ADVANCEMENTS IN LITHOGRAPHY TECHNIQUES: NANOIMPRINT LITHOGRAPHY (NIL)

[1]Akshada Thube, [2]Pranali Shelar, [3]Akshata Kawale,[4]Pranjali Jadhav
[5]Sangeeta Joshi,[6]Achanta Venu Gopal.
[5]Technical Advisor and Professor, [6]Scientific Officer, TIFR
[1-5]Department of Electronic Engineering,
[1-5]Vidyalankar Institute of Technology, Wadala (East), Mumbai, India.
[6]Department of Condensed materials and material science
Tata Institute of Fundamental Research, Homi Bhabha Road,Mumbai, India.

Abstract:The fabrication of an integrated circuit (IC) requires a variety of physical and chemical processes performed on semiconductor (e.g., silicon) substrate. In general, the various processes used to make an IC fall into three categories: Film deposition, Lithography and semiconductor doping. According to the Moore's Law made by Intel co-founder Gordon Moore in 1965, the number of transistors on a chip doubles every two years while the costs are halved. In order to satisfy Moore's law, the number of transistors in an integrated circuit should be doubled every two years while the chip size needs to be the same. This is made possible by the advancements in lithography process. The word lithography comes from Greek word lithos, meaning stones, and graphia, meaning to write. In case of semiconductor lithography our stones are silicon wafer and our patterns are written with light sensitive polymer called a photoresist. Lithography is the process of transferring geometrical patterns from a mask to the silicon wafer. The Importance of lithography can be stated in two ways. First, due to the large number of lithography steps needed in IC fabrication, lithography typically accounts for about 40 percent of the cost of manufacturing. Secondly, lithography tends to be the technical limiter for further advancements in feature size reduction, transistor speed and silicon area. The currently used lithography techniques are E-Beam Lithography (EBL), Dip-Pen Lithography, Nano-shaving, Electron Projection Lithography (EPL), Nano-grafting, Lithographically Induced Self-Assembly (LISA), Atom Lithography, Micro and Nano-Contact Printing, Ion Beam Lithography (IBL) and Nano-Imprint Lithography. In any lithographic process the two main figure of merits are resolution and throughput and we reviewed each of the existing technology with respect to these factor. This paper discusses the advancement in lithography process: Nano Imprint lithography. [2][3][7]

***Index Terms* - Nanotechnology, imprinting, patterning, resolution, throughput, NanoImprint lithography.**

I. Introduction

The two main figure of merit are Resolution and Throughput. Resolution means what is the minimum feature size and the precision with which the minimum feature size can be incorporated. Throughput means how many wafers can be processed in a given time and as an engineer, time is a very crucial aspect. Photolithography was the first form of lithography technique available and accompanied the use of optical lenses. Though this process results in high throughput but the resolution is limited to approximately 190nm because the numerical aperture cannot be exceeded more than 1.45 of the optical lenses used. Then comes the Electron beam lithography which has a higher resolution of about 10nm and also the need of mask is eliminated due to direct writing onto the wafer but the process is slow and hence the throughput is very low. In NanoImprint lithography a nanometer-size pattern is transferred not by electron, ion or other beams, but by a mask via mechanical contact between the mask and a substrate with a polymer. It has major advantages such as higher resolution, higher throughput, cost effective and flexiblesystem.

The commercially available NanoImprint lithography system was manufactured by Canon Inc. and provided to Toshiba Memory Corporation in 2017. Canon has been carrying out R&D since 2004 with the help of an American company Molecular Imprints, Inc. (now known as Canon Nanotechnologies, Inc.) in the field of next- generation semiconductor manufacturing equipment that utilizes NIL technology which achieves even more detailed circuit patterns as small as 10 nm at a lower cost. Other providers of NIL technology systems are SUSS MicroTec, Obducat and NIL Technologies etc. [2][3]

II. Principle of Imprint Lithography

Nano-Imprint lithography has two basic steps. The first is the imprint step in which a mold with nanostructures on its surface is pressed into a thin resist cast on a substrate, followed by removal of the mold. This step replicates the nanostructures on the mold in the resist film. The second step is the pattern transfer where an anisotropic etching process, such as reactive ion etching ~RIE, is used to remove the residual resist in the compressedarea.

