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Critical Illumination Condenser for Extreme Ultraviolet Projection Lithography

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Critical illumination condenser
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Abstract

A condenser system couples a radiation source to an imaging system. We have designed a critical illumination condenser system which meets the technical challenges of extreme ultraviolet projection lithography based on a ring field imaging system and a laser produced plasma source. The optical system, a three spherical mirror optical design, is capable of illuminating the extent of the mask plane by scanning either the primary mirror or the laser plasma source. This type of condenser optical design is sufficiently versatile to be employed with two distinct systems, one from Lawrence Livermore National Laboratory and one from AT&T/Sandia.

Introduction

In photo-lithography, a condenser optical system couples radiation from a source to illuminate a mask plane which is relayed onto a wafer by an imaging system (see Figure 1). There are two types of condenser illumination systems. A Köhler illumination condenser images the source plane onto the entrance pupil of the imaging system while the aperture stop of the condenser is imaged onto the mask plane. A critical illumination condenser images the source onto the mask plane while the aperture stop of the condenser is relayed to the entrance pupil of the imaging system.

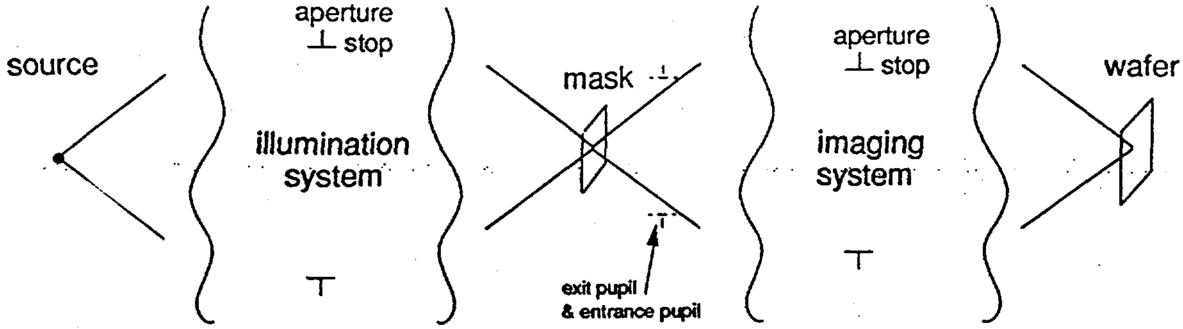
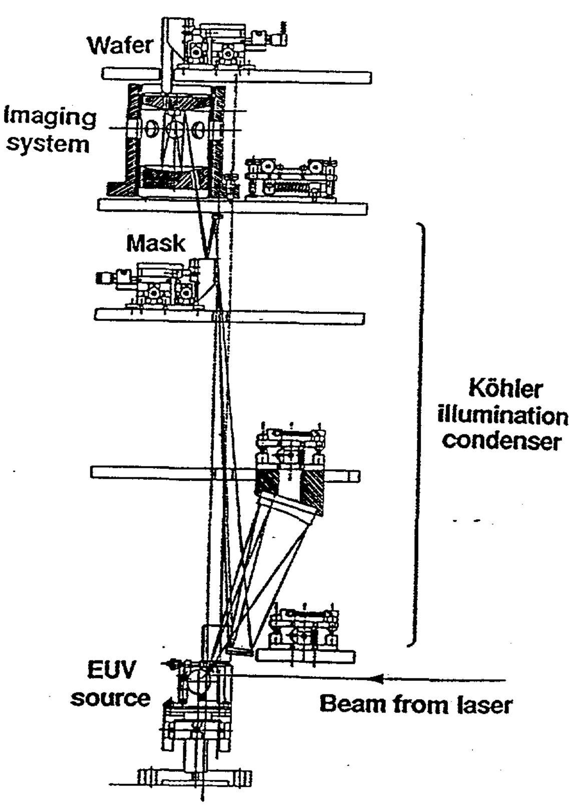


Figure 1: schematic of EUV lithography system.

Lawrence Livermore National Laboratory currently operates an extreme ultraviolet projection lithography (EUV) system with a Köhler illumination condenser[1,2]. Figure 2 is a schematic of this system. A laser beam (laser driver) incident upon a tin rod generates EUV radiation[3,4], in the 13nm regime, which is collected by a three spherical mirror Köhler illumination system. This radiation is directed toward a reflective mask which is imaged onto the wafer plane by the imaging system. The optical system is a ring field imaging system, where the image of the mask at the wafer is only acceptable over a ring shape which in this case is 4.5mm wide with an inner diameter of 75.1mm. A comparison is desired between the Köhler illumination condenser system and a critical illumination condenser using this same ring field imaging system. The design of a critical illumination system which meets the challenges associated with EUV lithography and works with the current imaging system was undertaken and the results are described here.



