Imperial Journal of Interdisciplinary Research (IJIR)
Vol-2, Issue-6, 2016
ISSN: 2454-1362, http://www.onlinejournal.in

Nanolithography: Processing Methods for Nanofabrication Development

Ruchita, Richa Srivastava* & B.C.Yadav

Department of Applied Physics, M.Tech. Nano-Optoelectronics Programme, Babasaheb Bhimrao Ambedkar University (A Central University), Lucknow-226025

Abstract: *The present review article deals with the detailedintroduction and classification of lithography techniques. Nanolithography is the branch of nanotechnology through which nanofabrication of the patterns or structures can be done very easily. Nanolithography can be considered as a revolutionizing advancement in nanotechnology. Nanolithography has various techniques and each technique has its own advantages and applications in different fields. This review also summarizes different types of direct and indirect techniques of fabrications using various substrates, photo resists and photo masks. The present article helps to know about the different methods or ways of fabricating nano patterns with ease or difficulty depending upon the technique. Also in this review, the advantages, disadvantages and applications of each lithography techniques are discussed.*

Keywords: *Nanolithography, photolithography, electron beam lithography, micro-contact printing, nano-imprint lithography, X-ray lithography, fabrication.*

1. Introduction

Nanolithography, as the name depicts is basically derived from the Greek words in which “nanos”, means dwarf; “lithos”, means rock or stone; and “graphy” means to write. Thus, the literal translation can be illustrated as "tiny writing on stone". Nanolithography is the branch of nanotechnology, which is concerned with the study and application of the structures or the patterns which are fabricated at nanometer scale [1]. Therefore, it means the nano patterning with at least one lateral dimension between the size of an individual atom and approximately 100 nm.

Nanolithography is considered to be the most advanced technique in patterning the ultra-high-resolution patterns of arbitrary shapes to a minimum feature size of a few nanometers. Thus, nanolithography is basically concerned with the fabrication of different patterns and on different substrates as required. Nanolithography includes the various mask or mask less, top-down or bottom-up, beam or tip-based, resist-based or resist-less and serial or parallel methods. So based on these particular methods, nanolithography techniques may include [2] -photolithography, electron-beam lithography, nano-imprint lithography, micro-contact lithography, scanning probe lithography, X-ray lithography etc.

These nanolithography techniques have been widely used in the semiconductor and IC industries and play a vital role in manufacturing nanoelectro-mechanical systems (NEMS) and micro electro-mechanical system (MEMS) devices.Besides this, nanolithography is useful in fabricating nanoscale photo detectors and ring transistors. It also includes various applicationsin cell biology, microelectronics, surface chemistry, micromachining, patterning cells, patterning DNA and patterning protein.

2. Types, Advantages, Disadvantages and Applications of Lithography

2.1 Photolithography

Photolithography, as the name depicts is again derived from the Greek words in which the words 'photo', 'litho', and 'graphy' all have the Greek meanings as 'light', 'stone' and 'writing'. Photolithography is basically a conventional and classical technique and it is also termed as optical lithography or UV lithography.In the 1820s, NicephoreNiepce invented a photographic process that used Bitumen of Judea, a natural asphalt as the first photo resist. In 1940, Oskar Suß created a positive photo resist by using diazonaphthoquinone. Later in 1954, Louis Plambeck Jr. developed the Dycryl polymeric letterpress plate, which made the plate making process faster.

A photolithography system generally consists of a light source, a mask, and an optical projection system. This technique basically utilizes the exposure of photo-resist to ultraviolet light to obtain the desired pattern.

For the procedure to start, it is required to prepare a wafer or substrate with an oxide layer on it. The process further continues with the spin coating of photo resist on the substrate. Generally, the commonly used photo resist is polymethyl methacrylate (PMMA). The PMMA is a polymer of methyl methacrylate with a chemical formula $(C_5H_8O_2)_{n.}$ It is basically a linear thermoplastic polymer with a melting point of 130°C and glass temperature of 100-105°C.Now, the UV light with wavelengths generally ranging from 193-436 nm is illuminated through the photo mask.This photo mask usually consists of the opaque features on a transparent substrate (e.g., quartz, glass) to make an exposure on a photo-resist. The exposed area of photo-resist break down which results in more soluble in a chemical solution called developer. Subsequently, the exposed photo-resist is removed to form the desired photo-resist pattern [3-8]. The technique of photolithography can be further explained with the help of a diagram as shown in Fig.1.

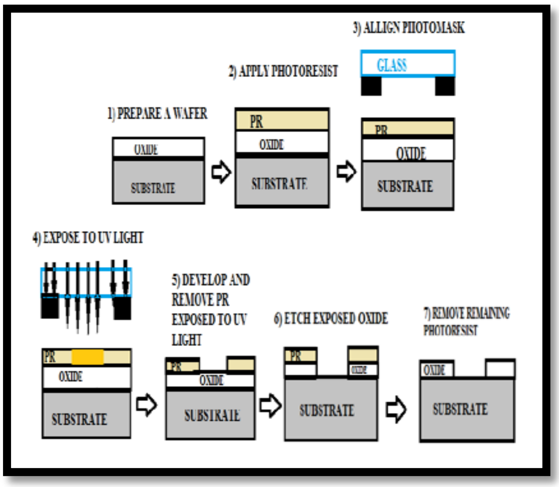

Figure 1.Various steps involved in Photolithography technique.