During the imprint step, the resist is heated to a temperature above its glass transition temperature. At that temperature, the resist, which is thermoplastic becomes a viscous liquid and can flow and therefore can be readily deformed into the shape of the mold. The resist's viscosity decreases as the temperature increases. Unlike conventional lithography methods, imprint lithography itselfdoes not use any energetic beams. Therefore effects of wave diffraction, scattering and interference in a resist and backscattering from a substrate is avoided.

III. Mold, Resist and Process Conditions

In general silicon were used as the mold materials. Certainly, other materials such as metals and ceramics could also be used. We will be discussing the generic process for NanoImprint lithography and the types of Nano-Imprint lithography techniques.

1. WAFER CLEANING PROCESS

The wafer cleaning is used to chemically clean the wafers .This removes particles and contaminant films from the wafer surface before they can get into the thin films on the wafer or into the silicon itself.

2. MOLD / MASK PREPARATION

The mold/mask can be fabricated out of any Metal, Insulator or Semiconductor material. For higher resolution and greater accuracy the mold is generally made by E-beam lithography technique in which the nanometer-size pattern is directly written onto the substrate material in a controlled environment (generally Clean Room). Precaution has to be taken while fabricating the mold/mask because even a slight error will be replicated on all the subsequent imprinted pattern.

3. SPIN COATING PROCESS

Spin coating has been used for several decades for the application of thin films. In this process, a small drop of the coating material is loaded onto the center of a substrate, which is then spun at a controlled high speed. In the spin coating process, the substrate spins around an axis which should be perpendicular to the coating area. As a result, the coating material spreads towards the edge and eventually off the edge of the substrate leaving a thin film of coating on the surface. Final film thickness and other properties will depend on the nature of the coating (viscosity, drying rate, percent solids, surface tension, etc.) and the parameters chosen for the spin process such as the rotation speed.[1]

IV. NANOIMPRINT LITHOGRAPHY METHODS

Different NanoImprint methods which are practiced currently are mentioned in this section.

