EXTREME ULTRAVIOLET LITHOGRAPHY

A SEMINAR REPORT

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DECLARATION

I hereby declare that the seminar report **"Extreme Ultraviolet Lithography"** , submitted for partial fulfillment of the requirements for the award of degree of Bachelor of Technology in Electronics and Communication Engineering of the APJ Abdul Kalam Technological University, Kerala is a bonafide work done by me under supervision of Mr. Joby James. This submission represents my ideas in my own words and where ideas or words of others have been included, I have adequately and accurately cited and referenced the original sources. I also declare that I have adhered to ethics of academic honesty and integrity and have not misrepresented or fabricated any data or idea or fact or source in my submission. I understand that any violation of the above will be a cause for disciplinary action by the Institute and/or the University and can also evoke penal action from the sources which have thus not been properly cited or from whom proper permission has not been obtained. This report has not been previously formed the basis for the award of any degree, diploma or similar title of any other University.

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CERTIFICATE

This is to certify that the report entitled **EXTREME ULTRAVIOLET LITHOGRAPHY** submitted by **ABHIJITH S**, to the APJ Abdul Kalam Technological University in partial fulfillment of the Bachelor of Technology degree in Electronics and Communication Engineering is a bonafide record of the seminar work carried out by him/her under our guidance and supervision.

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Abhijith S

Abstract

As we all know, an integrated circuit or chip is one of the biggest innovations of the 20th century it launched many of the technological innovations and revolutions created in silicon valley. at big tech conferences, chip manufacturers will announce they've hit impossibly small new mile stone, like 22nm then 14 nm and 10 nm designs. that means they've found a way to shrink the size and increase the number of features on a chip, which ultimately improves the overall processing power. this is what's been driving the semiconductor industry, which is also called Moore's law. Unfortunately, Moore's Law is starting to fail: transistors have become so small that simple physics began to block the process Moore's law has been predicted to be dying for a long time and yet it never is. because each generation engineers knows it's their expectation to keep working on it, going at a certain pace. EUVL is such an NGL that keeps Moore's law alive

Extreme ultraviolet lithography (also known as EUV or EUVL) is a lithography (mainly chip printing/making aka "fabricating") technology using a range of extreme ultraviolet (EUV) wavelengths, roughly spanning a 2% FWHM bandwidth about 13.5 nm. While EUV technology is available for mass production, only 53 machines worldwide capable of producing wafers using the technique were delivered during 2018 and 2019, while 201 immersion lithography systems were delivered during the same period. Extreme ultraviolet lithography (EUVL) technology and infrastructure development has made excellent progress over the past several years, and tool suppliers are delivering alpha tools to customers. Potential successors to optical projection lithography are being aggressively developed. These are known as "Next-Generation Lithographies" (NGL's). EUV lithography (EUVL) is one of the leading NGL technologies; others include x-ray lithography, ion beam projection lithography, and electron-beam projection lithography. Using extreme-ultraviolet (EUV) light to carve transistors in silicon wafers will lead to microprocessors that are up to 100 times faster than today's most powerful chips, and to memory chips with similar increases

in storage capacity. Significant efforts are also needed to achieve the resolution, line width roughness, and photo speed requirements for EUV photoresists. Cost of ownership and extendibility to future nodes are key factors in determining the outlook for the manufacturing insertion of EUVL. Since wafer throughput is a critical cost factor, source power, resist sensitivity, and system design all need to be carefully considered. However, if the technical and business challenges can be met, then EUVL will be the likely technology of choice for semiconductor manufacturing at the 32, 22, 16 and 11 nm half-pitch nodes

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Chapter 1

INTRODUCTION

After three decades of development, a new generation of lithography machines has now been shipped to large computer chip makers. It uses extreme ultraviolet (EUV) light at a wavelength of 13.5 nm to make silicon features down to a few nanometers in size on the memory chips and processors of tomorrow.with more than 100,000 components, such an EUV lithography system is one of the most complex machines ever built. It is pumped by the most powerful laser system ever made in serial production. In total, it weighs 180 tons and consumes more than 1 MW electrical power. It costs $120 million