The system of Photolithographycan exist in three forms [9] -

- **Contact Printing:** In the contact printing the photo mask is placed in direct contact with the photo resist. Photolithography uses these printings in most of research works.
- **Proximity Printing:** Proximityprinting is almost similar to the method of contact printing. In this, photo mask is not in direct contact but with a closed proximity with the photo resist.
- **Projection Printing:** A projection printing system uses an optical lens system to project UV pattern from an excimer laser (wavelength of 193 or 248 nm) on the photo-resist. This enables pattern-size reduction by 2-10 times. This system is capable in fabricating high-resolution patterns as small as a few tens of nanometers (37 nm) and at a high throughput of (60-80 wafers/hr). This system has a very expensive set up as it requires precision control systems of temperature and position and also requires a typical optical lens system. Thus, it is helpful in manufacturing advance IC and CPU chips.

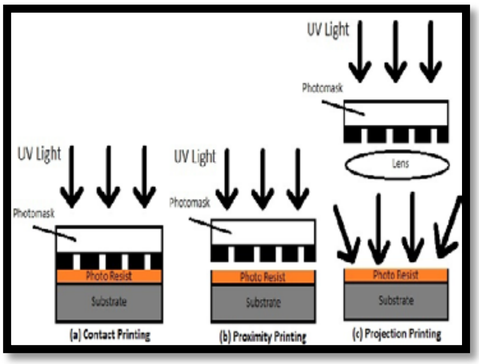

Figure 2.The three forms of Photolithography (a) Contact printing, (b) Proximity printing, (c) Projection printing

Advantages of Photolithography

The advantages of Photolithography are given as under:

i. The process of photolithography is less expensive and highly efficient in fabricating extremely small incisions on a substrate.

ii. This technique does not require any additional tool or material for etching patterns to form an integrated circuit andonly a single beam of UV light is sufficient for this task.

iii. The determination of exact shape and size of any substrate can be monitored by using the process of photolithography.

Disadvantages of Photolithography

Along with the advantages, Photolithography has various disadvantages given as follows:

i. The process of photolithography requires a clean room environment free from all liquids, contaminants and environmental hazards.

ii. In order to fabricate effective patterns, this technique requires a completely flat substrate.
iii. This technique is inefficient in producing flat objects.

Applications of Photolithography

Photolithography has numerous applications which include the following:

i. Photolithography can fabricate integrated circuits and other internal computer parts.
ii. This technique can be used for the fabrication of microcircuits [10], NEMS, MEMS etc.
iii. Photolithography can also be used to fabricate organic memory devices [11] for an array structure.

2.2 Electron Beam Lithography

Electron beam lithography is a form of mask less lithography [12], used for fabricating nanoscale patterns. The evolution of this technique started in 1960’s where the patterns were directly written on the wafer with a SEM type Gaussian beam system with one pixel at a time [13]. Now, during 1970’s IBM introduced the concept of shaped electron beams with multiple pixels leading to high throughput and manufacturing of large scale semiconductor chips [14].

This technique uses an accelerated beam of electrons to focus on an electron sensitive resist to make an exposure.Now, this electron beam is scanned on the surface of the resist with the diameter as small as a couple of nanometers in a layer by layer fashion to generate the required patterns in sequence.

For the process to be performed, it is required to prepare a resist i.e. polymethyl methacrylate (PMMA) by spin coating on the sample and is baked to remove any solvents and harden the film as discussed earlier in theprocess of photolithography [15-17]. After the resist coating, the area selected is exposed to high energy beam of electrons. This will lead to the development by sample immersion in the developer solvent to remove resist from the exposed area and generates the required pattern with anultra-high resolution down to 10 nm feature size [18].The process can be conducted in the following steps as shown in Fig. 3.

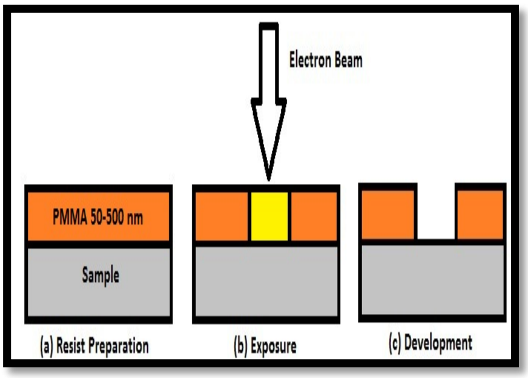

Figure3.Steps involved in the process of Electron Beam Lithography.

Advantages of Electron Beam Lithography

Electron Beam Lithography has several advantages mentioned as under:

i. This technique uses electron beam instead of photons.
ii. Pattern can be drawn directly on the substrate with high resolution.
iii. This technique is helpful in developing specialized and prototype devices.

