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Study of fabrication of large working area periodical nanostructure ceiling lights to optimize usage performance

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Abstract

The method offers a simple, fast, and cost-effective approach for the large-scale production of periodical nanostructures, which can be applied in various industrial applications. Firstly, the i-line stepper is used to expose the photoresist film on a silicon wafer. Then, the DoF and EL parameters are adjusted to achieve the desired pattern. Finally, the pattern is transferred to the wafer through the etching process. The patterns obtained are of high resolution and uniformity. In the experimental results demonstrate that this method is suitable for the large-scale production of periodical nanostructures. This method can be used to produce nanostructures with various shapes and sizes, which is of great importance for applications in the fields of microelectronics, optoelectronics, nanophotonics, and biomedicine.

Keyword: Photolithography; Nanostructures; Process window; cost-effective; DoF; EL

1. Introduction

Large-scale periodical semiconductor nanostructures have various mechanical, optical, and electrical properties, thus can be used on many applications including electronics, optoelectronics, bio-/ chemical- sensors, high-density storage, and ultra-thin display devices [1-3]. Currently, the most commonly methods for fabricating a large-scale nanostructures is nanoimprint lithography (NIL) and photolithography (PL) [4]. However, the mold of NIL requires costly e-beam lithography and PL can be limited by its resolution. Therefore, a low-cost and high-throughput fabrication method for large area periodic nanostructures will be vital to the development of nanotechnology [5].

In this part, femtosecond laser direct writing (FLDW) is a promising tool to fabricate periodic nanostructures, since it can draw large-scale periodic nanostructures with high throughput and resolution [5-6]. In FLDW, the interference between two femtosecond (fs) laser beams provides a controllable intensity modulation to induce a periodic modulation of the laser fluence [7-8]. By adjusting the laser parameters, such as the pulse duration, the wavelength, and the incident angle, the period, amplitude, and phase of the periodic nanostructures can be tuned. Additionally, FLDW is a contactless and non-destructive process, enabling the integration of the periodic nanostructures with other nanomaterials or nanodevices [9].

In this work, we demonstrate the fabrication of large-scale periodic nanostructures in a low-cost and high-throughput way by femtosecond laser direct writing. The periodic nanostructures are induced by the interference of two fs laser beams with a controllable period, amplitude, and phase. The laser parameters and process parameters were optimized to achieve the desired nanostructure patterns. The periodic nanostructures were analyzed by scanning electron microscopy (SEM) and atomic force microscopy (AFM) [8-10]. The results show that the periodic nanostructures have a period of ~100 nm and a depth of ~50 nm. The nanostructures have good uniformity over a large area of ~2 × 2 mm2.

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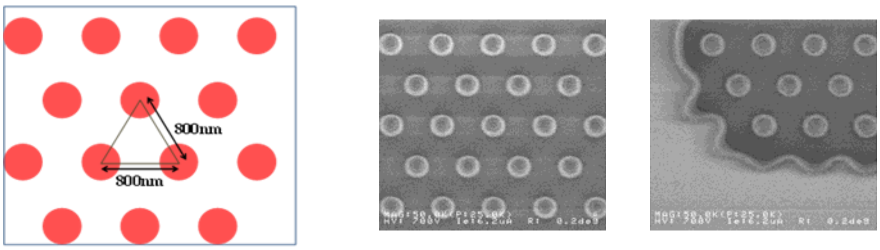
This study provides a cost-effective and high-throughput technique for fabricating large-scale periodic nanostructures for applications in nanotechnology.

1.1. Photolithography Design and manufacture

Fig.1 (a) showed a periodical triangular lattice which was constructed by the dots with the diameter of 400 nm and the lattice pitch is 800 nm. Firstly, tuning DoF and EL letting the center of the corner of an exposure fields both achieved the best exposure condition. Fig.1 (b) showed the SEM photo at center and corner of the exposure field [10].

First of all, we fix the focus at 0 mm, and find the exposure parameter at proper critical dimension (CD). Next, fix the exposure at 1350 and do it again. Then, to ensure the precision, we look back to focus at -0.2 mm again. To sum up, the target CD tolerance was +/- 10% yielding a depth of focus (DOF) of -0.2 mm and exposure latitude (EL) of 1350 J/m2 in elliptical process window as shown in Fig. 2 (b). After finding out the target process condition, Large area patterning has been implemented by stitching exposure fields using i-line stepper lithography on a 6 inch Si substrate.

(a) (b)



center corner

Focus=-0.2(um), Exposure Energy=1350(J/m2)

Figure 1 (a) 400nm in diameter and 800nm in pitch arranged triangular lattice. (b) The SEM photo at center and corner of the exposure field