Extreme ultraviolet (sometimes also called XUV) denotes soft x-rays with wavelengths between 124 and 10 nm or photon energies between 10 eV and 124 eV. The sun produces EUV; humans create it through synchrotrons, or from plasma. Up until now, chip makers have used ultraviolet light to project complex patterns onto silicon wafers coated with photoresist. In a process analogous to the development of the old paper photos, these patterns are developed and become conducting or isolating structures within one layer. This process is repeated until the complex systems forming an integrated circuit such as a microprocessor are complete.The development of such lithographic systems is driven by economy: Ever more computing power and storage capacity is needed while costs and power consumption must be lowered. This development can be described in a simple rule, well-known as Moore's law

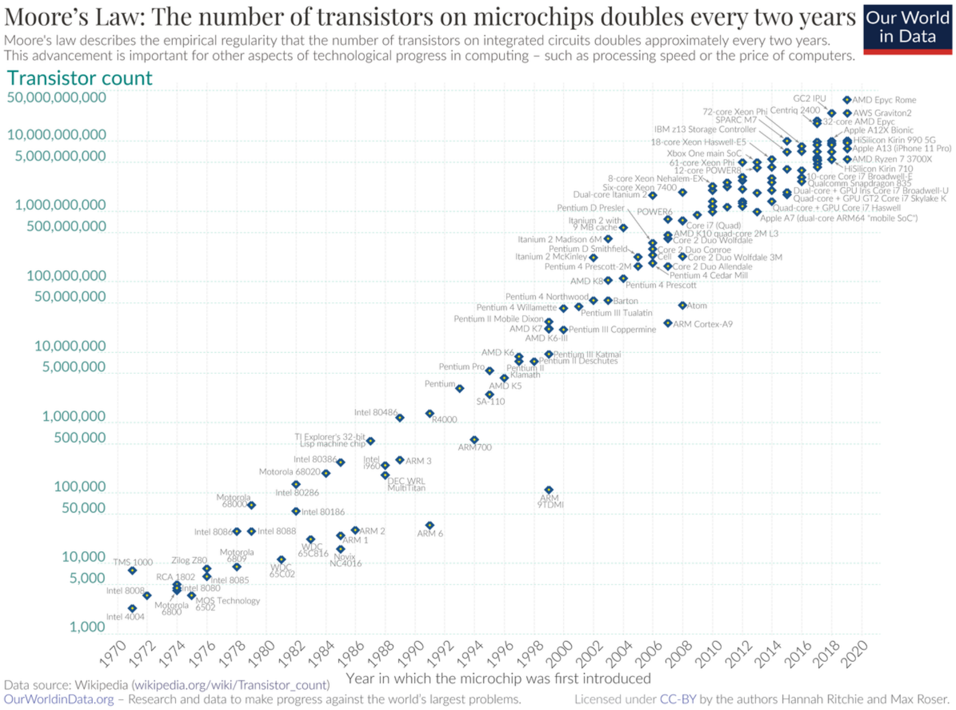

Figure 1.1: Moore's Law Transistor Count

1.1 Moore's Law

Moore's law is an observation and projection of a historical trend. Rather than a law of physics, Moore's law is an expectation it's not like a natural law or something. An expectation that we innovate at a pace of roughly doubling the density of transistors on a IC every two years. All these allow us to offer better products, allow us to offer cheaper products with the same capability and that in turn drives the demand for the overall industry. that means that we've got to be able to cram in, more and more functionality per square millimeter on a chip. all the design and everything have to be smaller in dimensions.