Disadvantages of Electron Beam Lithography

Electron Beam Lithography have also certain disadvantages including-

i. Machines available for this technique are costly.
ii. The system is too much complicated.
iii. The process is time taking and inefficient.

Applications of Electron Beam Lithography

Some of the applications of Electron Beam Lithography are as below:

i. Scanning electron microscope (SEM) can be converted and used as electron beam lithography (EBL) machine.

ii. This technology has potential applications in telecommunication, sensors, optical computing, photo-biology and photo medicines.

iii. 1D and 2D photonic crystals and photonic wires based upon the silicon insulator and III-IV semiconductor waveguide materials can be achieved using the process of electron beam lithography [19, 20].

2.3 Micro-Contact Printing

Micro-Contact printing is a form of soft lithography [21, 22]. This method was first introduced by George M. Whitesides and Amit Kumar at Harvard University. It basically uses patterns on a master i.e. polydimethylsiloxane (PDMS) stamp to form patterns of self-assembled monolayers (SAMs) of ink on the surface of asubstrate. The principles of this technique are followed by fabrication of templates, PDMS and molding, printing and patterning self-assembledmonolayer [23].

Fabrication of templates as we know is accomplished using the process of photolithography as discussed earlier using the photo resist (PMMA) and photo mask.Now, PDMS stamps are fabricated with relief features. PDMS stamps [24] are basically the silicon elastomers that can be very easily molded to a patterned template. At room temperature PDMS is a liquid prepolymer as it has a low melting point about -50^{o}C and glass transition temperature about -120^{o}C. Since PDMS is elastomeric in nature, and is cast on the substrate it deforms macroscopically and the deformable stamp is then allowed to be lifted off the substrate. Because of the low surface energy of the PDMS stamp it allows to be easily separated from the substrate during fabrication process, to reversibly bind to the substrate to be transferred during printing and provides the easy peeling of the stamp from the substrate after printing. The fabrication of the PDMS stamp is described in the Fig.4.

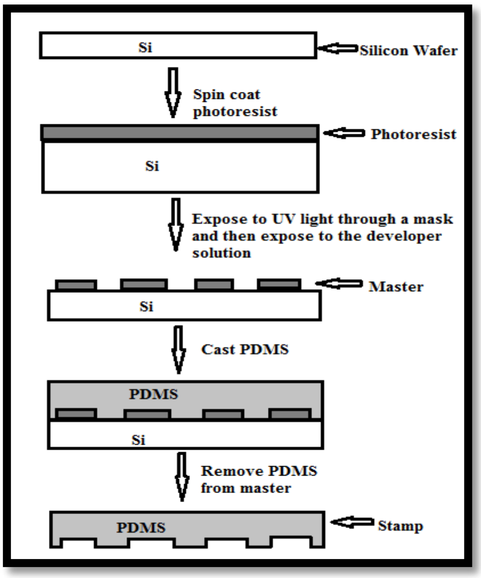

Figure 4.Step-wise fabrication of the PDMS stamp

Now for the process of printing, the peeled PDMS stamp is cut into size and is then inked with the material to be printed. Inking of the PDMS stamp is done using a thiol solution, i.e. the ink used is thiol. Thiol is basically an organosulphur compound which consists of a sulfhydryl group and basically a sulfur analogue of alcohol. Now for inking, the stamp is either immersed into the thiol solution or the thiol solution coating is done on the stamp using a Q-tip. During this process the solution is evenly diffused into the bulk of the stamp due to the hydrophobic nature of the PDMS which means that the solution is not only present on the surface but also to the bulk of the stamp material. An ink reservoir is created due to the diffusion into the bulk for multiple prints. The stamp filled with the thiol solution is then allowed to dry until no visible liquid is completely dried and an ink reservoir is created.After creating an ink reservoir, the stamp is placed in direct contact with the gold substrate due to which the thiol solution is immediately transferred to the substrate. Based on the features or the patterns of the stamp the thiol is selectively transferred to the surface of substrate. The carbon chains of the thiol during the process of transfer align with each other and thus, create a self-assembled monolayer (SAM). After printing the stamp is released and the process of etching is done after the creation of SAM [25] to obtain the required pattern.

The technique of printing can be shown by Fig.5.

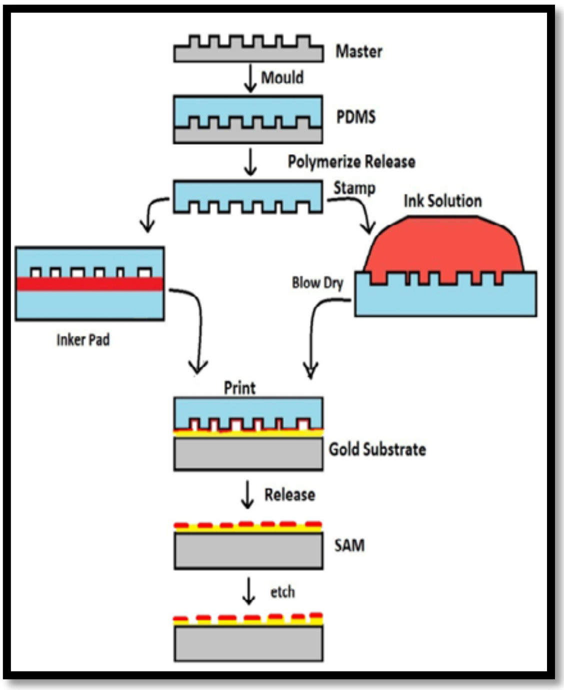

Figure 5.Diagram illustrating the method of Micro-Contact Printing.