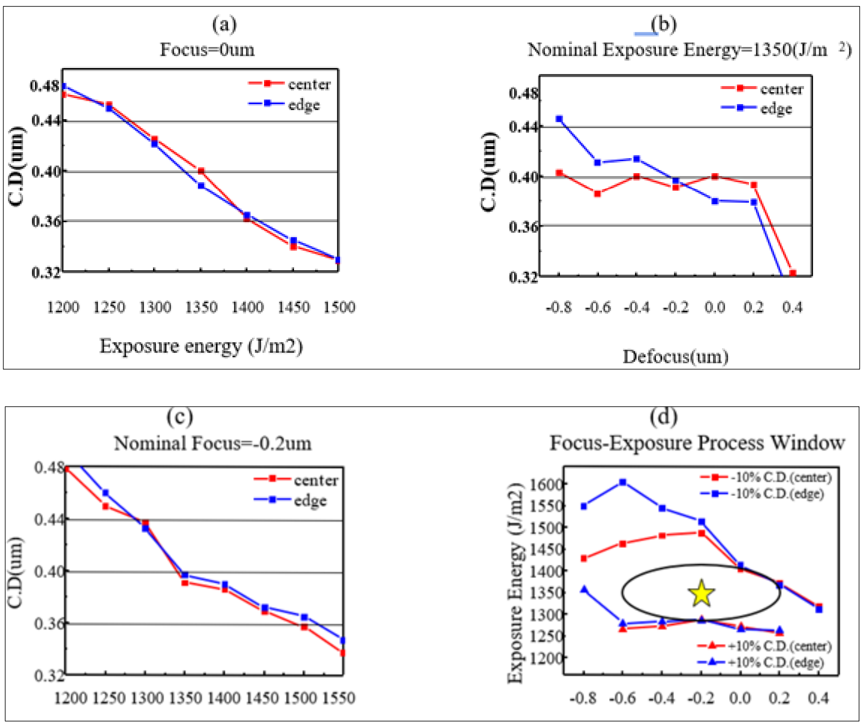


Figure 2 (a) (b) (c) (d) Process window

Our experimental demonstrates the capability to rapidly and controllably produce large area periodic patterns on wafer. The pattern obtained has a pitch of 2.5 µm and a CD of 0.2 µm. The pattern has high accuracy with respect to the design parameters and a low error rate, thus making it an effective way to achieve large area periodic patterns on Si substrates. This technique can be used for a variety of applications such as fabrication of photonic crystals, photonic waveguides, and other microstructures. The results suggest that i-line stepper lithography is a promising technique for producing large area periodic patterns with high accuracy and high yield.

2. Results and discussion

Large area periodic pattern was fabricated near perfectly ordered on a 6 inch Si substrate using i-line stepper lithography. However, using i-line stepper may cause some diffraction problems at the edge of exposure field which leads to pattern distortion as shown in Fig. 3. To reduce the distortion, firstly the image distortion near the edge of exposure field should be corrected. This can be done by taking field overlap into account, that is, by overlapping the exposure fields to provide partial overlapping. Secondly, the alignment accuracy should be improved. This can be achieved by using a higher numerical aperture (NA) stepper lens and improving the accuracy of the alignment stage. Thirdly, the use of higher resolution mask can help minimize the diffraction problem. Lastly, the illumination system should be optimized to reduce the diffraction effects. This can be done by using an ellipsoidal reflector and a high intensity illuminator.

In another hand, the RETs, such as phase-shifting techniques, optical diffraction techniques, and wavefront coding techniques, can be used to enhance the resolution of the CD-error. Phase-shifting techniques employ the principle of phase-shifting interferometry, which utilizes multiple phase-shifted images to reconstruct the phase information of the target. Optical diffraction techniques use the diffraction pattern of the target to reconstruct the phase information. Wavefront coding techniques use wavefront coding to encode the wavefront of the target, which is then used to reconstruct the phase information. All of these techniques can be used to improve the resolution of the CD-error.

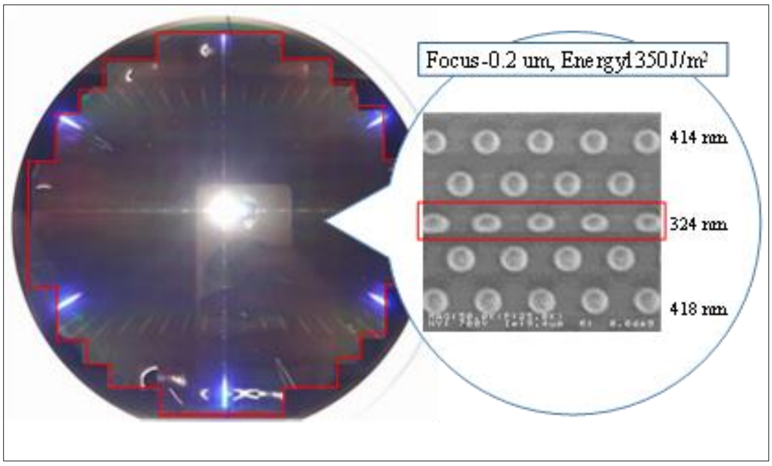


Figure 3 CD-error to the edge of exposure field

3. Conclusion

The results of the process show that we have achieved near perfect ordering of large area patterns in a 6 inch Si substrate. The best CD at DOF of -0.2 mm and exposure latitude of 1350 J/m2 was 0.6 µm. This demonstrates the capability to controllably and rapidly produce large area periodic patterns on wafer.

The pattern we obtained has periodic features with minimum CD at DOF of -0.2 mm and EL of 1350 J/m2. The pitch of the pattern is 2.5 µm and the CD is 0.2 µm. The pattern has high accuracy with respect to the design parameters, with a low error rate. The results suggest that our fabrication method is an effective way to achieve large area periodic patterns on Si substrates. In addition, we have demonstrated that the i-line stepper lithography is a promising technique for producing large area periodic patterns with high accuracy and high yield. This technique can be used for a variety of applications such as fabrication of photonic crystals, photonic waveguides.

Compliance with ethical standards

Acknowledgments

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Disclosure of conflict of interest

All authors contributed positively to the writing of this manuscript and there no conflict of interest as agreed to the content of this research.

Statement of informed consent

Informed consent was obtained from all individuals respondents included in the study

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