Introductory Chapter: The Eminence of Lithography—New Horizons of Next-Generation Lithography

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http://dx.doi.org/10.5772/intechopen.70725

1. Introduction

1.1. A laconic antiquity on lithography

Over the last three centuries the term "lithography" (from the ancient Greek *lithos*, meaning "stone," and *graphein*, meaning "to write") has been adopted [1]. And photogravure is a process that uses a stone (in general lithographic limestone) or the smooth surface of a metal plate. The printing technique of lithography was first invented by the German playwright and actor Alois Senefelder in the Kingdom of Bavaria in 1796, and was a viable method for publishing histrionic works [2, 3]. Lithography could be used to pattern a script or artwork on paper or other suitable material [4]. Only the stone parts would absorb the liquid; the design parts repelled it. Rolling on ink consisting of soap, wax, oil, and lampblack, the greasy material, which was coated over the pattern, could not cover the surface that was repelled by moisture in the blank areas. As soon as a sheet of paper was applied over the surface of the stone, a clean impression of the design was produced. Lithography established its popularity throughout the mid-1900s because the process inspired printers to discover additional practical and quicker techniques of printing drawings [5]. The history of lithography came about in four major steps: (1) the invention and early usage of the process; (2) the introduction of photography related to the process; (3) the addition of the offset press corresponding to the process; and (4) the discovery of the lithographic plate [6].

In 1850, the first *steam litho* press was invented by R. Hoe in France and was popularised in the United States in 1868 [7]. Lithographic stones were used to prepare the image and a cylinder covered with a blanket received the image from the plate, which was transformed to the respective substrate. Direct rotary presses used for lithography were comprised of zinc and aluminium metal plates, which were first produced in the 1890s. The first offset press was developed during 1906 by Ira W. Rubel [8] (who was a paper maker). From a press cylinder, an imprint was

S. No.	Techniques	Patterning methods	Optimum environments	Resolution	Merits	Limits	Examples
1.	Microlithography and nanolithography	Creates patterns by structuring material on a fine scale	Vacuum	10 μm and 100 nm	• Efficient and cost effective	• Several processing steps • More complexity	Double/multiple patterning lithography [10, 11]
2.	Contact lithography (CL)	Image printed is obtained by illumination of a photomask in direct contact with a substrate coated with an imaging photoresist layer	Vacuum	~ 100–1000 nm	• Lower-cost process • Stress-free usage	• Oxidation of the metal surface destroys plasmon resonance conditions	Fabrication of metal ring arrays on silicon substrate [12]
3.	Scanning probe microscope (SPM) lithography	A direct-write, maskless approach that bypasses the diffraction limit based on tip–sample interaction	Ambient vacuum or liquid phase	Below 50 nm	• Cost effective • Stress-free usage • Suitable for a wide range of materials • High sensitivity and efficiency	• Controllability and accessibility for large-scale production • Serial patterning	Micrometer-scale SPM local oxidation using the micrometer tip under contact-mode operation [13]
4.	Optical photolithography (OPL)	A lithographic printing process that selectively exposes plates or substrate to UV radiation for the formation of images	Vacuum	Usually at sub-100 nm[4]	• Highly efficient and cost effective • Controls the exact size and shape of the entire substrate • Pattern is parallel in nature	• High operation cost • Multiple processing steps	Structures with silver film were used as the exposure mask [14]
5.	Electron beam lithography (EBL)	Direct writing of structures down to sub-10 nm dimensions, and also facilitating high-volume nanoscale patterning technologies	Vacuum	High resolution up to sub-10 nm (maximum of ≤50 nm)	• Prints complex patterns directly on wafers • Eliminates the diffraction problem • Flexible technique	• Slower than optical lithography • Expensive and complicated	Recent developments in processing, tooling, resist and pattern [15]

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6.	Focused ion beam lithography (FIBL)	Consists of a focused beam of ions that can be operated at low beam currents for imaging or at high beam currents for site-specific sputtering	Vacuum	≤50 nm	• High sensitivity and efficiency • Diffraction effects are minimised • Less backscattering	• High operation cost • Multiple processing steps • Poor accessibility	Structuring approaches of novel patterns [16]
7.	Extreme ultraviolet lithography (EUVL)	Consists of burning intense beams of ultraviolet light that are reflected from a circuit design (semiconductor integrated circuits (ICs)) pattern into a wafer	High vacuum	≤13.5 nm	• Excellent multipattern-ing and additional layers • Eliminates the diffrac-tion problem • With low cycle times enhances yields on preparing IC chips • Helps produce smaller feature size	• Increased cost for new technology • Several processing steps • Complex	Next-generation semiconductor [17]
8.	Light coupling mask nanolithography (LCML)	Consists of a polymer mask placed in contact with the photoresist through transparent regions that protrude through the topographically patterned mask where exposure is required for obtaining the image	Vacuum	≤50–20 nm (365 and 436 nm)	• Lower-cost process • High density High optical resolution	• Wider gap between the mask and the substrate can cause images based on evanescent waves • Oxidation of the metal surface also extinguishes plas-mon resonance	Organic polymers assist amplitude mask for light-based lithographies [18]
9.	X-ray lithography (XL)	Uses X-rays to transfer a geometric pattern from a mask to a light-sensitive chemical photoresist on the substrate	Vacuum	≤20 nm	• Large-area patterning across an A4-size area • Not affected by organic defects in mask • Reduction in diffraction, reflection and scattering effects • Shorter wavelengths (0.1–10 nm)	• Shadow printing • Lateral magnifica-tion error • Brighter X-ray sources needed • More sensitive resists needed	Lithographic beam lines for soft and hard X-ray for micro- and nanofabrication [19]