Advantages of Micro-Contact Printing

Micro-contact printing is a soft lithography and it has various advantages gives as [26]:

i. Using this technique multiple stamps can be created using only a single master.
ii. This technique does not require a clean room facility and can be performed in traditional laboratory environment.
iii. It is a cheaper technique of fabrication.

Disadvantages of Micro-Contact Printing

Besides several advantages, micro-contact printing has also certain disadvantages which include [26]:

i. One of the major problems of this technique is shrinkage of stamp which leads to difference in patterning the desired dimensions of the substrate.
ii. This technique causes the contamination of substrate.
iii. Stamp deformation is one of the major problems.

Applications of Micro-Contact Printing

Micro-contact printing has numerous applications in various fields and these are as:

i. This technique has a wide range of applications in patterning cells, patterning DNA and patterning proteins.
ii. This technique is useful in fabricating microQRCode and also in MEMS [27-29].
iii. Cell biology [30], micromachining and surface chemistry are also the application fields for micro-contact printing.

2.4 Nano-Imprint Lithography

Nano scale patterns can be fabricated using the process of Nano-Imprint Lithography. It is a bit similar process to soft lithography. The process of nano-imprint lithography was first introduced in scientific literature in 1996 by Prof. Stephen Chou and his students, who published a report on it [31, 32]. Nano-imprint lithography is a simple process that can make required patterns by using a mould to emboss the photo resist. It is an emerging process that can produce features up to 10nm in size [33, 34]. In Nano-Imprint Lithography the resolution mainly depends upon the minimum feature size of the template that can be fabricated. The principle of nano-imprint lithography is based on thin polymer film modification i.e. mechanical stamp deformation using a template (mould or stamp) that contains nanopatterns, in a thermo-mechanical or UV curing process [35, 36]. So based on this,nano-imprint lithography has two fundamental process namely-

a. Hot-embossing lithography (HEL) or thermal nano-imprint lithography (T-NIL)
b. UV based nano-imprint lithography (UV-NIL)

Both these processes have a resolution to sub-10 nm. In the standard T-NIL process, a layer of resist is spin coated on to the substrate. This resist is basically a thermoplastic polymer. Now, the mold is brought in direct contact with the substrate and under certain pressure they are pressed together. This mould talked about has topological patterns whichare predefined and generally used materials for the mold are quartz and silicon that are considered to be as hard materials. When polymer is heated above the glass transition temperature (T_g), the patterns featured on the mold are pressed on the melt polymer film. After being cooled, the mold is separated from the substrate and a pattern present on the mold is left on the substrate. Now, reactive ion etching (RIE) which is a pattern transfer process is used to transfer a pattern on the resist to the underneath substrate. The process for T-NIL has been shown in Fig.6.

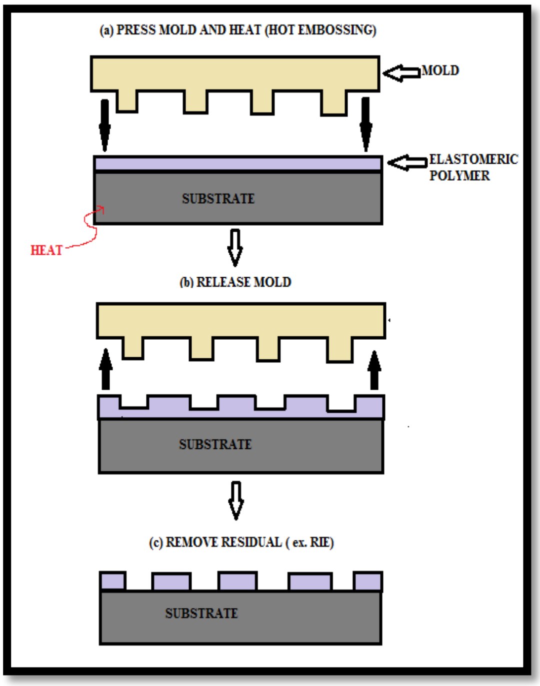

Figure 6.Schematic diagram illustrating the T-NIL process.

Now, in the second process of UV-NIL a UV curable monomer as a resist is used instead of an elastomeric polymer. This mentioned resist is applied to the substrate via spin coating. Now the mold made up of the transparent material like fused silica or quartz is kept in contact with the substrate, then after pressing the mold and substrate together the trenches are filled with the resist. After this the resist is cured with a UV light to make it a solid and further, a reactive ion etching (RIE) process can be done to transfer the pattern on the resist to the underneath substrate after the process of demolding.The process for UV-NIL has been shown in Fig.7.

