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Current Status and Future of ULSI Lithography

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Abstract

In the past 10 years, the development in optical lithography has been dramatic. However optical lithography is now facing major limitations in resolution and depth of focus. This paper describes current status and future of various lithography technologies. Several innovative ideas to overcome the limitation in optical lithography and other lithography technologies such as high throughput electron beam system and reduction projection X-ray lithography are introduced.

1. Introduction

According to the development of ULSI devices, the minimum feature size of the ULSI patterns has been reduced to sub-micron level. Through this development, optical lithography plays an important role. However, optical lithography is now facing the ultimate resolution limitation, due to wavelength. In addition, there is a serious problem in the focus latitude of the optical lens system. The focal depth of the newest lens system is almost the same as the surface profile of the device. Therefore, we must select the most appropriate lithographic system for the next generation ULSI devices. Many other lithographic technologies have been developed during the past 10 years. There are also many innovative ideas to overcome the resolution limitation in optical lithography.

In this paper, the details of new lithographic technologies and new innovative ideas to overcome the limitation in optical lithography will be discussed.

2. Current status and future of various lithography technologies.

2.1 Optical Lithography

The development of optical Lithography technology has been heavily dependent on the development of the optical lens system. The resolution of a reduction projection system is derived from the well-known Rayleigh's relation as shown below.

$$R= k_1 x\ l/NA$$

Depth of focus is also derived from the next expression.

$$DOF=k_2 x\ l/(NA)^2$$

Figure 1 shows the development of the optical system. A higher numerical aperture (NA) with larger field size lens systems were

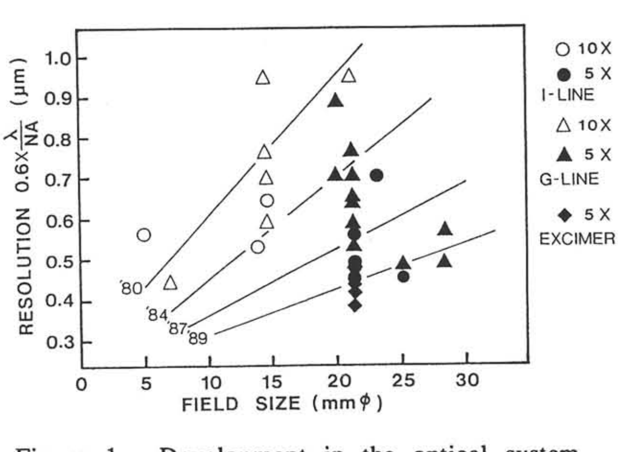


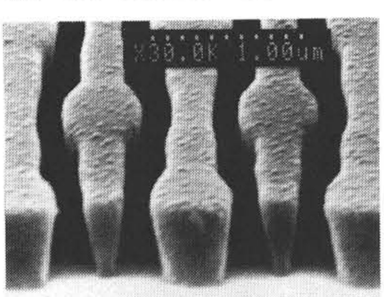
Figure 1, Development in the optical system.

sought during the past 10 years. However as shown in the above expression, the depth of focus decreases rapidly with increasing NA. Higher resolution was obtained by sacrificing depth of focus. As a result, the depth of focus has become almost equivalent to the surface profiles of the device. The remaining key issue of optical lithography is how to improve the resolution capability maintaining the depth of focus.

Using a shorter wavelength with a smaller NA is one way to achieve an improved resolution. The use of 365nm (i-line of mercury lamp) has already been attempted in an industrial environment. A half-micron or smaller pattern can be obtained using an i-line exposure. Much shorter wavelengths such as 248nm (KrF excimer laser light) or 193nm (ArF) have also been investigated intensively. [1],[2]

Various other approaches such as the FLEX and phase shifting technique have also been investigated.[3],[4] FLEX method realizes a very large depth of focus even though it uses a large NA lens system on isolated transparent patterns. With this method, several pattern images are created on the same light axis by multiple exposures. On the other hand, the phase shifting technique realizes higher resolution and a larger depth of focus on periodical patterns. It utilizes not only the light intensity information of pattern images but also their phase information.

These new techniques can be applied to both conventional and excimer laser sources. Figure 2 shows 0.17μm patterns delineated by a KrF excimer laser stepper using the phase shifting technique. This result shows the application possibility of these methods to 0.2μm technology by optical lithography.



