞)[1], **ZUO Ze-wen** (左则文)[1], **WANG Chang-tao** (王长涛)[2], and **LUO Xian-gang** (罗先刚)[2]

1. College of Physics and Electronic Information, Anhui Normal University, Wuhu 241000, China

2. State Key Laboratory of Optical Technologies for Microfabrication, Institute of Optics and Electronics, Chinese Academy of Sciences, Chengdu 610209, China

(Received 26 September 2013)

A new photolithography technique for 248 nm based on the interference of surface plasmon waves is proposed and demonstrated by using computer simulations. The basic structure consists of surface plasmon polariton (SPP) interference mask and multi-layer film superlens. Using the amplification effect of superlens on evanescent wave, the near field SPP interference pattern is imaged to the far field, and then is exposed on photo resist (PR). The simulation results based on finite difference time domain (FDTD) method show that the full width at half maximum (FWHM) of the interference pattern is about 19 nm when the p-polarization light from 248 nm source is vertically incident to the structure. Meanwhile, the focal depth is 150 nm for negative PR and 60 nm for positive PR, which is much greater than that in usual SPP photolithography.

Document code: A **Article ID:** 1673-1905(2014)01-0024-3

DOI 10.1007/s11801-014-3172-1

Surface plasmon polariton (SPP) interference photolithography is a new photolithography put forward in recent years[1-3], which makes full use of the characteristic that wave vector of surface plasmon (SP) is much greater than that of the same frequency in free space[4-6], so it is easy to implement deep sub-wavelength imaging. Even under the longer wavelength light, it can achieve nanometer level resolution, e.g., using 248 nm photolithography can realize 32 nm resolution, and using 193 nm photolithography can realize 20 nm resolution. Currently, various technical solutions are put forward to implement SPP interference photolithography[7-11], such as waveguide mode interference lithography, grating stimulated interference lithography and prism coupling interference lithography. These techniques can well realize the resolution at nanometer level, but because SPP is a surface evanescent wave, i.e., the exposure of interference pattern must be finished in the near field, and the focal depth of photolithography process is very short, generally within 10 nm, the technology implementation is quite difficult, which hinders the further development and application of the technology to a certain extent.

The paper proposes a superlens based SPP interference photolithography. It uses the amplification effect of superlens on evanescent wave[12-14], images the near field SPP interference pattern to the far field, and then exposes it on photo resist (PR). It can not only keep the super-resolution of patterns, but also increase the focal depth, and meanwhile, can reduce the difficulty of the process implementation.

The basic structure is shown in Fig.1, consisting of the SPP interference mask and multi-layer film superlens, and the PR is underneath the superlens. The interference masks on both ends have the same grating with a period of Λ, and the middle distance is L. One-dimensional gratings are used to convert free-space light into SP waves, and those waves propagating outside the grating area can form an interference pattern when they encounter each other at the middle area. The pattern is a surface electromagnetic model, which can only be localized on surface of the mask, thus cannot be transferred. The superlens under the mask has imaging function on evanescent wave, transmits the bounded interference pattern to the far field, and exposes it on the PR. The superlens can effectively filter out the zero-order diffracted wave vector, perfectly amplify the evanescent wave, thus improve the interference pattern contrast, and increase the focal depth in the PR.

The specific structure parameters for optimal design of the 248 nm UV photolithography are as follows. The thick-

---

* This work has been supported by the Open Fund of State Key Laboratory of Optical Technologies for Microfabrication, Institute of Optics and Electronics, Chinese Academy of Sciences (No.KFS-02).

** E-mail: shi_jian_ping@hotmail.com

ness of the Cr mask prepared on quartz substrate is 40 nm, the grating period Λ is 85 nm, the duty ratio is 1:1, the distance L is 1000 nm, and superlenses are alternately consisted by 8 pairs of GaN films (10 nm) and Al films (12 nm).

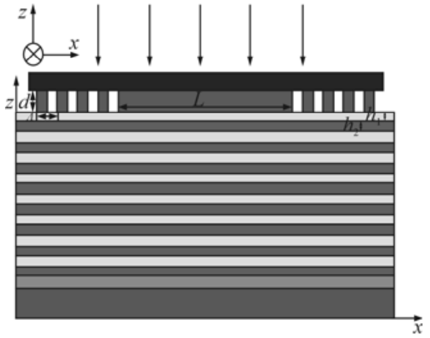


Fig.1 Schematic diagram of basic structure of the SPP

Imaging simulation is performed by finite difference time domain (FDTD) method[15]. The incident light with polarization perpendicular to the grating (p-polarization) is normally incident to the substrate. The permittivity of the Al film is described by Drude model. Fig.2 shows the optical transfer function (OTF) curve of the superlens, and there is an obvious transmission peak at $k_x=2k_0$, which shows that the structure can amplify the evanescent wave. Based on the conservation of momentum, surface plasmon waves with a wave vector of $K_{\text{spp}}=2p/L$ can be resonantly excited. When the incident wavelength is 248 nm, $k_0=2\pi/248$, so $k_x/k_0=2.9$, it is still in the ultra-transmission band of the superlens.

