**Group Activity 2: E-beam Lithography vs. X-ray Lithography**

Electron Beam Lithography is an alternative process that can be used to fabricate electronic devices on the micro and nanoscale. E-beam lithography uses a beam of focused electrons to directly expose the resist, creating a pattern on the substrate. 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. The pattern is created using a computer aid design program. There are two different methods used to write the pattern: raster scanning and vector scanning. Raster scanning involves exposing the beam in the horizontal direction at a specific rate and moving the wafer using a controlled stage. The beam turns on and off so this process can be repeated over the entire wafer. Vector scanning involves the ability to deflect the beam to the areas on the wafer that need exposure.

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Fig.1 E-beam Lithography machine diagram  
Fig.2 Electron gun diagram

There are several advantages of using e-beam lithography over photolithography and x-ray lithography. The most important advantage is the resolution of the critical dimension. The resolution, using photolithography, is limited due to diffraction. Since e-beam lithography is not an optical process, the resolution is not limited by diffraction, so the features of the pattern can be written on the nanoscale. Another advantage of e-beam processing is the ability to control energy and the beam dosage when exposing the resist. Since e-beam lithography is costly, it is mainly used to make masks used in photolithography, and developing specialized prototype devices. One solution to cut down on the cost of an e-beam machine is to convert a scanning electron microscope (SEM). E-beam lithography may be one process that will assist in developing advanced processing techniques and equipment for the future.
Even though e-beam lithography produces more precise patterns, there are also some disadvantages involved with the process. This process is not efficient for manufacturing microelectronics on an industrial level because of the time involved in e-beam patterning the entire wafer. While photolithography only takes a few minutes to pattern a wafer, using an e-beam process will take several hours. Another drawback is that the system has to be held in a vacuum. This makes the equipment for e-beam processing more complex as well as expensive. For an example, an e-beam system can cost more than four million dollars. Scattering of the beam is another disadvantage that influences the resolution of spot size. The e-beam can scatter through the resist, which exposes more of the resist than intended. Backscattering of the electrons from the substrate can also cause overexposure.

X-ray lithography is a process for transferring patterns from masks to silicon wafers using electromagnetic radiation such as X-ray instead of visible radiation such as ultraviolet light. The process is much like photolithography; however, X-ray masks are thinner than photolithography masks. Also, during the transferring process, the mask and silicon wafers are microns apart, not touching as they are in photolithography.

![Fig.3 X-ray lithography](image)

Since a different kind of radiation is used, X-ray resists must be placed on the silicon wafers instead of electron or photoresists. X-ray resists are more sensitive and are very thin, usually on the scale of 2 micrometers. Different X-ray masks must also be used for X-ray lithography. These masks are made of silicon carbide as the membrane material because they can endure long expose to X-rays and compounds of tantalum as the absorber material because they are compatible with numerous etching and cleaning process.

An advantage of X-ray lithography is that it uses shorter wavelengths to solve diffraction limits of photolithography. As of today, the limit on photolithography is a wavelength of 193 nm. Although this wavelength can be used to create 130 nm transistors, a smaller wavelength of X-ray lithography can be used to create even smaller transistors. The wavelength used in X-ray lithography is usually in the range of 0.1-10 nm. This reduces the size of transistors down to 17 nm. Another advantage deals with the refraction properties of x-rays. X-rays have an index of refraction near unity; this means that the reflection of x-rays is negligible. It helps decrease the “spurious splattering” of x-rays to unwanted areas of the silicon wafer.

A disadvantage of X-ray lithography is the X-ray mask. Since X-ray masks are very thin, they can easily deform or bend and they are more susceptible to vibrations during the masking process. Deformation is a problem for X-ray lithography because transferring patterns on the mask and the silicon wafers are one to one. So if the masks are slightly deformed, they cannot be used as the patterns will be skewed from the silicon wafer. Vibrations are an issue because during the transferring process, vibrations can cause the mask to move from their alignment. If the masks are not aligned with the silicon wafer, the transistors on the wafers will not work. Another
disadvantage of X-ray masks is that they take a very long time to make. Since conventional electron beam machines are used to make the masks, it can take days or even weeks to carve the small features of a transistor onto a mask.

![Diagram of X-ray mask](image)

**Fig. 4 X-ray mask**

The main application of X-ray lithography is to improve nanolithography. With current procedures of lithography focusing on microlithography, X-ray lithography plans on moving the fabrication process into the next stage, which is nanolithography. With shorter wavelengths, X-ray lithography can create smaller features on transistors. This means that more transistors can fit on a single silicon wafer. X-ray lithography will help in keeping up with Moore’s law to increase the number of transistors on a silicon wafer.

Both E-beam and X-ray lithography are alternative processes used to fabricate silicon wafers. They use more advance procedures to create smaller and more precise devices. While they both have advantages and disadvantages, these processes will be used to develop the next generation of fabrication techniques and equipment.
References