1.2 Photolithography

Photolithography, also called optical lithography or UV lithography, is a process used in microfabrication to pattern parts on a thin film or the bulk of a substrate (also called a wafer). It uses light to transfer a geometric pattern from a photomask (also called an optical mask) to a photosensitive (that is, light-sensitive) chemical photoresist on the substrate. A series of chemical treatments then either etches the exposure pattern into the material or enables deposition of a new material in the desired pattern upon the material underneath the photoresist

This method can create extremely small patterns, down to a few tens of nanometers in size. It provides precise control of the shape and size of the objects it creates and can create patterns over an entire surface cost-effectively. It's main disadvantages are that it requires a flat substrate to start with, it is not very effective at creating shapes that are not flat, and it can require extremely clean operating conditions. Photolithography is commonly used to produce computer chips. When producing computer chips, the substrate material is a resist covered wafer of silicon. This process allows hundreds of chips to be simultaneously built on a single silicon wafer.

1.3 Basic Concept

Major limitation in the lithography process comes from the laws of optics. German physicist Ernst Abbe found that the resolution of a microscope d is (roughly) limited to the wavelength λ of the light used in illumination:

$$d = \lambda/(nsin(\alpha))$$

where n is the refractive index of the medium between the lens and the object and λ is the half-angle of the objective's cone of light. For lithography, substituting numerical aperture (NA) for

$$nsin(\alpha)$$

and adding a factor k to the formula (because lithographic resolution can be strongly tweaked with illumination tricks), the minimum feasible structure, or critical dimension (CD), is:

$$CD = k\lambda/NA$$

This formula, which governs all lithographic imaging processes, makes obvious why the wavelength is such a crucial parameter. As a result, engineers have been looking for light sources with ever-shorter wavelengths to produce ever-smaller features. Beginning with UV mercury-vapor lamps, they moved to excimer lasers with a wavelength of 193 nm.

Chapter 2

EUVL

2.1 Introduction to EUVL

Optical projection lithography is the technology used to print the intricate patterns that define integrated circuits onto semiconductor wafers. Typically, a pattern on a mask is imaged, with a reduction of 4:1, by a highly accurate camera onto a silicon wafer coated with photoresist. Continued improvements in optical projection lithography have enabled the printing of ever finer features, the smallest feature size decreasing by about 30% every two years. This, in turn, has allowed the integrated circuit industry to produce ever more powerful and cost-effective semiconductor devices. On average, the number of transistors in a state-of-the-art integrated circuit has doubled every 18 months. Currently, the most advanced lithographic tools used in high-volume manufacture employ deep-ultraviolet (DUV) radiation with a wavelength of 248 nm to print features that have line widths as small as 200 nm. It is believed that new DUV tools, presently in advanced development, that employ radiation that has a wavelength of 193 nm, will enable optical lithography to print features as small as 100 nm, but only with very great difficulty for highvolume manufacture. Over the next several years it will be necessary for the semiconductor industry to identify a new lithographic technology that will carry it into the future, eventually enabling the printing of lines as small as 30 nm. Potential successors to optical projection lithography are being aggressively developed. These are known as "Next-Generation Lithographies" (NGL's). EUV lithography (EUVL) is one of the leading NGL technologies; others include X-Ray lithography, ionbeam projection lithography, and electron-beam projection lithography. In many respects, EUVL may be viewed as a natural extension of optical projection lithography since it uses short wavelength radiation (light) to carry out projection imaging. In spite of this similarity, there are major differences between the two technologies. Most of these differences occur because the properties of materials in the EUV portion of the electromagnetic spectrum are very different from those in the visible and UV wavelength ranges. The purpose of this paper is to explain what EUVL is and why it is of interest, to describe the current status of its development, and to provide the reader with an understanding of the challenges that must be overcome if EUVL is to fulfill its promise in high-volume manufacture.

EUVL technology is an advanced technology with a light source of 13.5 nm, which is extremely short wavelength and can be applied for beyond the 10 nm node. EUVL enables the use of only one mask exposure instead of multiexposure. However, there are still three issues to be solved before this technique can be applied in mass production: a light power source, resists, and mask infrastructure. Among these issues, to make such a lithography tool, economical production capacity and producing a stable light source are the most difficult issues to be solved. For a wafer-per-hour (WPH) up to 125 in the 12-inch production line, a light source power of 200 W is needed and EUVL has to satisfy this requirement. The development of resist material is one of the critical technical issues of EUVL. This material is necessary to have the excellent characteristics: high resolution, high sensitivity as well as low line-edge roughness (LER) and low outgassing simultaneously. When EUVL continues to move toward mass production manufacturing, the availability of a defect-free reflective photomask is also one of the critical challenges which needs to be considered. EUV's photomasks work in reflective mode. To produce these masks would introduce new materials and surfaces, which might cause high particle adhesion on the surface of masks, creating a cleaning issue. Therefore, a special pellicle is designed to protect the mask from particles adhesion when the EUV scanner is in use.

