

Advancement in Lithographic Techniques for Semiconductor Devices

Sakshi Singh

Department of Electronics and Communication Engineering
Faculty of Engineering, Teerthanker Mahaveer University, Moradabad, Uttar Pradesh, India

ABSTRACT: *Persistent quick contracting of highlight size of semiconductors made the specialists to look for elective designing techniques as the regular photolithography accompanies its inherent goals limit. Right now, encouraging methods have been proposed as cutting edge lithography (NGL) that has the possibilities to accomplish both high-volume creation and exceptionally high goals. This paper surveys the promising NGL strategies and presents the difficulties and a point of view on future headings of the NGL procedures. Outrageous bright lithography (EUVL) is considered as the principle possibility for sub-10-nm assembling, and it might meet the present necessities of the business. Wonderful advancement in EUVL has been made and the apparatuses will be accessible for business activity soon. Mask less lithography systems are utilized for designing in R&D, veil/form manufacture and low-volume chip structure. Guided self-get together has just been figured it out in research center and further exertion will be expected to make it as NGL arrangement. Nanoimprint lithography has developed appealingly because of its straightforward procedure steps, high throughput, high goals and ease and become one of the business stages for nanofabrication. Various testing issues are holding up ahead, and further innovative advances are required to make the systems huge and solid to fulfill the present need. At long last, a relative investigation is introduced among these procedures.*

KEYWORDS: *Nanolithography Throughput Resolution Defect thickness Overlay*

INTRODUCTION

Over the most recent couple of decades, the semiconductor ventures had adhered to the Moore's law; the quantity of transistors per chip had been multiplying each procedure age. The straight scale infers a multiplying of thickness at regular intervals. Intel has declared the new 10-nm process that accomplishes 100.8 million transistors for every square millimetre. This gives remarkable 2.7 occasion's transistor thickness improvement over its antecedent and recommends that Moore's law is likely not easing back down. This improvement of transistor thickness has been finished by contracting the extents of the transistors. Be that as it may, the enterprises have requested sub-10-nm hubs designing to meet the developing prerequisites. As announced by the International Technology Roadmap for Semiconductors new sort of rationale gadgets (Gate-all around structures) have just been presented. These new gadgets will supplant the balance structures soon. This report additionally exhibits the advancement of numerous new kinds of memory gadgets that can be the potential choices in the future. These new gadgets will likewise push designing to make much littler nanostructures. In spite of the fact that this quick contracting of highlight size licenses for quicker handling with more force effectiveness at a lower cost, it strongly improves the plan multifaceted nature and presents different assembling difficulties. Therefore, lithography must achieve the stringent modern prerequisites with fantastic capacity to meet upcoming challenges [1].

Photolithography has been the predominant strategy for designing nanoscale highlights for the microelectronics enterprises since the initiation of the ICs. Goals upgrade advancements (RET) and inundation technique empowers the photolithography with designing past its characteristic goals limit. RET improves the nature of a picture. It by and large incorporates stage move veil, optical nearness remedy (OPC), changed or off-hub enlightenment (OAI) and different designing. Despite the fact that they have expanded the capacity of the lithography procedure, these strategies experience a few limitations too. Stage move strategy has a few confinements on usage of veil because of stage end issues and cover manufacture challenges. The OPC method presents format limitations and restrictive expenses to make the revised veils, while OAI presents multifaceted nature to the brightening source in the wafer stepper and to the cover plan.

Numerous designing is the primary system for current sub-20-nm volume fabricating, which empowers to print the examples that are littler than the single introduction lithographic goals limit utilizing numerous procedure steps. There are a wide range of strategies to actualize various designing including litho-carve litho-draw (LELE), self-aligned twofold designing (SADP) and self-adjusted fourfold designing (SAQP). Nonetheless, to an ever increasing extent veils is required for better procedure hubs, coming about in restrictively costly assembling cost and it requires a lot more tightly overlay control than single designing. 193-nm drenching lithography (193i) has given compelling lift to the further improvement of microelectronics, and the 22- and 14-nm hubs are right now fabricated with multi-designing drenching ArF lithography [2]. This system brings huge procedure challenges like draining, drenching absconds and the filling strategies for a filtered medium.

