

Electron Beam and X-Ray Lithography

An essential procedure in the production of integrated circuits is lithography. Lithography is the process of transferring geometric design patterns from a mask onto a silicon wafer. There are several forms of lithography, such as photolithography, which uses UV light to expose the design pattern on the wafer surface. While photolithography has been successful in the industry, several alternative forms of lithography have come about that do not rely on the use of UV light, such as electron beam lithography and X-Ray lithography. Both processes possess unique procedures which have their advantages and disadvantages.

Electron beam lithography is a modern technology that uses beam of electrons that are extracted, focused and accelerated to 20kv. The three major sources of electrons are thermionic emitters, photo emitters, and field emitters. Currently, electron beam lithography is used principally in support of the integrated circuit industry. Its flexibility makes it ideal for making masks that can be used by other technologies including x ray lithography. It is also used for writing complex patterns directly on wafers. Procedures involved in electron beam lithography are almost similar with that of photolithography. Both technologies use different photo resist and chemicals to develop the exposed section. The most commonly used electron beam photo resist is polymethylmethacrylate (PMMA). PMMA breaks down into monomers upon exposure to electrons, which is later developed using a chemical called methyl-isobutyl-ketone (MIBK).

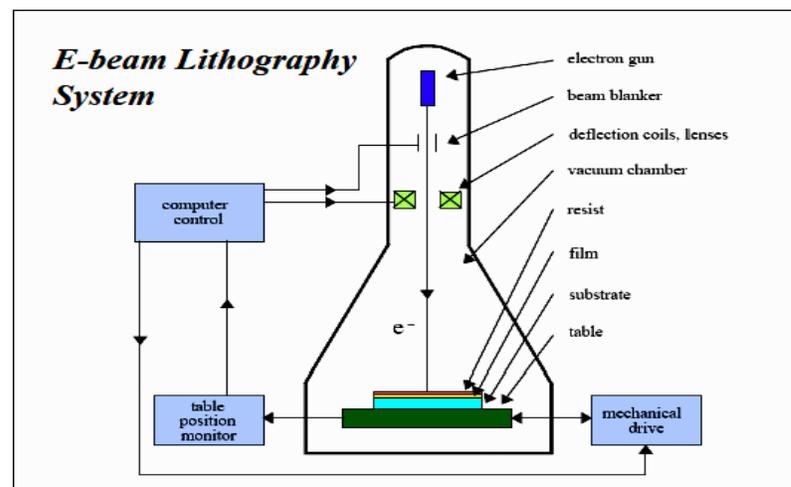


Fig. 1 - Electron Beam Lithography System

There are several advantages of using Electron beam lithography over photolithography. First and for most, it has high resolution up to 20 nm. Secondly, it can print complex computer generated patterns directly on the wafer. It is a very flexible technique that can work with a variety of materials and an almost infinite number of patterns. Some of its disadvantages include: it is very expensive and complex with high maintenance cost, forward scattering and back scattering problems, and slower speed. As the electrons penetrate the resist, some fraction of them will undergo small angle scattering. This forward scattering problem can result in a significantly broader beam profile at the bottom of the resist than at the top.

There are three important parts of electron beam lithography (EBL) machine: the electron gun, vacuum system, and control system. Electrons are emitted from a filament tip and are attracted to an

anode. The electrons emitted are focused into a beam using electromagnetic lenses, which defines the diameter of the spot size of the beam. Electromagnetic plates are also used to correct astigmatism that might occur when focusing the beam. The vacuum system is a crucial part of the EBL, because it isolates the beam from any outside interference.

X-ray lithography is another modern form of lithography in addition to electron beam lithography. X-ray lithography transfers the geometric patterns from a mask to the surface of the silicon wafer through the use of collimated (parallel) X-rays rather than the use of UV light. Similar to photolithography, photoresist is applied to the surface of the silicon wafer prior to exposure. However, due to the use of X-rays, the masks needed for this process are designed with unique materials and are thinner than those used in the photolithography process. Typically, X-ray mask membranes are made of elements with low atomic numbers because elements with high atomic numbers, such as gold, have a high X-ray mass attenuation coefficient, which means they are able to absorb X-ray radiation. The membrane allows X-rays to go through the mask and expose the surface of the silicon wafer. On the membrane, an absorber is placed to take in radiated X-rays and shift them to the proper location. Similar to electron beam lithography, X-ray lithography uses PMMA as the photoresist, which is able to harden on contact with the X-ray. Etching processes allow unwanted regions in the pattern to be removed. In addition, like photolithography, X-ray lithography requires a gap between the mask and the silicon wafer surface.