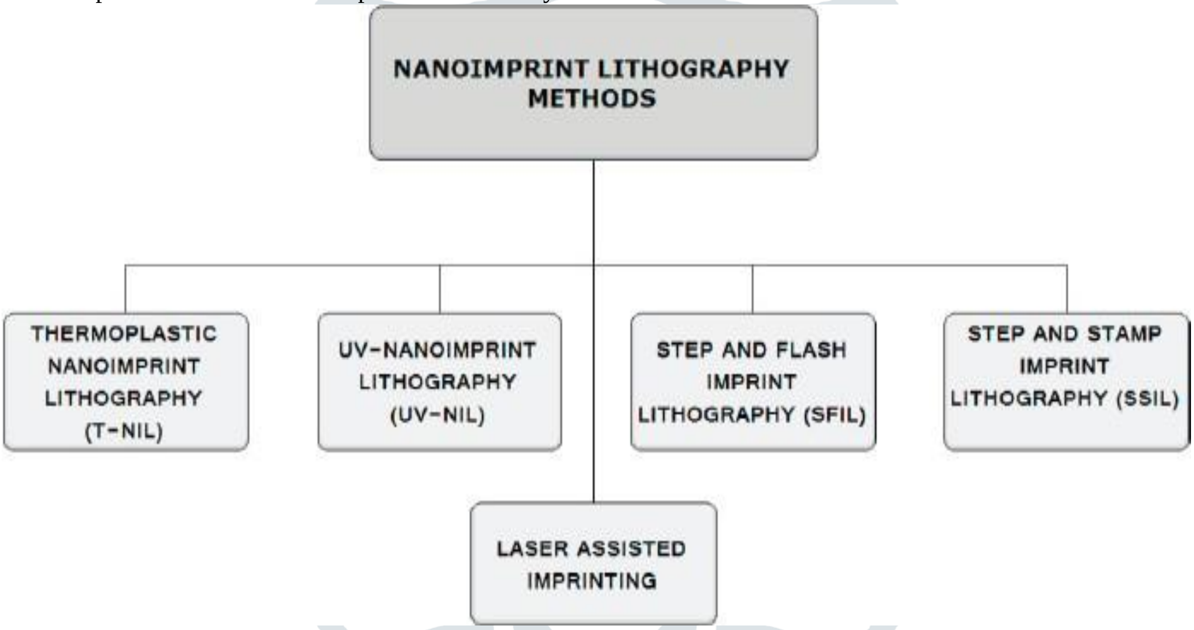

Fig. (1) Types of NanoImprint Lithography Process[4]

V. THERMOPLASTIC NANOIMPRINT LITHOGRAPHY (T-NIL)

In Thermoplastic NIL process a thermo cure resist is spin coated on the substrate. The property of thermo cure resist is that once it is heated above the glass transition, the polymer is of liquid state. After cooling it becomeshardened by crosslinking. Using this property of the resist, the mold of specific feature is pressed on to the resist upon heating above the glass transition temperature. After cooling, the pattern gets transferred to the resist from the mold and the mold is separated from the resist. Features in the mold can be transferred to the substrate by using chemically reactive plasma to selectively remove the depositedmaterial. [6]

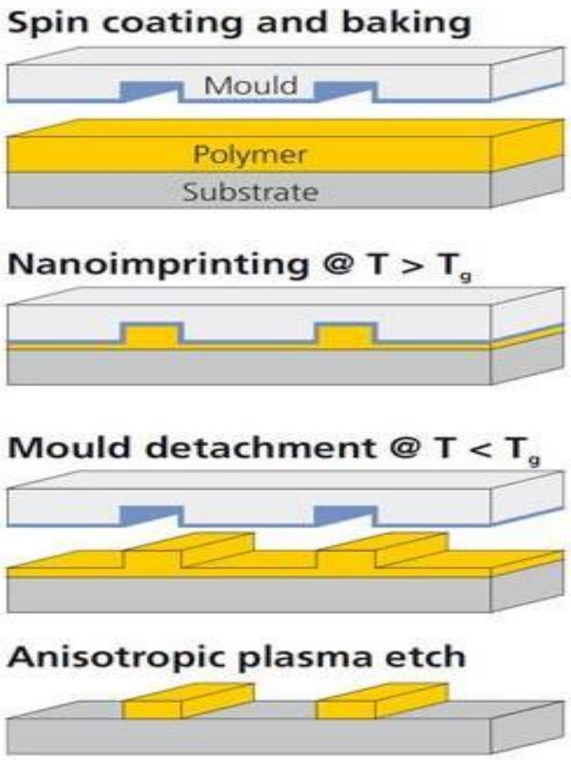

Fig. (2) Process Flow of Thermal-NIL Technique[8]

VI. Ultraviolet-Nanoimprint Lithography (UV-NIL)

The process of UV-NIL is almost same as like T- NIL, but the resin used is UV curable. The property of the UV curable resin is that initially it is at liquid state which is then hardened and cross-linked by exposing it to UV radiation. In this process, the mold is pressed on to the resin and then it is cured by UV radiation. Later mold is separated from the resin leaving back the features on to the resin which is then cleaned to remove any residuals. Positive aspects of this method are that it can be performed at room temperature and with low imprint pressure, so the alignment accuracy is better.[5]

