Applications of optical near field technology in photolithography and in repairing surface roughness

Conventional photolithography methods have not been able to find any industrial applications as they are marred by diffraction limit. The present lecture deals with the nonadiabatic photochemical reaction to photolithography.

This lecture also purports to the smoothing of rough surfaces in various nanophotonic devices irrespective of their surface curvature.

1 Disadvantages of conventional photolithography

Conventional photolithography is marred by diffraction limit as it employs propagating light. The wave properties of light prove detrimental for high resolution photolithography. There is no proper matching between the optical coherence length that is required for fabricating high density corrugations and the separation between adjacent elements of corrugation. Moreover, scattered light produces interference effects that cannot be fully suppressed by the photo resist. The polarization dependence of the intensity of propagating light that is transmitted through a photomask further adds up to the already existing woe.

2 Dressed photon-coherent phonon model

The Dressed photon-coherent phonon model is basically used for investigating the physical mechanism of photolithography. According to the model, the exciton-phonon polaritons are generated at the apex of an optical near field probe. When gas and adsorbed molecules are placed very close to the optical near field probe tip, the exciton-phonon polaritons are transferred from the probe tip to the adsorbed gas molecules. The dressed photons incident into the probe-tip are responsible for the electronic excitations near the probe tip. These electronic excitations inturn result in the anharmonic coupling of the phonons, thereby forming a renormalized phonon. Hence multiple phonons can be thought of as coherent phonons in the original representation which can interact simultaneously with an exciton or an exciton polariton.

3 Dressed photon-coherent phonon assisted photolithography

The experimental setup for phonon assisted non adiabatic photolithography is depicted in Figure 1. On employing a visible light source, the dressed photon-coherent phonon assisted photolithography enhances the patterning of commercial photoresists. The main highlight is that the propagating light does not pattern the photoresist as the photoresist is sensitive only to UV propagating light. However a dressed-photon coherent phonon gets generated at the photoresist edge. The photoresist gets activated by the transfer of energy from the dressed photon coherent phonon to the photoresist and thereby gets patterned due to the phonon assisted process. Moreover, as the energy gets transferred not only to the surface of the photoresist but also to its interior, the photoresist gets effectively patterned within a short exposure time. Thus by properly manipulating the exposure time, the photoresist can be patterned to have a stable spatial profile. By employing a light source of appropriate laser frequency, high resolution can be achieved when the wavelength of the light source