Regardless of the difficulties, it has been the standard lithographic procedure utilized in assembling ventures since a decade ago. Presently it is arriving at its inborn limits. Notwithstanding the high-goals abilities, X-beam lithography (uses X-beams frequency of 0.4–4 nm) systems were demonstrated ineffective to give a financially alluring lithographic procedure because of certain troubles. One of them was to locate the correct blend of materials and frequency. Wrapping of safeguard material because of inward stresses is an issue to alleviate. Besides, the most basic point is the inability to outfit appropriate veils as these covers must be solidarity amplification and the necessity of making the cover from enough X-beam engrossing materials. Once more, the prerequisite of thick safeguard layers and membranous nature of the substrate made X-beam lithography disliked in nanofabrication field.

As the regular photolithography has drawn nearer its definitive cut-off points, extensive endeavours have been dedicated to NGL methods by different research labs and businesses around the world. These procedures are outrageous bright lithography (EUVL), electron-bar lithography (EBL), centred paper bar lithography (FIBL), nanoimprint lithography (NIL) and guided self-gathering (DSA). They have the possibilities as the substitution to customary photolithography. With the expanding in designing goals, oppose is one of the key difficulties for the appropriation of the designing methods in HVM ventures. The people to come potential methods drive the requirement for oppose materials with high goals, high affectability and low LWR. Be that as it may, it is hard to accomplish high goals, low line edge harshness (LER) and low affectability all the while due to an inborn exchange off connection between one another (RLS exchange off). In this way, the improvement of cutting edge stand up to materials will be required to sever the RLS exchange relationship. Also, the cutting edge opposes must can moderate the stochastic obstruction [3].

The progression of new oppose materials is entering another age with difficulties and chances to satisfy the stringent necessities for the future designing methods. Right now, we will examine the component, by and large status and the difficult issues for the NGL procedures just as the general issues identified with oppose materials.

EXTREME ULTRAVIOLET LITHOGRAPHY

1. Mechanism

Because of frequency constraints, current considerations are coordinated toward creating EUVL which utilizes outrageous bright radiation to build productivity, decreases fabricating cost and supports the advancement of preparing power. In the most recent decade, scientists put broad intrigue in EUVL as a 'next frequency' trade for 193-nm thick UV lithography. EUVL uses 13.5-nm photons that are gotten normally from a plasma source [4]. EUV light is then gathered by an optical component called a 'gatherer.' Light from the authority is engaged into the illuminator (shaped of multilayer-covered ordinary rate reflects as well as brushing frequency mirrors) through a middle center. The illuminator enlightens the perfect measure of light furthermore, guides it onto the reticule arrange (i.e., a veil). The reflected picture of the reticule shows up into the projection optics (comprise of at least six multilayer mirrors) with a demagnification. At last, the picture is engaged onto the wafer stage to frame an example into a substrate covered with a photoresist.

Each progression is worked in a low-hydrocarbon, high-vacuum condition. Figure 1 shows a schematic of a EUVL introduction system.