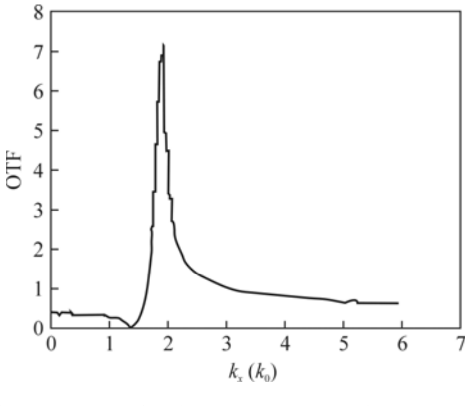
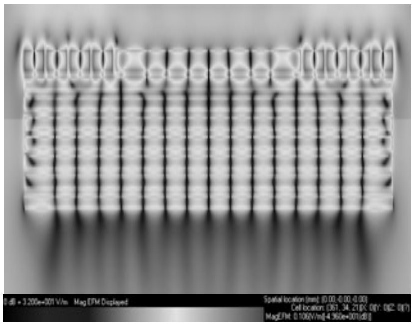
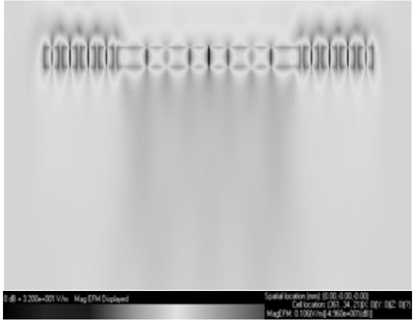


Fig.2 Optical transfer function curve of the superlens

Fig.3 shows the total electric field distributions with and without superlens when p-polarization light from 248 nm source is vertically incident to the structure. When SP interference pattern passes through superlens and is imaged on PR, the pattern is clear and uniform as shown in Fig.3(a), while the interference patterns without superlens can only be limited on the surface of the mask as shown in Fig.3(b). For the further analyses of photolithography imaging quality, we measure the electric fields at different depths of PR at 10 nm, 20 nm, 30 nm and 40 nm as shown in Fig.4. It can be seen from Fig.4 that the patterns in the PR have consistent period, the characteristic line width, i.e., full width at half maximum (FWHM), is about 19 nm, and the ratio of wavelength 248 nm to FWHM is 13, which shows that the structure can achieve imaging far beyond the diffraction limit. It also can be seen from Fig.4 that when the distance away from the lower surface of superlens is farther, the light intensity declines, and the visibility of interference fringe becomes lower and lower, which are the characteristics of the SP evanescent wave. In the photolithography process, the negative PR requires a minimum visibility of interference fringe of 0.2, so the patterns with visibility lower than this value cannot be exposed. So we define the distance with the visibility of interference fringe of 0.2 as the focal depth. The focal depth of the structure in the paper measured from Fig.3(b) is 150 nm, which is far greater than that of usual SPP photolithography (about 10 nm). If the positive PR is adopted, the visibility of interference fringe is required to be greater than 0.4, so the focal depth is 60 nm, which is several times larger than that of usual SPP photolithography.