However, an EUV mask with a pellicle has still some remaining issues to be solved. These issues are also addressed: the stress of the protective film module may cause an overlay shift; it may also prevent the film from light absorbing, and the mask inspection can be limited to photochemical light, which reduces the valuable EUV power. In addition to EUV technology, very extremely short wavelength techniques such as using the X-ray lithography (XRL) with 1 nm wavelength and deep X-ray lithography (DXRL) with 0.1 nm wavelength are under development and they belong to next-generation lithography (NGL), which may provide a solution for technology node beyond 5 nm in future.

2.2 Why EUV ?

In order to keep pace with the demand for the printing of ever smaller features, lithography tool manufacturers have found it necessary to gradually reduce the wavelength of the light used for imaging and to design imaging systems with ever larger numerical apertures. The reasons for these changes can be understood from the following equations that describe two of the most fundamental characteristics of an imaging system: resolution (RES) and depth of focus (DOF). These equations are usually expressed as

$$RES = k_1\lambda/NA$$

$$DOF = k_2\lambda/(NA)^2$$

where l is the wavelength of the radiation used to carry out the imaging, and NA is the numerical aperture of the imaging system (or camera). These equations show that better resolution can be achieved by reducing l and increasing NA. The penalty for doing this, however, is that the DOF is decreased. Until recently, the DOF used in manufacturing exceeded 0.5 mm, which provided for sufficient process control. The case $k_1 = k_2 = \frac{1}{2}$ corresponds to the usual definition of diffraction-limited imaging. In practice, however, the acceptable values for k_1 and k_2 are determined experimentally and are those values which yield the desired control of critical dimensions (CD's) within a tolerable process window.

Camera performance has a major impact on determining these values; other factors that have nothing to do with the camera also play a role. Such factors include the contrast of the resist being used and the characteristics of any etching processes used. Historically, values for k_1 and k_2 greater than 0.6 have been used comfortably in high-volume manufacture. Recently, however, it has been necessary to extend imaging technologies to ever better resolution by using smaller values for k_1 and k_2 and by accepting the need for tighter process control. This scenario is schematically diagrammed in Figure 2.1, where the values for k_1 and DOF associated with lithography using light at 248 nm and 193 nm to print past, present, and future CD's ranging from 350 nm to 100 nm are shown. The "Comfort Zone for Manufacture" corresponds to the region for which $k_1 > 0.6$ and DOF > 0.5 mm. Also shown are the k_1 and DOF values currently associated with the EUVL printing of 100 nm features, which will be explained later. As shown in the figure, in the very near future it will be necessary to utilize k_1 values that are considerably less than 0.5. Problems associated with small k_1 values include a large iso/dense bias (different conditions needed for the proper printing of isolated and dense features), poor CD control, nonlinear printing (different conditions needed for the proper printing of large and small features), and magnification of mask CD errors. Figure 2.1 also shows that the DOF values associated with future lithography will be uncomfortably small. Of course, resolution enhancement techniques such as phase-shift masks, modified illumination schemes, and optical proximity correction can be used to enhance resolution while increasing the effective DOF. However, these techniques are not generally applicable to all feature geometries and are difficult to implement in manufacturing. The degree to which these techniques can be employed in manufacturing will determine how far optical lithography can be extended before an NGL is needed.