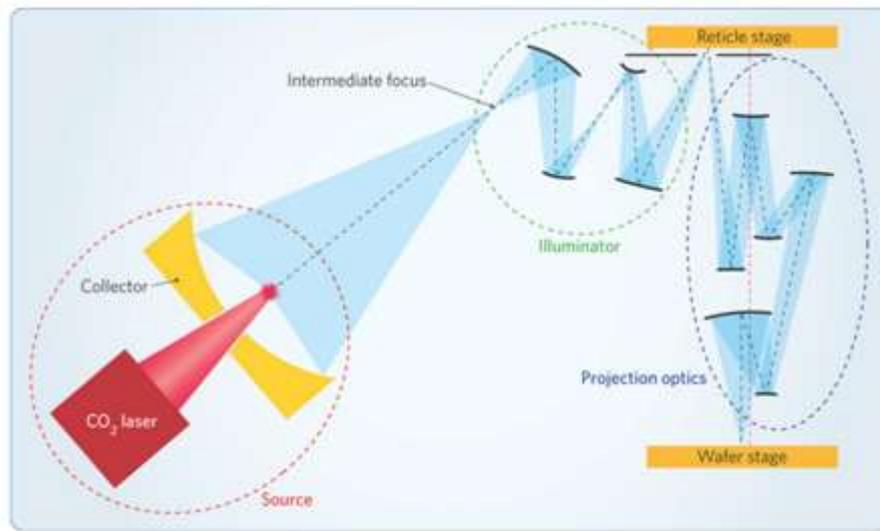


Figure 1: EUVL introduction system

2. Status and Challenges

In the course of the most recent couple of years, extensive advancement has been made to move EUVL toward expanded high-volume fabricating (HVM) feasibility. Most strikingly, there have been significant improvements to presentation throughput, unwavering quality, fluctuation control and designing materials for the high goals required. Presently, EUVL is anticipated to use in assembling at the 7-nm hub or past. ASML, a main organization engaged with the advancement of EUVL instruments, uncovered that more than 1000 wafers every day had been uncovered on its NXE: 3300B EUV framework over numerous weeks' span. They have moreover guaranteed that the throughput detail of 125–150 wafers every hour has been accomplished on TWINSCAN NXE: 3400B lithography framework [11]. In spite of the fact that, the focused on 4-week normal accessibility (80%) has been accomplished by 2016, it needs to keep on improving further.

As far as creation timescales, ASML predicts it will go into creation in 2018. The source power, veils and oppose materials despite everything have basic issues for large scale manufacturing. For the future innovation at the 5-nm hub and past, sources forces of 500–1000 W at a diminished operational expense per wafer might be required. Laser created plasma (LPP) and release delivered plasma (DPP) are two principle methods to deliver EUV sources. The source power has been improved multiple times in last five a long time.

Mitsubishi electric has effectively investigated a higher normal force CO₂ laser more than 20 kW at yield power. Presently they are growing new high-power HVM LPP-EUV source with in excess of 25 kW CO₂ driver laser framework. Despite the fact that EUV source innovation is extremely near the necessities, some expense of possession issues should be researched before the addition of EUVL into HVM. For additional improvement, novel methodologies for power sources are as a rule despite everything researched [5].

A key factor for appropriation of EUVL in HVM is the decision of EUV oppose with high affectability, high goals, low LER, low LWR and better contact gap CDU. Artificially enhanced opposes (CARs) have adequately accomplished the scaling necessities of the semiconductor business. RLS execution and stochastic varieties are the key issues for the CARs just as for other oppose materials. High-affectability (20 mJ/cm²) oppose materials are required to diminish the improvement cost of high-power introduction sources that thusly prompts enormous LER esteems.

Corrosive dispersion in CARs impacts these exhibitions. The researchers have detailed that by choosing an suitable proportion of quencher to PAG (photograph corrosive generator), an EUV portion decrease of up to 12% can be accomplished with 240 s PEB (post-introduction prepare) time, while keeping LWR and goals consistent. For better advancement of these parameters, some other oppose materials and approaches have been contemplated. Non-chemically enhanced opposes (non-CARs) show high-goals capacity, high affectability and low LER as they have no corrosive dissemination issues. A few analysts have revealed the advancement of the metal containing photoresist that has high affectability execution, which will be exceptionally supportive for the low-vitality power source to figure it out EUVL. Some other new procedures including

nano-paper photoresists with high affectability have been revealed. Of late at the 2016 SPIE Advanced Lithography gathering [6], a great measure of papers was introduced exhibiting the generous research on Photosensitized CARs. Additionally, a few methodologies have been acquainted with improve affectability, LWR and nearby CDU from numerous bearings.

It is earnest need to alleviate the stochastic disappointments, for example, broken line, Nano-connect, blending gaps furthermore, shutting gaps. These Nano-disappointments are affected by numerous elements including ethereal picture quality, photon retention, corrosive shot commotion and corrosive dissemination. The likely arrangements lie with the co-enhancement of assortment of various viewpoints (materials utilized, equipment, metrology and so on). Introduction portion can be a powerful handle to drive down the disappointments. Higher portion safeguard materials can decrease the stochastics. In addition, the substrate underneath the stand up to impacts the introduction portion and the LWR, and in this way, improvement of the substrates could be a potential improvement handle to the introduction portion and LWR decrease.