NA:0.42 (NIKON)

Figure 2, 0.17μm pattern delineated by KrF Excimer stepper using phase shifting technique.

2.2 Electron Beam Lithography

Electron beam lithography is capable of achieving very high resolution. However, it has not widely been applied to ULSI fabrication. The reason is due to its poor throughput capability. To improve the throughput, various modifications to the exposure system has been performed. A major improvement is the change in the beam shape.

A point beam system was developed first. It had a very high resolution capability although the throughput was very low. Subsequently,a variably shaped beam system was later developed to obtain a larger beam size.[5] A variably shaped beam system can create a rectangular pattern of a certain size up to 25μm^2 with only one exposure shot. By the development of this system, the throughput was improved significantly.

With respect to the advancement of ULSIs, the minimum feature size has been reduced greatly and the number of patterns on a chip has been increased markedly. In 64Mb DRAMs, the minimum feature size of a pattern is almost equivalent to the beam size of the point beam system. There is no advantage concerning the increase in beam size by a variably shaped beam system any more. To overcome this situation, a new cell projection procedure was proposed recently.[6] This procedure utilizes a specially tailored aperture which has patterns that coincide with those of memory cell array. Figure 3 shows the basic idea of a cell projection system. With this system the number of exposure shots for the memory pattern can be drastically decreased . It also has a capability of making variably shaped beam exposures to create random patterns such as a peripheral

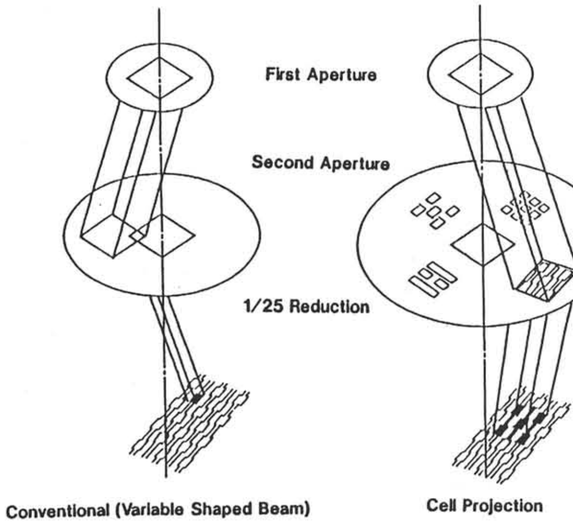


Figure 3, The basic idea of Cell-Projection Procedure.

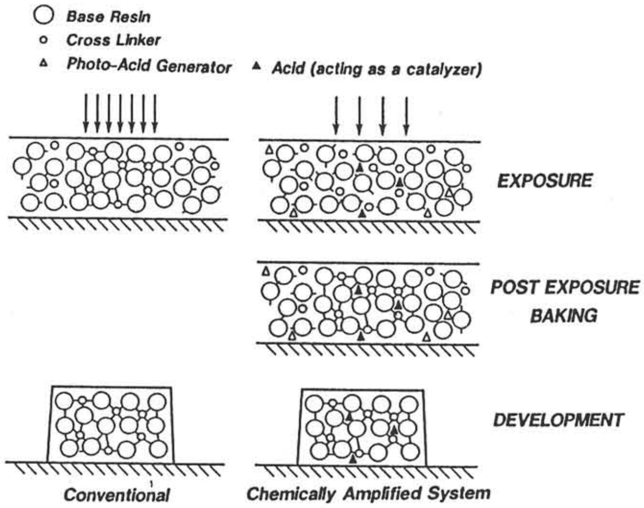


Figure 4, Chemical amplification resist system.

circuit pattern. Utilizing this exposure concept, the throughput of the electron beam system can be improved drastically.

Resist sensitivity also relates to throughput capability. Recently, a chemically amplified resist system was developed.(7) This system achieves higher sensitivity than that of conventional resist system by using an acid catalyzed system. Figure 4 shows the basic concept of this system. This new resist system is composed of three components: base resin, crosslinker, and acid generator. An acid generator generates acid by the irradiation of electron beam. Acid acts as a catalyst in the cross linking reaction at the baking stage following the exposure. Note that the quantity of acid can be very small for a catalytic reaction. Consequently, the electron beam dose can also be minimized.