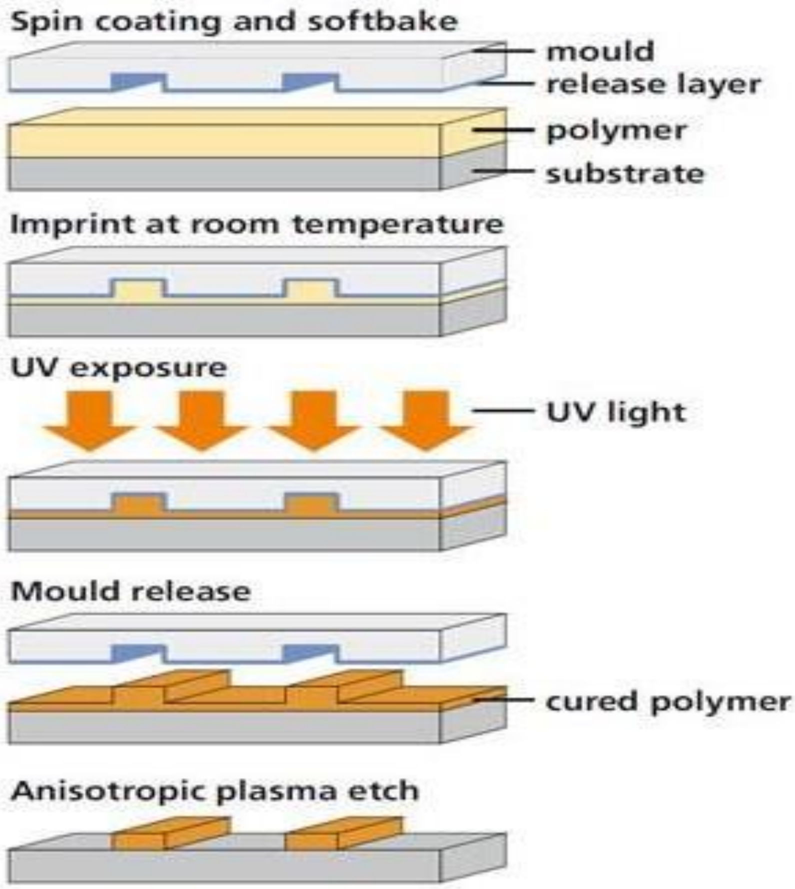

Fig. (3) Process Flow of UV-NIL Technique[8]

VII. Step and Flash Imprint Lithography (SFIL)

SFIL uses a low viscosity, photo-curable, organosilicon liquid. Template used in this is transparent, rigid so that it allows layer-to-layer alignment. High throughput, low cost, no projection optics and operation at room temperature is the main advantages of the SFIL. Repeated use per wafer decreases stamp lifetime.

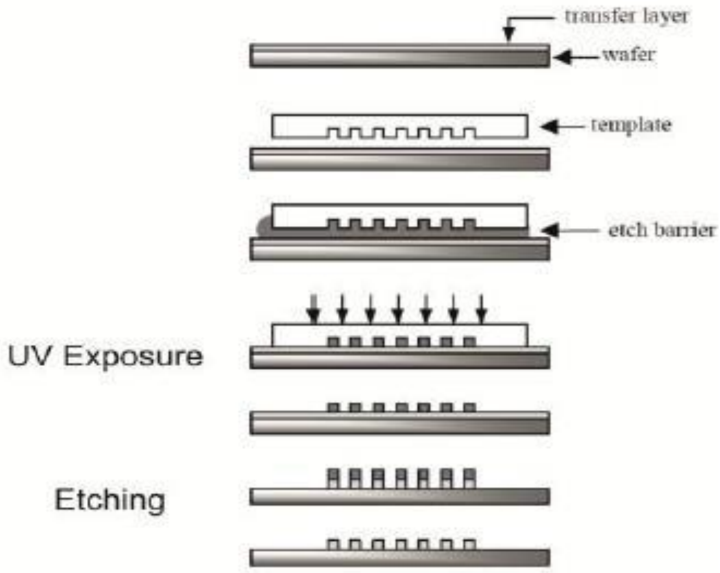

Fig. (4) Process Flow of SFIL Technique[4]

VIII. Step And Stamp Imprint Lithography (SSIL)

In this technique, a stamp is pressed on to the polymer for creating the imprints. Stamp is lifted and pressed next to create more imprints. And the process is repeated to produce more of same imprints. Alignment of stamp to already existing features on the substrate makes it possible to use SSIL together with UV lithography for mix andmatch.