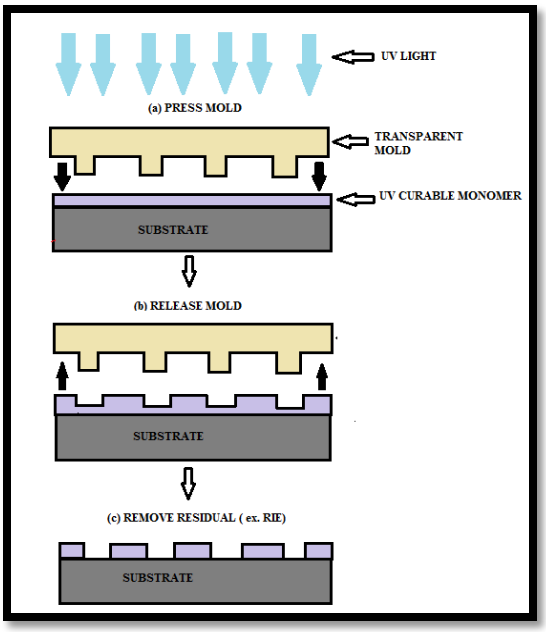

Figure 7.Schematic diagram illustrating the UV-NIL process.

The major difference between UV-NIL and T-NIL lithography is that at room temperature, the resin which is in form of liquid is shaped or structured by a moderate pressure which is further cross-linked and hardened by curing. Both the process have their own advantages, in which the process of UV-NIL can be conducted at low pressure and at room temperature while on the other hand T-NIL utilizes non-transparent molds and therefore, they are of low cost [37-39].

Advantages of Nano-Imprint Lithography

The various advantages of Nano-Imprint Lithography are as follows:

i. It is a simple process and does not require any complex optics or high energy radiation sources.
ii. This technology does not require any well designed or tuned tools for sensitivity or higher resolution and thus it results in low cost.
iii. Nano-imprint lithography offers three-dimensional patterns and also the chips manufactured using a single imprint step for multiple layers results in low fabrication cost and offers high throughput.

Disadvantages of Nano-Imprint Lithography

Nano-imprint lithography has also certain disadvantages which include:

i. High resolution template patterning is difficult for this technique as it can be used for patterns down to 20nm and below.
ii. Template wear is one of the problems which results due to the pressure applied to the contacts and also enters the layer during the imprint accelerates the wear of templates.
iii. Overlay is also a major problem as the alignment between the template and the resist on the substrate is quiet difficult during the process of imprinting.

Applications of Nano-Imprint Lithography

Various applications of nano-imprint lithography are as follows:

i. This technique has a huge application in fabricating low cost LED devices, polarizers, plasmonic devices and photonic crystals for high efficiency [40].
ii. This technology is also efficient in fabricating electronic devices like-MOSFET, O-TFT, single electron memory etc.
iii. It has also a key application in patterning magnetic media for hard disc drives and also used in optical storage (EBR) etc.

2.5 X-Ray Lithography

The technique of X-ray lithography is an extension to photolithography. The only difference is that the X-ray lithography utilizes X-rays to irradiate the resist instead of the UV light in case of photolithography. In X-ray lithography direct writing or patterning is not possible so it requires a mask. X-ray lithography is usually done using the process of proximity printing. It means that the mask is brought in close proximity to the substrate.International business machines (IBM) was the first to combine electrode position and X-ray lithography together in 1969. Also in 1972, D.L. Spears and H.I. Smith developed a high resolution pattern replication using soft X-rays.

X-ray lithography is a technique that can pattern transistors with very small features[41, 42]. The process basically uses X-rays to transfer a geometric pattern from a mask to the resist spin coated on a substrate. By using a small wavelength of 1nm for illumination, X-ray lithography can be extended to a resolution of 15nm. Optical lithography's diffraction limit is overcome by the X-ray lithography because of its shorter wavelength (below 1nm) and is able to produce small feature size objects.

X-ray lithography uses a resist that is spin coated on a substrate, a mask and X-rays [43-46]. The first step starts with the high energy beam of X-rays from a synchrotron to fall on a thin layer of resist through a mask. If the X-ray source do not collimate with the synchrotron radiation, diffractive lenses or elementary collimating mirrors are used instead of the refractive lenses for optics. Here, the X-ray mask is in the form of thin membrane so that the beam of X-rays could easily pass through it with a gold coating on the top surface. Gold is normally used as absorber material for X-ray. The membrane material can either be a polyamide, silicon, aluminum oxide or silicon nitride.

Now, the region with gold coating does not allow the X-ray to pass through it while the region with no coating permits the rays to pass through. In this way, by the use of X-rays the pattern is etched into the substrate. The damaged material is dissolved using a chemical solvent, which results in a negative relief replica of the mask pattern. A freestanding metal structure is produced after the removal of photo resist. The schematic for this technique is shown in Fig.8.