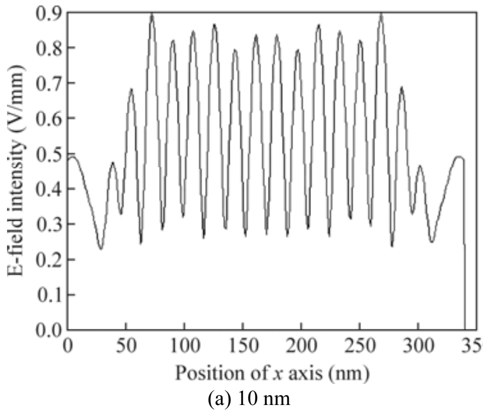


(a) With superlens

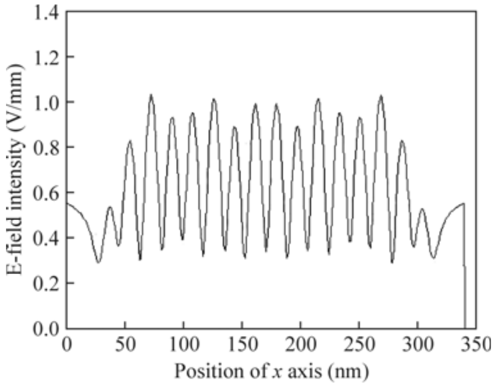


(b) Without superlens

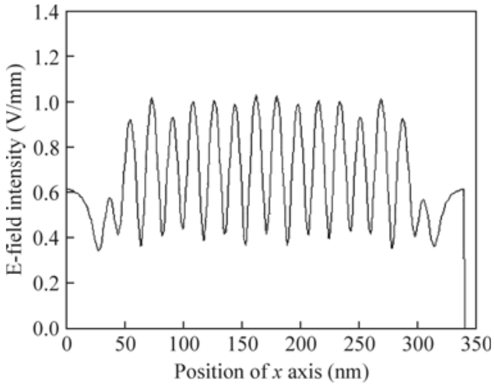
Fig.3 Cross sections of the total electric field distributions with and without superlens



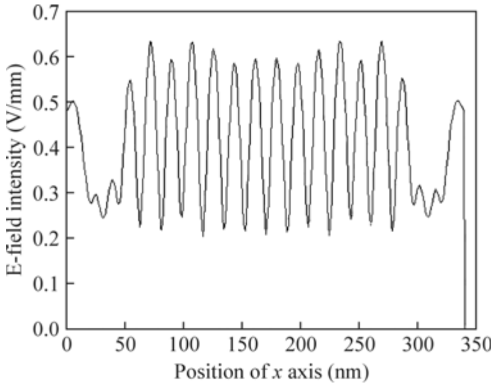
(a) 10 nm



(b) 20 nm



(c) 30 nm



(d) 40 nm

Fig.4 Electric field distributions at different depths in PR

In conclusion, SPP interference lithography can realize deep sub-wavelength resolution, its application prospect is exciting in the field of micromachining, but its focal depth is limited because it is the near field imaging. This paper proposes the superlens based SPP interference photolithography, which not only can keep the pattern with super-resolution, but also can increase the focal depth and reduce the difficulty of process implementation.

References

[1] Z. W. Liu, Q. H. Wei and X. Zhang, Nano Letters **5**, 957 (2005).

[2] T. Xu, Y. Zhao, J. Ma, C. Wang, J. Cui, C. Du and X. Luo, Optics Express **16**, 13579 (2008).

[3] V. M. Murukeshan and K. V. Sreekanth, Optics Lettters **34**, 845 (2009).

[4] LI Hai-jun, ZHANG Xiao-dong, WANG Min-rui, LIN Wen-kui, SHI Wen-hua, ZHONG Fei and ZHANG Bao-shun, Optoelectronics Letters **6**, 211 (2010).

[5] E. Ozbay, Science **311**, 189 (2006).

[6] WANG Chao, QIN Wen-jing, MA Chun-yu, ZHANG Qiang, YANG Li-ying and YIN Shou-gen, Optoelectronics Letters **8**, 401 (2012).

[7] Bing Wang, Ah Bian Chew, Jinghua Teng, Guangyuan Si and Aaron J. Danner, Applied Physics Letters **99**, 151106 (2011).

[8] M. He, Z. Zhang, S. Shi, J. Du, X. Li, S. Li and W. Ma, Optics Express **18** , 15975 (2010).

[9] K. V. Sreekanth and V. M. Murukeshan, Journal of Optical Society of America A **27**, 95 (2010).

[10] Yunxiang Li, Fang Liu, Long Xiao, Kaiyu Cui, Xue Feng, Wei Zhang and Yidong Huang, Applied Physics Letters **102**, 063113 (2013).

[11] Y. Xiong, Z. Liu, C. Sun and X. Zhang, Nano Letters **7**, 3360 (2007).

[12] He-Xiu Xu, Guang-Ming Wang, Mei-Qing Qi, Lian-Ming Li and Tie-Jun Cui, Advanced Optical Materials **1**, 494 (2013).

[13] M. Xiao and C. T. Chan, Beating Diffraction Limit in an Absorptive Superlens, APS March Meeting, Bulletin of the American Physical Society **58** (2013).

[14] J. Dong, J. Liu, X. Zhao, P. Liu, J. Liu, G. Kang, J. Xie and Y. Wang, A Super Lens System for Demagnification Imaging Beyond the Diffraction Limit, Plasmonics **8** (2013).

[15] D. B. Shao and S. C. Chen, Optics Express **13**, 6964 (2005).