Applying highly sensitive resist materials to the cell projection system, the throughput capability of an electron beam system can be equivalent to that of an optical system.

2.3 X-ray Lithography

X-ray Lithography also has a very high resolution capability. A conventional X-ray lithographic system is a proximity printing system. As this system utilizes a 1:1 mask, the fabrication of a precise mask is the key issue for this technology. The distortion of the mask membrane and the absorber pattern placement error due to the electron beam exposure error relate directly to the alignment accuracy.

The type of X-ray source is also a key issue for the X-ray technology. There are several candidates for the source. Synchrotron radiation source (SR or SOR) shows the highest capability from a technical standpoint. For industrial use, equipment cost and large foot print are big problems.

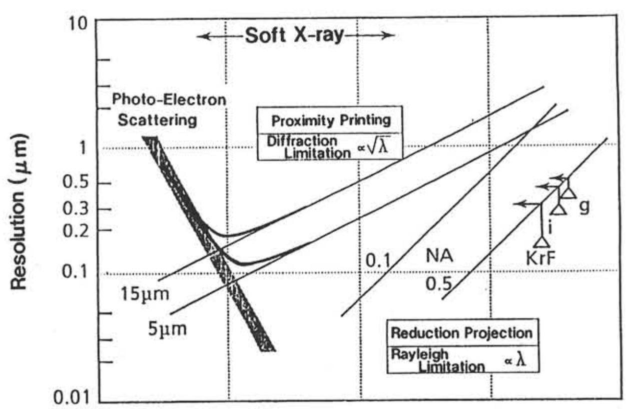


Figure 5, The relation between resolution and wavelength.

The resolution limitation of 1:1 X-ray lithography is mainly determined by the Fresnel diffraction. The resolution R is derived from the next expression.

$$R = k3 \times \sqrt{\lambda \times s}$$

where s is the separation between wafer and mask. Figure 5 shows the relation between resolution and wavelength. Resolution of the reduction system is also shown in this figure.

When a 1 nm or shorter wavelength X-ray generates photo or Auger electrons, the resolution can not be determined by Fresnel diffraction. Instead, the scattering range of these electrons determines the resolution. From this, it is apparent that the resolution of X-ray proximity printing can not be improved by shortening the wavelength. The minimum resolution seems to be around 0.1 μm in a proximity printing system.

X-ray reduction projection will be one solution to obtain higher resolution in the future. Recently, promising experimental results of X-ray reduction were reported. Figure 6 shows an experimental reduction system using Schwarzschild optics, 0.1 μm resolution has already been obtained by this method.[8] This result shows a possibility of realizing a production tool for 0.1 μm ULSI technology.

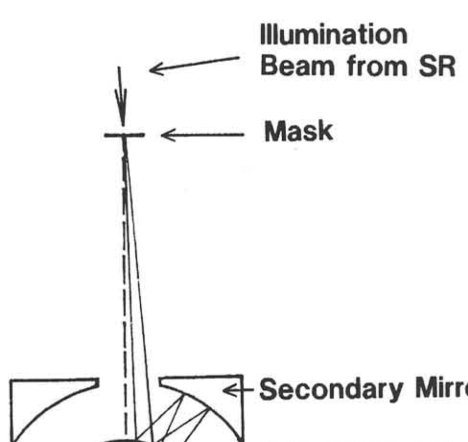


Figure 6, Schwarzschild type objective for X-ray reduction projection.

3. Summary

Optical lithography has been widely used for ULSI fabrication. However, it is facing a big problem concerning the resolution improvement. Many ideas to overcome this obstacle were proposed. However, up to now no perfect solution has been found. Other lithographic technologies such as electron beam and X-ray have a possibility to overtake optical lithography in the area of ULSI fabrication. X-ray lithography using 1:1 printing was thought to be the greatest candidate for the development of the next generation of ULSI devices. However,this method still has big problems. In addition, it is approaching its resolution limit. Electron beam lithography using the cell projection method and an X-ray reduction projection system has become a great candidate for the development of ULSI devices smaller than 0.3 μm.

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