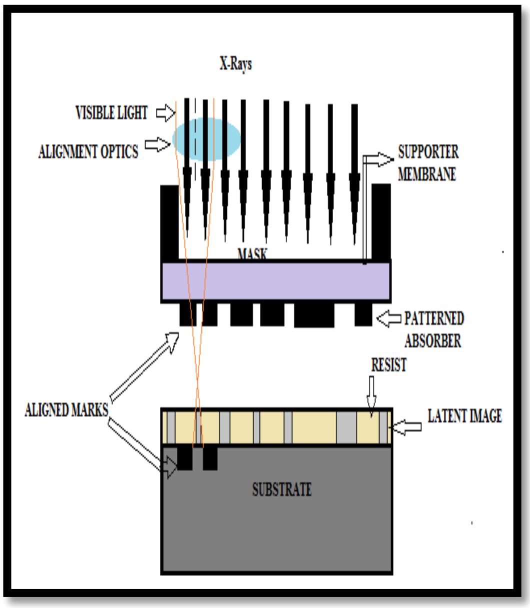

Figure 8.Procedure for X-Ray Lithography.

Advantages of X-Ray Lithography

The advantages of using the X-ray lithography are:

i. For this technique, shorter wavelengths (0.1-10nm) can be utilized.
ii. Diffraction issues can be resolved using this technique for such a small wavelength used.
iii. The principle used for this technique is simple and does not require any complex optics but only an X-ray mask and a source.

Disadvantages of X-Ray Lithography

The disadvantages of using this technique are:

i. The resist (PMMA) is typically insensitive and need a long time to expose.
ii. This technique requires a mask which is difficult to fabricate due to the following reasons- defects, bending due to heating, fragile and aspect ratio.
iii. This technique results in the scattering of secondary electrons on the resist and its resolution is limited due to Fresnel diffraction.

Applications of X-Ray Lithography

The various applications of X-ray lithography are:

i. X-ray lithography can be used for building block integrated micro fluidic structures [47].
ii. This technique has potential application for genetic and potential analysis with the fabrication of miniaturized devices like microchips and also in micro electrophoresis devices [48].
iii. X-ray lithography can be used for producing blazed diffractive optical elements with the help of a single X-ray mask [49].

3. Comparison

The entire review report has been summarized and depicted in following Table 1.

Table 1. Comparison between the different Lithography techniques.

S.No.	**Nanolithography Technique**	**Feature Size**	**Throughput**	**Applications**
1.	Photolithography (Contact, Proximity Printing)	2-3 µm	Very high	Fabrication of MEMS devices and patterning in laboratories.
2.	Photolithography (Projection Printing)	37 nm	High-Very high	Production of IC's and CPU chips.
3.	Electron Beam Lithography	< 5 nm	Very low	IC's fabrication and production in R&D including photonic crystals.
4.	Micro-contact Printing	30 nm	High	Patterning devices and fabrication of MEMS and microQRcode.
5.	Nano-imprint lithography	6-40 nm	High	Fabrication of bio-sensors, MOSFET, nano-wires.
6.	X-ray lithography	15 nm	Low	Fabrication of microchips and micro fluidic structures.

4. Conclusion

The study in present review is very helpful for fabrication of nanodevices of different types and for distinction of different types of lithography. The entire review report has been summarized and depicted in following Table 1. We conclude that nanolithography has wide spectrum of techniques and each technique has its own advantages and disadvantages with applications in different fields. The detailed applications, benefits and drawbacks of lithography techniques which are discussed in this review are a great tool for fabrication of different types of sensors and other devices including nanoscale components. Through the present study it is clear that nanolithography technology is helpful in building the future of nanoscience and technology.

References

1. VenugopalGunasekaran and KimSang-Jae,"Nanolithography",*InTech*, (2013) 188-206.
2. PimpinAlongkornand SrituravanichWerayut, "Review on Micro- and Nanolithography Techniques and their Applications",*Engineering Journal*, 16(2012) 38-55.
3. Hai-HuaLi,JianChen, and Qing-KangWang, "Research of photolithography technology based on surface plasmon",*Chin. Phys. B*, 19 (2010 1-5.
4. KhumpuangSommawan, Maekawa Hitoshi, Hara Shiro, "Photolithography for Minimal Fab System",*IEEJ Transactions on Sensors and* Micromachines, 133(2013) 272-277.
5. WaitsChristopherM., MorganBrian, and GhodssiReza,"Double-Exposure Grayscale Photolithography Lance Mosher",*IEEE, Journal of Microelectromechanical Systems*, 18 (2009) 308-315.
6. WilliamsJohn D., WangWanjun,"Study on the postbaking process and the effectson UV lithography of high aspect ratio SU-

8microstructures”,*J.Microlith.,Microfab.,Microsyst.*, 3 (2004) 563-568.