A few techniques have been proposed to alleviate this issue. Since the slim powers are one reason for design breakdown, killing any procedure steps where fluid air interface arrives at the oppose surface can be a powerful method to keep away from this issue. Also, precisely solid opposes are less defenceless to the harm because of the fine powers. Another way could be controlling the thickness of the oppose film appropriately as flimsy film can keep away from design breakdown during improvement and wash. Some different procedures were concentrated to diminish design breakdown with expanded goals. Notwithstanding, conventional goals upgrade strategies are utilized to expand the EUVL including OPC and source-cover enhancement (SMO). By utilizing SMO strategy, edge arrangement mistake (EPE) can be diminished fundamentally. In the course of the most recent couple of years some association like CNSE of SUNY Polytech related with SUNY Polytech SEMATECH have bolstered the examination of EUV oppose materials and different EUV opposes assessment.

Veil clear imperfections and yield limit the relevance of EUVL [3]. They are proceeding to improve. In any case, broad inquiries about are as yet expected to improve cover materials, creation forms, deformity assessment and attitude metrology and cover assurance. To determine, pellicle and cover investigation are two basic issues to improve in general process effectivity. Exceptionally transmitted and durable pellicles are attractive. The communication between the slanted episode EUV light and the designed safeguard may cause the cover 3D impacts at wafer level. The researchers have recommended some other safeguard materials (nickel and, cobalt) to lessen the veil 3D impacts and improving the general imaging window. For the imperfection free veil fabricating, an EUV elevated picture metrology framework, the AIMSTM EUV, has been created by ZEISS and the SUNY POLY SEMATECH EUVL Mask Infrastructure consortium to actinic survey of EUV veil.

These actinic apparatuses are extremely valuable for clear investigation, design cover assessment, and imperfection fix check. On the side of EUVL guide, small scale field introduction apparatuses (13.5 nm, 0.5 NA R&D) have been created by Zygo Corporation [4]. As per ITRS2015 report, ASML is going to create a 0.55 NA EUV scanner with various amplification in both x and y bearings, and it could be accessible to use in assembling in 2021. ASML has likewise presented of its fifth generation EUV scanner, the NXE: 3400B, with improved goals, overlay and center. Nonetheless, the achievement of EUVL as a major aspect of the coordinated designing procedures stays a basic issue and subsequently the usefulness of EUVL as a designing system proceeds to quicken.

MASKLESS LITHOGRAPHY

1. Mechanism

EBL and FIBL are mask less methods that are generally utilized in nanostructure designing and IC creations with its capacity to frame self-assertive two-dimensional examples down to the nanometre scale. EBL utilizes a quickened electron pillar to significantly adjust the solvency of a stand up to material during a consequent improvement step. The electron shaft is centred around the oppose and afterward examined on the surface of the oppose with the width as little as a couple of nanometres in a speck by spot style. At that point the examples can be moved to the substrate material by scratching like other lithographic techniques [5].

Additionally, FIBL includes the introduction by a quickened paper shaft to legitimately hit the example surface. When high speed papers hit the example surface, vitality is transmitted to molecules on a superficial level, which prompts five potential responses:

- Sputtering of unbiased ionized and energized surface iotas.
- electron discharge
- removal of molecules in the strong
- discharge of photons, and
- Synthetic responses.

In light of these marvels, FIBL frameworks are too utilized for storing materials, for example, tungsten, platinum, and carbon through paper shaft initiated testimony and the implantation that can alter a material surface. Figure 2 shows the procedure steps of EBL and FIBL framework.

2. Favourable Circumstances and Disadvantages

Electron bar and centred paper pillar lithography have favourable circumstances of high goals, high thickness, high affectability and, high unwavering quality. As these procedures are mask less, they are the perfect apparatuses for adaptable age for low-volume applications. Because of their characteristically high goals, fantastic example definition can be accomplished. They are profoundly mechanized and exceptionally exact control of example with direct composition. EBL has more prominent profundity of center and furthermore an extraordinary decision for the development of covers and layouts for the optical lithography and nanoimprint lithography. On the other hand, it has the disadvantage of low speed and low throughput. It is entangled and costly framework also. It likewise experiences dispersing and over introduction issues. Thus this strategy isn't effective for mechanical handling.