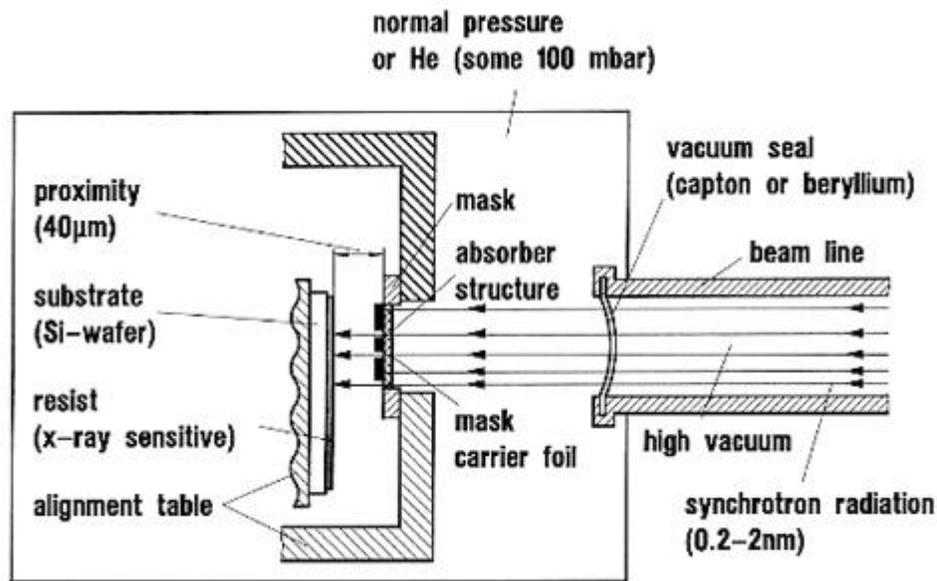


Fig. 2 – X-Ray Lithography System

Like electron beam lithography, X-ray lithography has many advantages and disadvantages. One advantage of X-ray lithography is that X-rays have shorter wavelengths than UV light (approximately 0.4 to 4 nanometers), which allow for greater more energy to be carried and therefore a higher lateral resolution. With an increase of lateral resolution, X-rays do not suffer from diffraction issues that are common in UV light during photolithography. With the reduction of diffraction, the X-ray mask can be placed further away from the silicon wafer, compared to the gap distance in the photolithography process. With a greater gap, masks have a greater life span. In addition, smaller wavelengths allow for greater precision, allowing for smaller designs to be produced on silicon wafers. Also, X-rays have a uniform refraction pattern, which reduces the chances of X-rays scattering to unwanted regions of the wafer during the exposure process.

A major disadvantage of X-ray lithography is the X-ray mask. The mask membrane must be made very thin and internal stress could result in distortion of the absorber. In addition, unlike UV light, X-rays cannot be focused through a lens. In photolithography, a lens is used to focus UV light and create proportionally smaller designs on the wafer than the size of the designs on the mask. In X-ray lithography, the size of the designs on the mask will be the size of the designs on the wafer. This means that in order to produce small designs on the silicon wafer, one must create equally small designs on the mask. Also, the mask is quite expensive to produce. The membrane uses materials that have small atomic attenuation coefficients, such as diamond. The absorber must use materials with high attenuation coefficients, such as gold.

X-ray lithography has primarily been used in the field of nanolithography. With the small wavelength of X-rays, X-ray lithography is able to create small feature sizes on silicon wafers. This will allow for a greater number of transistors to be produced on a single silicon wafer compared to what can be produced in photolithography. The cost of X-ray lithography is cheaper than that of electron beam lithography. Also, the entire lithographical process is much faster using the X-ray system than the electron beam system. This makes X-ray lithography a good alternative for high-volume integrated circuit fabrication.

Electron beam and X-ray lithography are two modern alternative forms of lithography. While photolithography relies on UV light to expose its photoresist substrate, electron beam and X-ray lithography utilize electron beams and X-rays respectively in their lithographical processes. Electron beam lithography is quite expensive, and has been primarily used to design masks for X-ray lithography. However, it does not require the use of a mask, and is able to print design patterns directly on the surface of silicon wafers with great resolution. X-ray lithography is a much more efficient process compared to electron beam lithography; however an expensive and thin X-ray mask brings down its overall appeal. Advances are being made with both processes, and in the near future, it will come as no surprise to see cheaper forms of both lithographical processes that will be more lucrative to the integrated circuit industry.

Work citation

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