7. Dhahi Th. S., Ali M. E., Hashim U., SaifAla’eddin A. and NazwaT.,”5nm gap via conventional photolithography and pattern-size reduction technique”,*International Journal of the Physical Sciences*, 6 (2011) 3649-3656.
8. Huang Fujian, XuHuaguo, TanWeihong, and LiangHaojun,”Multicolor and Erasable DNA Photolithography”,*ACS Nano*, 8 (2014) 6849-6855.
9. RathodGhansyam B., Paul Robinson P., SolankiMilendra Kumar M., Patel Hiren J.,”Review on Extreme Ultraviolet Lithography”,*International Journal of Advanced Research in Computer Science and Software Engineering*, 4 (2014) 682-687.
10. Stevenson J T M and Gundlach A M,”The application of photolithography to the fabrication of microcircuits”,*Journal of Physics E: Scientific Instruments*, 19 (2014) 654-667.
11. ChoByungjin, Nam Kyu Hyun, Song Sunghoon, JiYongsung, Jung Gun-Young, LeeTakhee,”The application of conventional photolithography to microscale organic resistive memory devices”,*B. Cho et al. / Current Applied Physics*, 12 (2012) 940-944.
12. ChaudhariAnkit, IbrahimMusa,”Electron Beam and X-Ray Lithography”,*ENEE*, 21 (2011) 416-418.
13. Pfeiffer Hans C.,”Direct write electron beam lithography: a historical overview”,*Proc. SPIE*, 7823 (2010) 782316.
14. HohnF. J.,”Electron beam lithography: Its applications”,*J. Vac. Sci. Technol. B*, 7 (1989) 1405.
15. Coane Philip, *Louisiana Tech University,”*Introduction to Electron Beam Lithography”, *Institute for Micromanufacturing*, 41, 1-15.
16. Tseng Ampere A., Chen Kuan, Chen Chii D., and Ma Kung J.,”Electron Beam Lithography in Nanoscale Fabrication: Recent Development”,*IEEE Transactions on Electronics Packaging Manufacturing*, 26 (2003) 141-149.
17. Adams Michael and Dr. Bell David,”Research and Development of Electron-beam Lithography Using a Transmission Electron Microscope at 200 kV”,*Journal of Young Investigators*, (2007) 1539-4026.
18. Vieu C., Carcenac F., Pépin A., Chen Y., Mejias M.,Lebib A, Manin-Ferlazzo L., Couraud L., Launois H.,”Direct microcontact printing of oligonucleotides for biochip applications”,*C. Vieu et al. / Applied Surface Science*, 164 (2000) 111-117.
19. Hu Wenchuang,”Ultrahigh Resolution Electron Beam Lithography For Molecular Electronics”, *Graduate Program in Electrical Engineering* (2004) 1-184.
20. Trasobares Jorge, Vaurette François, François Marc, Romijn Hans, Codron Jean-Louis, Vuillaume Dominique, ThéronDidierand Clément Nicolas,”High speed e-beam lithography for gold nanoarray fabrication and use innanotechnology”,*Beilstein J. Nanotechnol.*, 5 (2014) 1918-1925.
21. James C. D., Davis R., Meyer M., Turner A., Turner S., Withers G., Kam L., Banker G., Craighead H., Isaacson M., Turner J., and Shain W.,”Aligned Microcontact Printing of Micrometer-Scale Poly-L-Lysine Structures for Controlled Growth of Cultured Neurons on Planar Microelectrode Arrays”,*IEEE Transactions On Biomedical Engineering*, 47 (2000) 17-21.
22. ThibaultC,Berre V Le, S Casimirius, E Trévisiol, J François and C Vieu,”Direct microcontact printing of oligonucleotides for biochip applications”,*Journal of Nanobiotechnology*,3:7(2005) 1-184.
23. Ruizab Sami Alom and Chen Christopher S.,”Microcontact printing: A tool to pattern”,*Soft Matter*, 3 (2007) 168-177.
24. Yang Yumi, Hwang Youngkyu, Cho Hyun A, Song Jung-Hoon, Park Seong-Ju, Rogers John A., and KoHeung Cho,”Nanoimprint Lithography: A Promising Technique for Efficient Polymer Solar Cells”,*Small*, 7 (2011) 484-545.
25. Tien Joe, Xia Younan, And Whiteside George M.,”Micro contact Printing of SAMs”,*Academic Press*, 24 (l998) 227-250.
26. Perl Andra’s,Reinhoudt David N., and HuskensJurriaan,”Microcontact Printing: Limitations and Achievements”,*Adv.* Mater, 21 (2009) 2257-2268.
27. Chakra ElieBou, Hannes Benjamin & Cabrera Michel,”A new instrument for automated microcontactprinting.Applications to MEMS and biochips fabrication”, *Grenoble*, 27 (2007) 1-6.
28. Packard C. E., MurarkaA.,BulovićV.,”Direct Patterning of Metallic MEMS through Microcontact Printing”,*Ms.5 Microsystems Technology Laboratories Annual Research* Report, (2009).
29. Choonee, Kaushal R V,”MEMS MICRO CONTACT PRINTING ENGINES”,*Imperial College London*, (2007) 1-209.
30. ShenKeyue, Qi Jie, and KamLance C.,”Microcontact Printing of Proteins for Cell Biology”,*J Vis Exp.*, 22 (2008) 1065-1069.
31. Chou Stephen Y., Krauss Peter R., and RenstromPreston J.,”Microcontact Printing of Proteins for Cell Biology”,*J. Vac. Sci. Technol. B*, 14 (1996) 4129-4133.
32. Lan Hongbo and Ding Yucheng,”NanoimprintLithography”,*INTECH*, 3 (2010) 458-494.
33. Wu Wei,Tong William M., Bartman Jonathan, Chen Yufeng, Walmsley Robert, Yu Zhaoning, Xia Qiangfei, Park Inkyu, Picciotto Carl, GaoJun, Wang Shih-Yuan,MorecroftDeborah, Yang Joel, Berggren Karl K., Williams R.