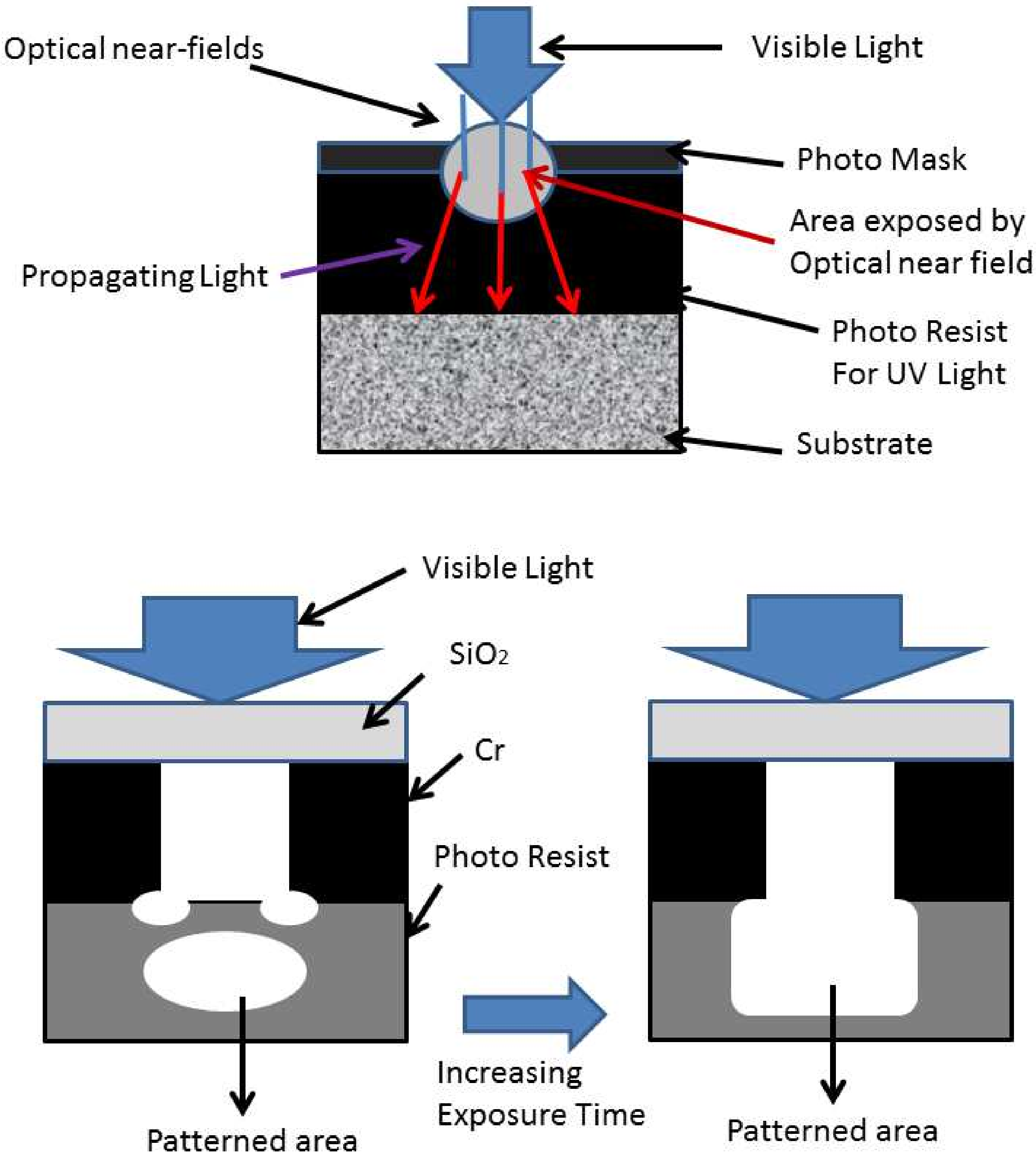

Fig. 1: Phonon assisted non adiabatic photolithography

is greater than the wavelength of absorption band edge of the photoresist. Hence phonon assisted photolithography is not expensive as it does not require either short wavelength X-ray or UV light source for patterning. The advantage of using phonon assisted photolithography is that complicated patterns can be obtained with high resolution when subject to multiple exposures as the photoresist is insensitive to incident visible light. Phonon assisted photolithography has the ability to pattern even an optically inactive film.

3.1 Industrial application

Ohtsu research group came up with an innovative prototype machine for producing commercial products. The size of the machine is as small as $1m^2$ and it employs a conventional Xe lamp as the light source. It is automated by computer-controlled robotics. A resolution of $20-50nm$ is obtained for a substrate area of $50mm \times 60mm$. A high aspect ratio pattern can be obtained by employing a two-layer resist film. Without damaging the photomask surface, the photomask can be removed from the photoresist by coating it with an appropriate lubricant. Diffraction grating and Fresnal zane plates for soft X-rays with a wavelength of 0.5-1.0 nm are some of the fabricated structures of the prototype lithography machine which guarantee high efficiency, high resolution and high reproducibility.