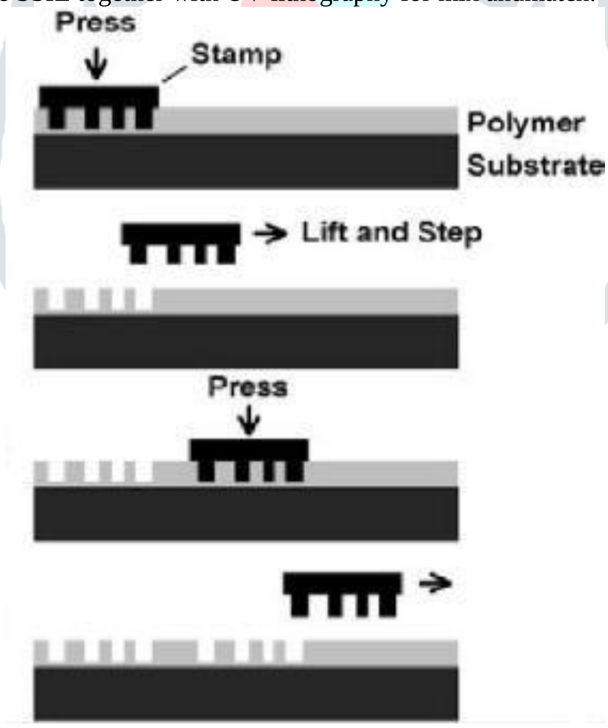

Fig. (5) Process Flow of SSIL Technique[4]

IX. Laser Assisted Direct Imprinting (LADI)

In this method, imprints are made directly with the use of lasers. The quartz molds were diced to fit within the excimer laser beam area, ensuring that all the silicon beneath the mold melts during (Laser Assisted Direct Imprinting) LADI. Then the pressure between the mold and silicon wafer were applied by sandwiching them between two large press plates. Mold is placed above the silicon wafer. Mold is placed above the silicon wafer. Mold is made of fused quartz and hence transparent to the laser beam. Based on the reflectivity of the silicon, the process monitored. When silicon melts, it changes from a semiconductor to a metal, hence its surface reflectivity to visible light increases.

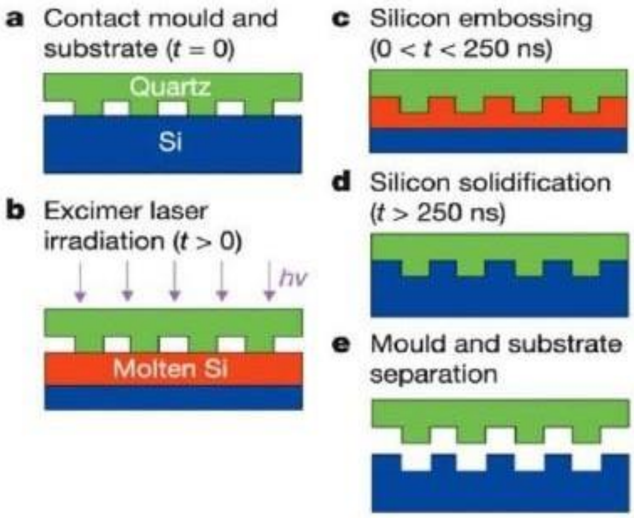

Fig. (6) Process Flow of Laser Assisted Direct Imprinting Technique[4]

X. Conclusion

Nanopatterning and Nanoimprinting has more scope in coming years. It has several applications in various fields. Accurate and precise operation is one of the major advantages of this technology. NanoImprint lithography involves the mechanical replicas of patterns, which is neither limited by diffraction, scattering effects nor secondary electrons. It is a very promising technology for the production of micro/nano structures on the wafer level. This facilitates the miniaturization process. Merits of these technologies are cost effective, efficient, reliable system and low powerconsumption.

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