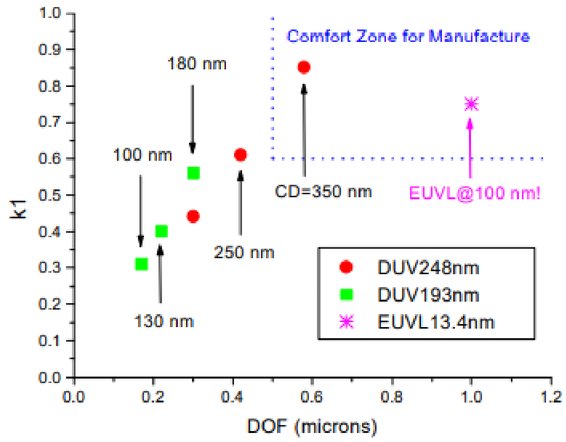

Figure 2.1: The k_1 and DOF values associated with 248 nm and 193 nm lithographies for the printing of CD values ranging from 350 nm down to 100nm assuming that $k_2 = k_1$ and NA $= 0.6$

EUVL alleviates the foregoing problems by drastically decreasing the wavelength used to carry out imaging. Consider Figure 2.2. The dashed black line shows the locus of points corresponding to a resolution of 100 nm; the region to the right of the line corresponds to even better resolution.

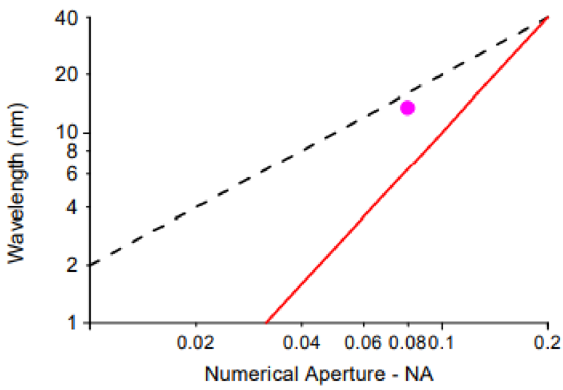

Figure 2.2: The region between the lines shows the wavelength and numerical aperture of cameras simultaneously having a resolution of 100 nm or better and a DOF of 0.5 mm or better

The solid red line shows the locus of points for which the DOF is 0.5 mm; in the region to the left of that line the DOF values are larger. Points in the region between the two lines correspond to situations in which the resolution is 100 nm or better, and the DOF is 0.5 mm or longer. As shown, to be in this favorable region, the wavelength of the light used for imaging must be less than 40 nm, and the NA of the imaging system must be less than 0.2. The solid circle shows the parameters used in current imaging experiments. Light having wavelengths in the spectral region from 40 nm to 1 nm is variously referred to as extreme uv, vacuum uv, or soft x-ray radiation. Projection lithography carried out with light in this region has come to be known as EUV lithography (EUVL). Early in the development of EUVL, the technology was called soft x-ray projection lithography (SXPL), but that name was dropped in order to avoid confusion with x-ray lithographyy, which is a 1:1, near contact printing technology

As explained above, EUVL is capable of printing features of 100 nm and smaller while achieving a DOF of 0.5 mm and larger. Currently, most EUVL work is carried out in a wavelength region around 13 nm using cameras that have an NA of about 0.1, which places the technology well within the "Comfort Zone for Manufacture" as shown in Figure 1 by the data point farthest to the right.

2.3 Working

working: EUVL is a significant departure from the deep ultraviolet lithography standard. Attached to the EUV scanner, the source consists of a droplet generator, collector and a vacuum chamber. In EUV, the process takes place in a vacuum environment, because nearly everything absorbs EUV light. All optical elements, including the photomask, must use defect-free molybdenum/silicon (Mo/Si) multilayers (consisting of 40 Mo/Si bilayers) that act to reflect light by means of interlayer interference; any one of these mirrors absorb around 30% of the incident light.