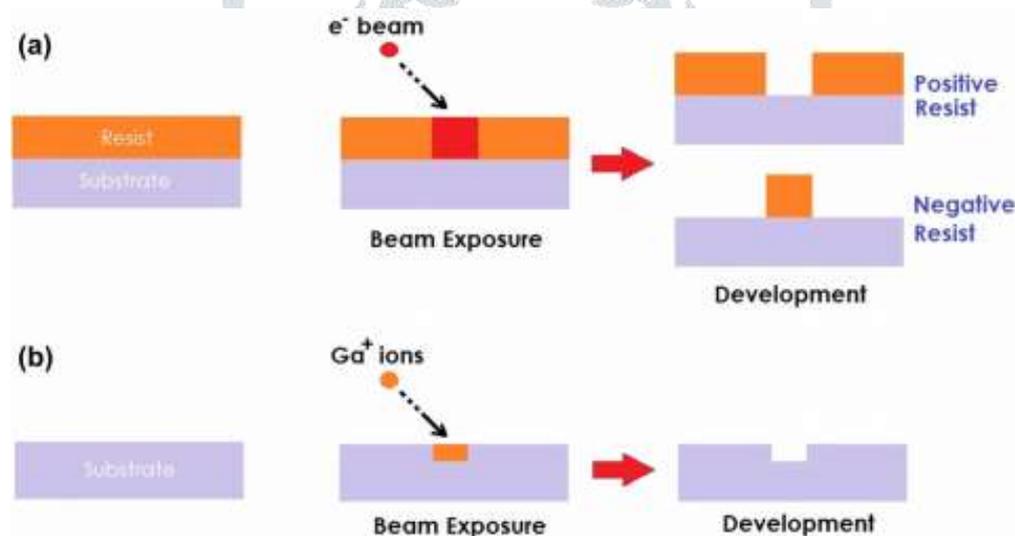


Figure 2: procedure steps of a. EBL and b. FIBL framework.

NANO-IMPRINT LITHOGRAPHY

1. Mechanism

Nanoimprint lithography is a propelled nanofabrication strategy that is able to do high-throughput designing of nanostructures with high goals (down to the 5-nm system). In light of the ease, decreased procedure steps and, high devotion, NIL turned into an appealing system for a wide scope of utilizations. Nanoimprint lithography techniques can be characterized into four classes: warm NIL, UV-NIL, laser-helped NIL and electrochemical nanoimprints. In warm NIL, a fine film of a thermoplastic polymer (engrave oppose) is saved first by turn covering onto the substrate. The subsequent stage is to press the pre-assembled form with the substrate together under a specific tension. Resulting warming is utilized over the polymer's glass change point to accomplish the mollified polymeric film. In the post-warm cooling process, the substrate is chilled off, and, form is expelled from it, while keeping the example oppose on the substrate. At last, a carving procedure is utilized to expel oppose lingering layer [6].

Reproducing of ultra-accuracy micron scale structures can be accomplished with this warm roller engraving process at the output speed of 0.1–10 mm/s. UV-NIL is a room temperature and low-pressure engrave system which includes covering of the example surface with an UV-reparable fluid stand up to. The oppose material is presented to the UV light and the consequent cementing of oppose under UV radiation. Thereafter, an optically straightforward shape is squeezed into the substrate to separate the designs [7]. A bit of leeway of utilizing straightforward shape is to offer the opportunities for simple optical and high-accuracy arrangement. This advantage is utilized in step-and-blaze engrave lithography (S-FIL), a propelled adaptation of UV-NIL, which can nano pattern the entire wafer in a decreased handling time. In S-FIL, the engraving material (low-consistency, photograph treatable monomer) is apportioned dropwise on the substrate.