4 Application of dressed photon technology in repairing surface roughness

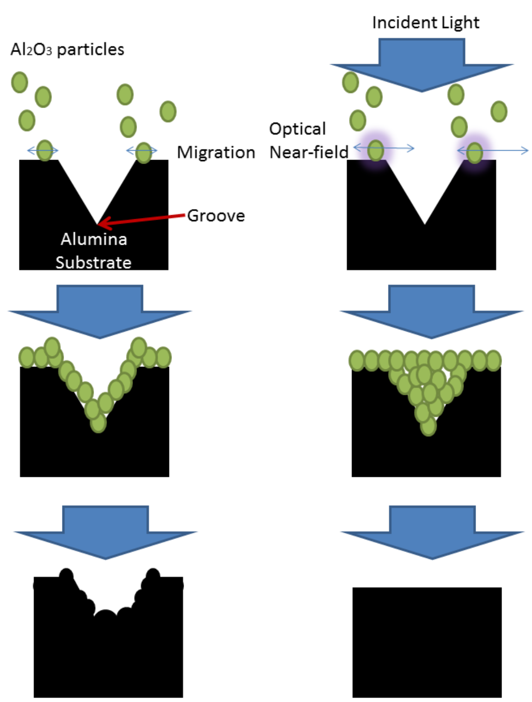

Fig. 2: Smoothing of surface roughness

Ohtsu research group have demonstrated that the optical near field and the ensuing dressed photon-coherent phonons can be generated and applied to a nanometric rough surface material, when illuminated with a light source. On employing dressed photon technology, Ohtsu research group have devised two novel methods for repairing surface roughness, namely, etching and desorption.

4.1 Etching

Ohtsu research group utilized the concept of dressed photon technology especially for smoothing rough surfaces of glasses of irrespective of their surface curvature. The experimental setup devised by the Ohtsu research group is given below: A Gaseous Cl_2 molecules were filled in a vacuum chamber consisting of a glass substrate having nanometric surface roughness. Gaseous Cl_2 molecules have the absorption band edge wavelength of the order of $400nm$. Still Ohtsu research group employed green propagating light having a wavelength of the order of $532nm$ for photochemical etching. In the absence of dressed-photon coherent-phonons, the gaseous Cl_2 molecules remain stable over the glass plate having a flat curvature. Due to bumps on the illuminated rough surface, dressed-photons-coherent phonons are generated. On exchanging the dressed photon coherent phonons with the bumps, the Cl_2 molecules get dissociated to produce radical Cl atoms. The dissociated radical Cl atoms are found to etch the bump tips. Hence due to phonon-assisted process, the photochemical etching starts spantaneously. When the bumps are illuminated with propagating light, due to spontaneous etching, they are removed and the glass surfaces become flat due to smopthening. As soon as the glass surfaces become flat, the generation of the dressed photons-coherent phonons stops and hence the spontaneous photochemical etching process stops spontaneously, thereby becoming a self-organized method.

4.2 Desorption

Transparent alumina, a hard polycrystalline ceramic, is used in ceramic lasers for providing low loss gain. Such a setup is usually used in laser-driven spark plugs as ignition systems in automobile engines. By placing alumina substrate in a vacuum chamber, transparent alumina are deposited on the substrate by radio frequency sputtering. As illustrated in the figure given below, transparent alumina particles get deposited preferentially on the ridges of the scratches and when illuminated with visible light, the alumina substrates becomes smoothened. The visible light is operated at the wavelength of 473 nm which is larger than the absorption band edge wavelength of transparent alumina (260 nm). When illuminated dressed photons- coherent phonons are formed on the ridges of the scratches thereby causing the transparent alumina particles to be activated by increasing the migration length. Thus the transparent alumina particles are desorbed from the ridges. The dressed photons-coherent phonons are not generated on the flat surfaces. Hence the transparent alumina are deposited with the same deposition rate. Thus by properly manoeuvering the transparent alumina particles, the scratches are repaired in an efficient manner. This also falls under the category of self-organized method. The above mentioned phonon assisted smoothing of rough surface is depicted on the right hand side of Figure 2. The left hand side of Figure 2 portrays the conventional type of smoothing of rough surface which does not repair surface roughness in an efficient manner. Thus from Figure 2, one can infer that via optical near field technology, phonon assisted smoothing of surface roughness is far more efficient than any conventional type of smoothing of rough surface.

5 Additional reading and references

1. M. Ohtsu, K. Kobayashi, T. Kawazoe and T. Yatsui, Principles of Nanophotonics (CRC Press, New York, 2008).

2. M. Ohtsu (Ed.), Progress in Nanophotonics 1 (Springer-Verlag, Berlin, 2011).

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