Stanley,”Sub-10 nm Nanoimprint Lithography by Wafer Bowing”,Nano Lett. *American Chemical Society*, 8 (2008) 3865-3869.

34. Tao L., Nelson C. T., Trivedi K., Ramachandran S., Goeckner M., Overzet L., and HuWalter,”Sub-50 nm scratch-proof DLC molds for reversal nanoimprint lithography”,*J. Vac. Sci. Technol. B*, (2006) 2993-2997.
35. Zhou Weimin, Min Guoquan, Zhang Jing, Liu Yanbo , Wang Jinhe , Zhang Yanping, Sun Feng,”Nanoimprint lithography: a processing technique for nanofabrication advancement”,*Nano-Micro Letters*, 3 (2011)135-140.
36. Chen J. G., Liu L. J., Zhao Z. X., Liu J. R.,”Research and Development of Nanoimprint Lithography Technology”,*Applied Mechanics and Materials*, 757 (2015) 99-103.
37. Yang Yi,”Nanoimprint Lithography: A Promising Technique for Efficient Polymer Solar Cells”*ACS Nano, Nanoscale and Nanotechnology*(2014).
38. PankratovDmitry, Sundberg Richard , Sotres Javier , Suyatin Dmitry B. ,Maximo Ivan , Shleev Sergey and Montelius Lars ,”Scalable, high performance, enzymatic cathodes based on nanoimprint lithography”*BeilsteinJ. Nanotechnol.*, 6 (2015) 1377-1384.
39. Malloy Matt, Litt Lloyd C.,”Technology review and assessment of nanoimprint lithography for semiconductor and patterned media manufacturing”,*J. Micro/Nanolith. MEMS MOEMS*, 10 (2011) 03200-1-03200-14.
40. ViheriäläJukka, NiemiTapio, KontioJuha and Pessa Markus,”Nanoimprint Lithography -Next Generation Nanopatterning Methods for Nanophotonics Fabrication”,*Concertation meeting on Nano-Photonics*, (2009) 1-23.
41. DestaaYohannes M., Dinger Georg Aige1', ZancaaKevin J., CoanecPhil, GöttertbJost, MurphyaMichael C.,”Fabrication of Graphite Masks for Deep and Ultra-deep X-ray Lithography”,*Proceedings of SPIE*, 4175 (2000) 122-130.
42. Coane P., Giasolli R., Ledger S., Lian K., Ling Z., Göttert J.,”Fabrication of HARM Structures by Deep-X-ray Lithography Using Graphite Mask Technology”,*Microsystem Technologies*, 6 (2000) 94-98.
43. Rousseaux F., Haghiri-GosnetA., Chen Y., Ravet M., Launois H.,”X-ray lithography: an overview and recent activities at super-ACO”,*JOURNAL DE PHYSIQUE IV Colloque C9, supplement au Journal de Physique HI*, 4(1994) 237-244.
44. BollepalliSrinivas B., Khan M. and Cerrina F.,”Modeling Image Formation In Layered Structures: Application To X-ray Lithography”,*Technical Proceedings of the 1998 International Conference on Modeling and Simulation of Microsystems*, (2015) 53-58.
45. Spiller E., Feder R., Topalian J., *Soviet Physics Tech. Phys*., 20, (1976) 564-571.
46. Seeger David, Thomas J.,”X-Ray Lithography and X-Ray Microscopy”,*IBM Journal of Research and Development*, 37 (1993) 435-448.
47. RomanatoF. , TormenM. , BusinaroL. , VaccariL. , StomeoT. , PassaseoA. , FabrizioE. Di ,”X-ray lithography for 3D microfluidic applications”, *Micro and Nano Engineering 2003*, 73–74 (2004) 870-875.
48. Ford SM, Davies J, Kar B, Qi SD, McWhorter S, Soper SA, Malek CK,”Micromachining in plastics using X-ray lithography for the fabrication of microelectrophoresis devices”,*J BiomechEng*, 121 (1999) 13-21.
49. Makarov Oleg A. , Chen Zheng, KrasnoperovaAzalia A. ,Cerrina Franco ,CherkashinVadim V. ,Poleshchuk Alexander G. ,KoronkevichVoldemar P. ,”New application for x-ray lithography: fabrication of blazed diffractive optical elements with a deep-phase profile”, *Lithographiesfor Manufacturing VI*, 2723 (1996) 261.