The laser-helped direct engraving (LADI) is a resistless procedure that doesn't require drawing. With this method, a solitary excimer laser beat is uncovered through the straightforward quartz shape to dissolve a slim surface layer of silicon substrate. At that point, the subsequent fluid layer is emblazoned by the quartz form. At last, the shape is discharged after the substrate has chilled off. Different nanostructures with sub-10-nm goals could be engraved into silicon wafer utilizing LADI with the emblazoning time underneath 250 ns [8].

The capacity of high-goals and rapid designing makes the LADI as a promising procedure for an assortment of applications, and it very well may be stretched out to different materials (polysilicon, Ge, and dielectrics) and preparing methods. Thus, laser-helped nanoimprint (LAN) lithography uses a solitary excimer laser heartbeat to liquefy the polymer. At that point an intertwined quartz form is utilized to design the nanostructures. This procedure can be utilized in designing different polymer films on a Si or quartz substrate with high constancy over the whole form region. Utilizing LAN system, the engraving time could be under 500 ns. The warming furthermore, development of the substrate and form can likewise be diminished altogether with the goal that better overlay arrangement between the two can be accomplished.

Electrochemical nanoimprinting is a resistless methodology that utilizes a shape created from a superionic conductor. In this procedure, a voltage is applied between the shape and the target substrate. When the surfaces of the form are in contact with the substrate, current streams between them. The solid electric motion from the protrusive pieces of the shape to the substrate results anodic oxidation of the substrate surface relating to the protrusive pieces of the shape with the dampness present between the form and the substrate [9].

In this manner, the substrate is carved to accomplish the nanostructures like different strategies.

2. *Favourable circumstances and Disadvantages*

NIL is the very basic procedure and offers a promising minimal effort elective lithography innovation with a few different points of interest, for example, high goals, CDU and littler LER. NIL is a quick procedure. Since it very well may be utilized to manufacture Nano-patterns at an enormous scope in a brief timeframe, this can be a high-throughput strategy. It has likewise minimal effort of proprietorship and high-goals extendibility. All things considered, NIL could offer its 3D designing ability for the headway of 3D chip innovation. As a result of its adaptability and capacity to consolidate with different strategies, it has made enormous open doors for the future lithographic strategies for some others potential applications. Be that as it may, low overlay structure exactness and warm extension impacts are the hindrances of the NIL. One of the downsides of NIL over other nanofabrication procedures is the adaptability of designing. The shape must be remanufactured when the structured example is changed somewhat. Another impediment is the present dependence on other lithography procedures to manufacture the form, and the shape creation needs bunches of cash and time.

GUIDED SELF-ASSEMBLY

1. *Mechanism*

DSA is one of the promising procedures for high-volume minimal effort fabricating at a sub-lithographic goals. DSA empowers better goals that pulled in a lot of enthusiasm from significant semiconductor makers. Later advancements in DSA materials and preparing make it convincing cutting edge designing systems. There are two sorts of DSA forms: 'epitaxial self-get together' (Chemo-epitaxy) and 'graph epitaxy.' In epitaxial self-assembly, thick concoction designs are

utilized to coordinate square copolymer (BCP) self-gathering. Exceptionally requested Nano-patterns can be accomplished if the time of the surface synthetic example is proportionate with the balance time of the BCP self-collected nanostructure. Graph epitaxy guides designing by geographical geometry for DSA. The specific wetting of a BCP segment at the channel side dividers implements the sidelong requesting of the self-collected BCP Nano domains along the channels [10].

Hence, it improves the example thickness by subdividing the geographical pre-design.

2. Advantages and Disadvantages

By DSA, the general goals can be expanded to a level that is perfect with the 7-and 5-nm rationale hubs. DSA could rearrange and lessen the procedure steps. It can ease process reconciliation and give minimal effort preparing in propelled semiconductor forms. Different focal points of DSA are diminished effectivity through material and procedure streamlining, expanded example constancy, better material quality control at HVM and high throughput. The square copolymers have abandons fix inclination in the examples produced by other photolithographic systems. With this capacity, DSA can assume a significant job later on for semiconductor manufacture [5]. Likewise, required example geometries are on the whole conceivable utilizing structured DSA. By DSA, it is conceivable to characterize precisely the direction, auxiliary measurements and example thickness. In any case, regarding LER and, CD control, DSA appears to be still to be well behind EUVL. Different inconveniences are effectivity, constrained example types, arbitrary direction and relative long preparing time.

