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Extended Abstract

Archives of Physics Research, 2021, 13 (1)
(https://www.scholarsresearchlibrary.com/journals/archives-of-physics-research/)

ISSN 0976-0970
CODEN (USA): APRRC7

A fabrication of nanostructures by controlling a gap distance in a transmission and a diffraction light

Taeyeon Kim

Pusan National University, Republic of Korea

E-mail: ktyeon09@pusan.ac.kr

Recently, the photolithography is the most widely used technique in nano / microscale pattern manufacturing. This technique can produce patterns quickly and inexpensively over a relatively large area compared to other methods. However, since conventional photolithography has a fundamental cause of diffraction limit, it is difficult to fabricate a very small nano-sized pattern. Many techniques, such as Extreme Ultraviolet (EUV) lithography, nanoimprint lithography, dip pen lithography, and plasmonic lithography, have been studied to overcome these limitations in order to make the pattern smaller. EUV lithography has reduced resolution by using a laser with a wavelength of 13.5 nm in conventional photolithography. Nanoimprint lithography is a method of continuously forming patterns using fabricated molds, and dip pen lithography produces patterns directly using atomic force microscope probes in liquid inks. Unfortunately, these techniques are difficult to fabricate over a wide range of patterns and require a high amount of cost and a long time. We have adopted plasmonic lithography using a nanohole array metal mask to overcome this limitation. This method uses a beam of an Extraordinary Optical Transmission (EOT) phenomenon generated by collective oscillation of electrons at the metal and dielectric interfaces, so that a smaller size pattern can be produced. In this study, we designed an experiment to observe the fabricated nano-sized structures by the diffraction and the transmission light. Also, we experimented with the gap distance between the mask and the photoresist, such as Talbot lithography.

For decades, optical nano-patterning has been the key technique to drive the discoveries in many nanotechnology areas. The long-standing target in the optical nano-patterning development is to achieve both high resolution and high throughput at low costs1. Particularly, for economically creating periodic structures over a larger area, many effective lithographic techniques have been developed, such as block-copolymer self-assembly lithography, self-assembled nano-particles, and nano-sphere lithography.
Before lithography, Shipley S1805 photoresist was spun on a quartz substrate at 4500 rpm, giving a thickness of 400 nm. The mask and the resist substrate were held with 5-axis degree-of-freedom, all controlled by piezoelectric stages. The resist substrate can scan in x, y and z directions with a positioning resolution of 0.4 nm. The stage can also adjust its tip-tilt angle to obtain a uniform gap between the mask and resist substrate. At the initial stage of lithography, the working gap between the resist substrate and the mask is calibrated by first bringing the substrate into light contact with the island on the mask and then lifting the mask to a desired working distance. Since the surface roughness of the undeveloped photoresist is less than 1.5 nm, it does not have a significant effect on the ISPI readings. During lithography, the mask is illuminated by the UV exposure laser beam. By modulating the laser beam according to the motion of the resist substrate in the x-y plane vector scan, an arbitrary pattern can be produced.

The control of the gap between the mask and the substrate contributes greatly to the quality of the lithography result. When the working gap is larger than tens of nanometers, the transmitted optical energy will be too low to expose the photoresist at high throughput and the optical hot spot will diverge significantly, leading to a poor lithography resolution. If the aperture mask and the photoresist are too close, i.e., less than a few nm, the interfacial forces start to play a role in mechanical alignment and scanning processes. When the aperture and the photoresist are in contact, the adhesion and friction may cause unfavorable hysteresis in scanning trajectories, photoresist deformations, and even material damages. The ideal working distance is to bring the mask as close to the substrate as possible, but avoid any contact. Besides the gap distance, the scanning speed and exposure dose are also important parameters which contribute significantly to the quality of the lithographic patterns. For a particular gap distance, increase of scanning speed means less exposure time at a given location which can cause shallower or even no lithography results. Conversely, for a particular scanning speed, increase of exposure dose makes the lithographic lines thicker due to more energy being deposited. It was found experimentally that the required exposure dose increases roughly linearly with the scanning speed. Any possible imperfections of the substrate and the mask will also have some influences on the lithography quality. It was found that the roughness of the photoresist lies within 1.5 nm and the specified flatness of the quartz substrates that were used for the mask and the substrate is $\lambda/20$ ($\lambda = 633$ nm) = 37 nm over a 0.5″ x 0.5″ area, which translates to a flatness better than 1 nm over the 150 μm x 150 μm island where the bowtie apertures are fabricated.

Bottom Note: *This work is partly presented at New Frontiers in Optics, Photonics, Lasers and Communication Systems, May 13, 2019, Tokyo, Japan*