The source of the light is a tiny little droplet of tin. they're smaller than the diameter of a human hair in which we fire across the vessel and then we intercept those with a pulsed laser beam of very high power and have to hit with an accuracy of just a few microns The droplets are 25 microns in diameter and are falling at a rate of 50,000 times a second

In the vessel, there is a camera. A droplet passes a certain position in the chamber. Then, the camera tells the seed laser in the sub-fab to fire a laser pulse into the main vacuum chamber. This is called the pre-pulse

Then comes the really hard part. The pre-pulse laser hits the spherical tin droplet and turns it into a pancake-like shape. Then the laser unit fires again, representing the main pulse. The main pulse hits the pancake-like tin droplet and vaporizes it.

At that point, the tin vapor becomes plasma. The plasma, in turn, emits EUV light at 13.5nm wavelengths

The goal is to hit a droplet with precision This determines how much of the laser power gets turned into EUV light, which is referred to as conversion efficiency

this video illustrates the process There's a collector mirror that collects that light and sends it into the scanner. then there are four mirrors that essentially shape that light into a slit that bounces off the reticle. The light bounces off the collector and travels through an intermediate focus unit into the scanner then you will see a reticle stage doing this, and a wafer stage doing this Video

and what's happening is step and scan. which basically means we continue to reproduce that particular pattern over and over again

EUV light is propelled into the scanner. In the scanner, the light bounces off a complex scheme of 10 surfaces or multi-layer mirrors. First, the light goes through a programmable illuminator. This forms a pupil shape to illuminate the right amount of light for the EUV mask.

Then, EUV light hits the mask, which is also reflective. It bounces off six multi-layer mirrors in the projection optics. Finally, the light hits the wafer at an angle of 6

EUV photomasks work by reflecting light, which is achieved by using multiple alternating layers of molybdenum and silicon. This is in contrast to conventional photomasks which work by blocking light using a single chromium layer on a quartz substrate. An EUV mask consists of 40 alternating silicon and molybdenum layers; [7] this multilayer acts to reflect the extreme ultraviolet light through Bragg diffraction; the reflectance is a strong function of incident angle and wavelength, with longer wavelengths reflecting more near normal incidence and shorter wavelengths reflecting more away from normal incidence. The pattern is defined in a tantalum-based absorbing layer over the multilayer. The multilayer may be protected by a thin ruthenium layer.

Current EUVL systems contain at least two condenser multilayer mirrors, six projection multilayer mirrors and a multilayer object (mask). Since the mirrors absorb 96% of the EUV light, the ideal EUV source needs to be much brighter than its predecessors. EUV source development has focused on plasmas generated by laser or discharge pulses. The mirror responsible for collecting the light is directly exposed to the plasma and is vulnerable to damage from high-energy ions and other debris[19] such as tin droplets, which require the costly collector mirror to be replaced every year.

Very precise extremely flat micro-mirrors to focus the light onto the silicon wafer to produce even finer feature widths.

2.4 EUVL mask

Photoresists are a critical part of lithography. Resists are light-sensitive materials. They form patterns on a surface when exposed to light. For EUV, they are critical. The basic requirements for EUVL resist are sensitivity, resolution, Line Width Roughness (LWR) or Line Edge Roughness (LER), outgassing, a pattern cross-sectional aspect ratio and profile, etch resistance, defect density, and reproducibility. Among them, it is a critical challenge to meet the requirements simultaneously on resolution, LWR, and sensitivity (RLS). EUVL uses Chemically Amplified Resist (CAR) due to the advantages of high sensitivity and resolution, but its LWR is relatively high, which becomes a significant issue. For the 22 nm feature, LWR should be controlled below 2 nm, which is about half of the current best available values

Chapter 3

CONCLUSION

The EUV scanner is the most technically advanced tool of any kind, that's ever been made. It's so far from normal human experience from my understanding There's an insatiable amount of data, so you can build chips to store data, move data around. the whole cloud is lots and lots of doing all three of those things. there's a lots of processing power needed in the field of science and research field area, like as in case of particle accelerators and they're going to accelerate trillions of events every second. And there's no way to make sense of all of that even with this generation of computers. so you have to go build ever faster computers , large data storage, just to make sense of the science that's going on. part of predicting the future is around diagnosing trends in technology.

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