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10.	Nanoimprint lithography (NIL)	Creates patterns by mechanical deformation of imprint resist and subsequent processes	High vacuum or ambient	Resolution up to ~100 nm	• Low cost • High throughput • High resolution	• Precession issue • Multiple steps for large-scale production	Polymer material (h-PDMS) [20]
11.	Dip-pen nanolithography (DPN)	Direct-write patterning technique based on atomic force microscopy (AFM) scanning probe technology on a range of substances with a variety of inks	Vacuum	Minimum resolution up to ~50 nm	• High density • Lower cost • High-throughput printing through organic and inorganic inks	• Smooth surfaces to work on • Write head can be turned on/off at will	Molecular electronics to materials assembly [12]
12.	Neutral atomic beam lithography	Creates patterns by using a neutral atomic beam to create permanent structures on surfaces	Vacuum	~70 nm	• High-throughput printing • Novel lithographic schemes based on the optical quenching of internal energy	• Multiple steps for large-scale production	Self-assembled monolayers of alkanethiolates on Au and alkylsiloxanes on SiO_2 [21]
13.	Interference lithography	Creates patterns by regular arrays of fine features, without the use of complex optical systems or photomasks	Vacuum	~50 nm	• Quick generation of dense features over a wide area without loss of focus	• Limited to uniformly distributed aperiodic patterns only • Affected by electron interference lithography non-optical effects	3D photonic crystals [22]
14.	Hot-embossing lithography	Creates patterns using polymer or glass substrates to imprint structures created on a master stamp	Vacuum	~50–100 nm	• Low cost • Flexible fabrication • High resolution	• Controllability and accessibility for large-scale production	Polymer-based interdigitated electrodes [23]

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15.	• Projection microstereo-lithography (PμSL) • (3D printing technology)	Creates patterns using rapid photopolymerisation of an entire layer with a flash of UV illumination at microscale resolution; in addition, the mask can control individual pixel light intensity, allowing control of material properties of the fabricated structure with desired spatial distribution	Ambient temperature and atmosphere	~500 μm	• Enables integration of multiple material elements in a single process	• High operation cost • Multiple steps for large-scale production	Lincoln Monument [24]
16.	Charged-particle lithography	Used for creating patterns; the imaging action is mediated by charged particles such as electrons (as in EBL) and ions (as in ion beam lithography).	High vacuum or ambient	~50–100 nm	• High sensitivity and efficiency • Diffraction effects are minimised • Flexible fabrication • High resolution	• Slower than optical lithography • Expensive and complicated	Fabrication of electronic devices and microstructures using high-resolution organic resists [25]
17.	Neutral-particle lithography	Used for creating patterns; a broad beam of energetic neutral atoms floods a stencil mask and transmitted beamlets transfer the mask pattern to resist on a substrate	Vacuum	~50–100 nm	• High resolution • High-throughput printing • Novel lithographic schemes based on the optical quenching of internal energy	• Multiple steps for large-scale production	Bird's-eye view of a 50 nm wide slot [26]
18.	Atomic force microscopic nanolithography or scanning force microscopy (SFM)	The simplest way to attain single structure formation in which the tip is immobilised at a specific surface site, and a large force is then applied to the tip to indent the surface	Ultra-high vacuum (UHV)	~100 nm	• For visualising samples that do not require any special treatments such as metal/carbon coatings • AFM can provide higher resolution than SFM	• Height of 10–20 μm (resolution) • AFM probes cannot normally measure steep walls or overhangs	Development of more complex nanodevices such as single-electron transistors [27]