CONCLUSION AND DISCUSSION

Every procedure has it's possess qualities and restrictions. In spite of the fact that, these lithography strategies demonstrate the promising capacity to meet the future interest, they need further improvement in a few angles. In wording of goals, all the cutting edge lithography strategies can accomplish goals levels 10 nm and past. Mask less and nanoimprint lithography are restricted by low throughput. Slow blanking speed is one of the significant issues for the EBL framework speed and the framework multifaceted nature let it hard to improve. In NIL, a few factors are answerable for low throughput, for example, engrave time, form alteration and engraving process. Large area designing may improve the throughput, however further improvement is expected to meet the mechanical necessities. High overlay precision is one of the noteworthy issues in NGL methods.

Overlay in NIL has been accomplished beneath 5 nm while many nm in mask less lithography. For better overlay exactness, a ton of innovation upgrades are required, for example, overlay control precision for devices, the metrology to absolutely gauge arrangement and picture position precision. In any case, the likelihood of imperfections increments with the upgraded goals. In spite of the fact that, it is hard to improve deformity thickness because of the contact nature in NIL process, significant explores are occurring to improve it close to the necessary worth. Alongside different issues, effectivity is still the principle challenge to DSA usage to different business gadget fabricating circumstances as a NGL arrangement. In most recent 2 years, imperfection thickness has been improved fundamentally from 24 cm-2 to * 0 deformity cm-2.

Two additional sets of size are as yet expected to meet the modern necessity of 0.01 imperfections cm-2. At long last yet critically, the central factor for the lithography methods is its cost effectiveness as opposed to its specialized presentation. EUVL foundation and instruments are expensive and huge quantities of veil steps required make the procedure moderately costly. Mask less lithography is additionally expensive because of its costly hardware. Despite what might be expected, NIL and DSA are the promising minimal effort systems for what's to come designing hubs.

CONCLUSION

For a long time, nanolithography innovation has added to the development in the nonmanufacturing business and, is impacting the eventual fate of nanoscience and innovation. Adaptability, high throughput, high goals, high unwavering quality, high productivity and ease are the necessities for the nanolithography systems to meet the future interest. Traditional photolithography has been the principle lithography system that meets the current throughput interest for the semiconductor business yet accompanies its goals limit. In the most recent decade, extensive exertion has been made in the improvement of nanolithography systems for large scale

manufacturing of coordinated circuits. Through this audit, a general status of the potential cutting edge lithography procedures has been given.

- EUVL is relied upon to be accessible in the blink of an eye with high resolution capacity yet its reception in HVM industry stays unsure. The EUVL framework needs generous advancement including source unwavering quality, LER/ LWR improvement and effectivity. More examinations are required to build up the issues identified with cost of possession. EUVL can be more practical by empowering new joining plans through different methods (planarization, DSA). It can likewise incorporate multi-patterning (Double uncover), LELE procedure to get ready this system for cutting edge designing in future.
- Although, EBL and FIBL systems have high-thickness ultra-high-goals designing capacity, designing speed altogether constrains their application inside low volume creation. To accomplish elite from these systems, the instrument, the oppose parameters, and the by and large lithography process must be enhanced.
- NIL has shown the possibilities to accomplish the expanding interest for high-volume creation. Regardless of the immense business achievement, there are still numerous difficulties that lie in NIL manufacture forms. Effectivity and overlay precision remains the fundamental concerns and further enhancements are required to meet the mechanical prerequisites.
- DSA is considered as a promising designing alternative that can decrease multi-designing procedures. In spite of being gained acceptable ground, a few issues identified with effectivity, arrangement exactness and instrument configuration need to be examined appropriately. Likewise, the difficulties of DSA mix into fab stream and structuring chips around the innovation additionally should be tended to previously the total execution in manufacturing. All these systems are as yet being created to reach the guide necessities and are relied upon to go over as a novel cutting edge lithography procedure.

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