Abstract

Over the past few decades, the study of field distribution at the geometrical focus of a lens (PSF) has gained a huge research interest in field ranging from Nanolithography to microscopy. The central theme of this thesis is to study the intricate details of the field distribution through theoretical modelling, computational studies and experimentation. Specifically, spatial filtering techniques have been proposed to understand and manipulate the field distribution for demanding applications. Based on the findings during the theoretical modelling and computational studies we have proposed light sheet based optical lithography technique.

Optical lithography (Photolithography) has emerged as an efficient tool for the fabrication of micro/Nanostructures. It uses photon energy to create patterns on the substrate coated with a photosensitive material. The photochemical reactions which are necessary for the fabrication are spatially confined by the 3D extent of the field distribution. Hence the knowledge of field distribution plays a very crucial role in photolithography. State of the art techniques in optical lithography such as, two photon direct laser writing lithography, interference-based lithography techniques and STED Nano-lithography have made optical lithography a highly sought-after technique for the fabrication of micro/Nanostructures. Specifically, two photon direct lithography is used for making complex 3D structures. Interference based lithography techniques are used for fabricating 1D, 2D and 3D periodic Nanostructures whereas, STED Nano-lithography is capable of fabricating diffraction unlimited structures.

The first chapter provides an overview of all the keywords and concepts used in photolithography. A brief summary of the emergence of the field is provided along with the development of different optical lithography techniques. The discovery of photopolymerization process and invention of various photoresist systems has helped in the development of photolithography. These techniques have made physics, chemistry and biology accessible to Nano-scale level. An introduction to photoresist systems and them brief classification is given in this chapter. In addition, we have also provided a brief description to recent techniques in photolithography that is widely used for micro/nanofabrication. Understanding these techniques helps us in identifying the novelty of the proposed lithography technique. A brief introduction is given to understand the field distribution/ point spread function (PSF) that provides the foundation for the entire thesis.

In the second chapter, we describe the vectoral model for theoretically understanding the PSF for a spherical lens geometry. This is predominantly since the existing lithography techniques relay on spherical lens geometry. In view of demanding applications, the illumination PSF is tailored by employing spatial filtering techniques. We intend to employ spatial filter in order to add new features to lithography and expand its reach. For example, introduction of spatial filter at the back aperture of an objective lens produce a Bessel like beam which is generally used for applications that requires greater depth of focus. Bessel beams have self-reconstructing property which helps to achieve a greater depth of focus in scattering mediums. The extent of the PSF along the axial direction (z-direction) is 2-3 times greater when compared to the lateral extent. Hence the resolution along z-direction is 2-3 times worse when compared to its lateral counterpart. 4 geometry is generally employed to improve the axial resolution in spherical lens system. But this technique suffers from side-lobes that can cause artefacts. In order to reduce side lobes, we employed spatial filter in a 4_ geometry. A detailed description of these techniques is given in chapter 2. These

techniques may add new features to Nano-lithography techniques and bring new applications in Nano-biology and Nanophysics.

Chapters 3, 4 and 5 of the theses are dedicated to light-sheet based lithography for the fabrication of micro/Nanostructures. We begin by studying the field distribution at the geometrical focus of a cylindrical lens system. Unlike a spherical lens system, cylindrical lens system has a one-dimensional focusing property that results in a sheet of light. light-sheets are known for their selective plane illumination capabilities. They are widely used in bioimaging and optical microscopy. The intricate details about the field distribution are studied using the vectoral theory for cylindrical lens system. We have conducted experiments to validate the vectoral theory for cylindrical lens. _2 test revealed a good _t between experiment and theoretically obtained values.

Like spatial filtering techniques in spherical lens geometry, we have carried out spatial filtering in cylindrical lens geometry to add new functionalists/ features in lithography. It is shown that the introduction of spatial filter at the back aperture of the cylindrical lens has resulted in the generation of multiple light-sheets. Spatial filter structures the incident wave front that is focused by the cylindrical lens thereby resulting in a distinct field distribution at and near the focal plane. The theory behind the generation of multiple light-sheets is discussed in chapter 3. We have demonstrated the generation of multiple light-sheets through computational simulations and experiment. Multiple light-sheets have the capability of illuminating multiple planes of the specimen simultaneously. The experimental results are discussed in chapter 3.

Chapter 4 describes the fabrication of periodic micron structures using multiple light sheets. We have used a photoresist mixture which is sensitive to visible light. UV- Vis absorption spectroscopy was used to determine the sensitivity of the photoresist mixture. The photochemistry was studied using a 532 nm continuous laser. We could control the periodicity and the feature size by changing the spatial filter parameters. This technique is hoped to be a single shot fabrication technique for generating high aspect ratio periodic micron structures over a large area.

In chapter 5, we have proposed and experimentally demonstrated the generation of periodic Nanostructures using counter propagating coherent light-sheets. The technique involves two opposing cylindrical lenses. When these lenses illuminate the common geometrical focus with a coherent beam of light a constructive interference takes place between two counter propagating light-sheets. The resulting interference structures can be captured on a substrate coated with the photoresist. Selective plane illumination nature of light-sheets is exploited to carry out patterning in the desired plane of a positive photoresist. A mathematical equation is derived that describes the field distribution at and around the common geometrical focus of two opposing cylindrical lens system. Before carrying out the fabrication, we have studied the field distribution in depth through computational simulations. Th periodicity is found to be half the wavelength of illumination light, whereas feature size is found to be approximately one fourth of the wavelength. This clearly indicates that sub-diffraction limited features can be generated using the proposed technique. The remaining part of this chapter describes the fabrication processes for the commercially available photoresist, S1813. This technique can be used for the fabrication of Nano-channels. Interesting applications are in bio-molecular research and protein analysis. Nano-channels are widely used in the detection and analysis of biomolecules such as DNA, proteins and ions.

The ability to carve 2D periodic Nanostructures has a great potential for future technology development. Multiple beam interference lithography is most widely used technique for the fabrication of 2D and 3D periodic Nanostructures. In this technique, parameters (like amplitude and polarization angle) of the individual beam and the angle between the beams control the interference pattern. Choosing the right set of parameters for the individual beam is highly challenging. Phase mask lithography can produce desired beams from a single source. But these experiments are highly complex and requires expertise. Processes involved in the fabrication of phase mask are exigent. Chapter 6 describes the fabrication of 2D periodic Nanostructures. We have integrated spatial filtering technique with 2_ illumination to generate of 2D periodic Nanostructures. Theoretical and computational studies show that multiple light-sheets can be generated using an amplitude binary filter. Interference of counter propagating multiple light sheets result in a 2D periodic intensity distribution at the common geometrical focus which can be used for the fabrication of 2D periodic Nanostructures. This technique can be a stepping stone towards the fabrication of nanoelectromechanical systems (NEMS), fabrication of metamaterials and photonic crystals. Finally, we conclude the thesis with a brief description on the contribution of the thesis and the future scope of the research work.