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19.	Magneto-lithography	Creates patterns based on the magnetic field on a substrate, using paramagnetic or diamagnetic masks, that defines the shape and strength of the magnetic field	High vacuum or ambient	~100 nm	• Simple • High resolution • High-density patterned surfaces	• Less expensive • Multiple steps for large-scale production	Magnetic Fe_3O_4 nanoparticles pattern on a gold thin film [28]
20.	Multibeam or complementary E-beam lithography (CEBL)	Uses multiple miniature columns and vector scanning of shaped beams (critical layers) to boost throughput	UHV	~50–100 nm	• High resolution • High-throughput printing • Novel lithographic schemes based on the optical quenching of internal energy	• Controllability and accessibility for large-scale production	Development of more complex nanodevices [29]
21.	Scattering with angular limitation in projection electron beam lithography (SCALPEL)	Creates patterns with extremely small features in microelectronic circuits. Electrons are projected onto a "mask", which then pass straight through the mask, transferring the image of the mask to the wafer	UHV	~70 nm	• High resolution • Novel lithographic schemes based on the optical quenching of internal energy • High-quality patterned images	• High operation cost • Multiple steps for large-scale production • Controllability and accessibility for large-scale production	For semiconductor manufacturing lithography with feature sizes beyond the capabilities of optical lithography [30]

Table 1. List of various lithography techniques in the nanometer and micrometer range.

inadvertently printed over the impression cylinder's rubber blanket. Once a sheet of paper was run along the press, an intense image was printed on it using the imprint that was being counterpoised on the rubber blanket. A.F. Harris, the inventor of offset lithography, noticed a similar effect. He then established an offset press applicable for the Harris Automatic Press Company in the same year. Harrold and Wright [9] invented the offset process and created the most familiar method of offset lithography from the 1925s to the 1950s using enhanced plates, inks (multicolour), multicylinders, papers, etc. In the late 1950s, offset lithographic printing dominated all other offset printing methods because it produced sharper, clearer images than letterpress and also cost less when compared to engraving. Currently, the mainstream of offset lithographic printing (more than 50%), including newspapers, is mainly produced by using offset printing methods. Lithography, as well as the planographic printing method, makes the best use of the incompatibility of water and grease. In the offset lithographic technique, liquid/powder ink is coated onto a grease-treated image over the flat printing surface; the blank portions that attract moisture repel the lithographic ink. **Table 1** summarises the various lithography techniques in the nanometer and micrometer ranges and the prediction of innovative occurrences [10–31].

2. Next-generation lithography in the new skylines of science and engineering

Fabrication on micro- and nanoarchitectures has opened new horizons in the area of engineering, science and technology. The success of improving and yielding micro- and nanodevices and integrated circuits (ICs) by using photolithography practices is prominently incredible. Nanofabrication is considered as a "gating" technology for the accomplishment of all future advanced nanodevices. Over the past two decades, photolithography had been broadly used for the purpose of microdevices and integrated circuit (IC) technology. However, the wavelength of photons and the search for optics and resistance offered by the materials have limited the resolution of nanostructures prepared from lithography to about 100 nm. In addition, next-generation lithography (NGL) processes, such as maskless, E-beam and direct write lithography, require specific and expert intervention to open up new product/market combinations. The movement towards 450 mm wafers presents its own set of challenges. The larger wafers require new processes, and equipment cost control is a key concern. The equipment needed to support these techniques needs to be as precise and reliable as the chips they make. There are five important candidates for NGL [32] technology to ensure rigorous growth: (1) X-ray proximity, (2) extreme ultraviolet lithography (EUV), (3) ion projection lithography (IPL), (4) scattering with angular limitation projection electron-beam lithography (SCALPEL), and (5) nanoimprint lithography (NIL). NGL technology would be familiarised and alike adept for the probable imminent in a mix-and-match mode along with optical lithography. Continuing developments based on NIL are leading semiconductor manufacturers to use this technological development as a probable auxiliary for optical lithography, but which may be limiting due to its reduced capacity [33, 34]. As a consequence, the existing tumult in the fabrication of novel technological developments is associated with the development of innovative thoughts on the emerging field of nanotechnology, high-power LEDs, nano/micro-ICs and so on.

A maskless NGL tool could meet the following requirements: cycle time, mask cost, removal of the mask input to the compact disk (CD) control, etc. With a comparable industrial price for numerous wafers per mask, there would be a need for this NGL implement by means of no issue whether the manufactured goods is logic, flash, or Dynamic Random Access Memory (DRAM). This trend continues uninterrupted. As followed by Moore's law, it is required to follow the incessant progressions in lithographic steadfastness.

3. Conclusion

In light of the aforementioned discussion, lithography has shown that, with high novel scientific achievements and research, it may outshine other innovative applications for the purpose of common interest. Among the major notable growth areas are the diverse fields of nanotechnology, photovoltaics/solar cells, displays, LEDs and eco-friendly materials. Differences in innovative lithographic printing techniques continue to be improved through novel global progressions in spectral imaging, time-correlated single-photon counting, noninvasive optical biopsy, visual implants and kinetic chemical reaction rates. Hence, research on exclusive lithographic printing technological accomplishments would lead the way to more effective techniques, while coating thin films at the atomic level may turn out to be the ideal printing technology for the future.

Acknowledgements

The authors apologise for inadvertent omission of any pertinent references.

Conflict of interest

The authors declare that there is no conflict of interest related to the publication of this chapter.

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