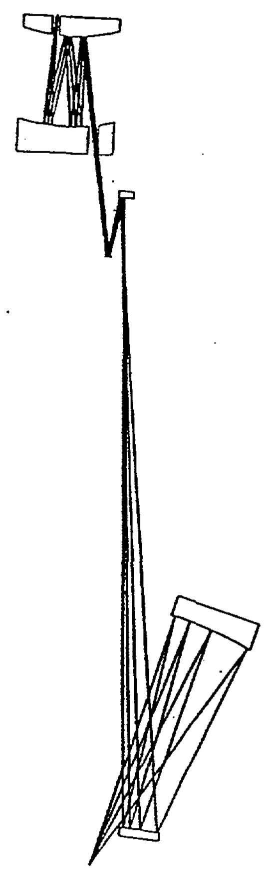


Figure 2a: Current LLNL EUV lithography setup; Figure 2b: EUV optical system only

Critical illumination condenser optical design

There are a number of other requirements for the critical illumination condenser, in addition to the placement of the image plane and exit pupil locations, which must be met by this optical system. The magnification of the pupil relay is an important factor which can effect the uniformity and partial coherence requirements of the imaging system. The exit pupil of the condenser system, which is relayed to the entrance pupil of the imaging system and subsequently to its aperture stop, is specified to achieve a 60% fill factor at the aperture stop of the imaging system[5]. The mirrors will need reflective coatings which satisfy the complex multilayer requirements and can realistically be manufactured. Multilayer mirror coatings for the EUV are only reflective over a narrow bandwidth and a small range of angles of incidence[6]. The angles of radiation incident upon each mirror of the critical illumination condenser must vary by less than 8 degrees. The current coating chamber dimensions also constrain the maximum diameter for any optic to approximately 100mm. Quite a lot of particulates (debris) emanate from the source along with the EUV radiation. A debris shield is necessary to protect the optics, that are closest to the source, from contamination. The particles would cover the components and reduce the reflective properties of the mirrors. The debris shield must be placed at least 25mm from the source, but even at this distance there is a gradual loss of transmission, to the shield, and it must often be replaced. The critical illumination condenser must also be able to scan over the extent of the ring field imaging system. Since the imaging system already exists, the first order parameters for the condenser are all defined. The critical illumination condenser has a 200μm source and requires a magnification of 26x.

The critical illumination condenser optical design is composed of 3 spherical mirrors (see Figure 3). The objective is a two mirror inverse Cassegrain, or schwarzschild configuration, with a 25% area obscuration (50% linear obscuration). The third mirror provides the final pupil and image relay. The numerical aperture of the system is 0.3 radians (f/1.67) which is a solid angle collecting 0.2 sr of radiation emitted by the source (out of 2π). This optical system is 505mm long from the source to the third mirror (5mm shorter than the Köhler illumination condenser), and meets all the requirements for the imaging system. Figure 4 is a perspective plot of the critical illumination condenser with the EUV imaging system.

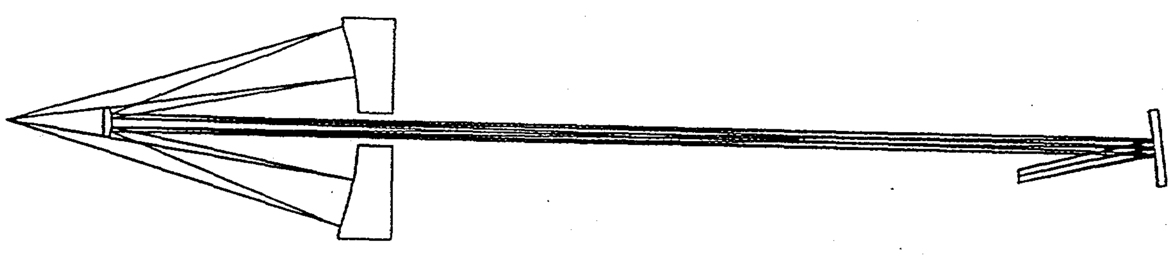


Figure 3: Critical illumination condenser for EUV lithography

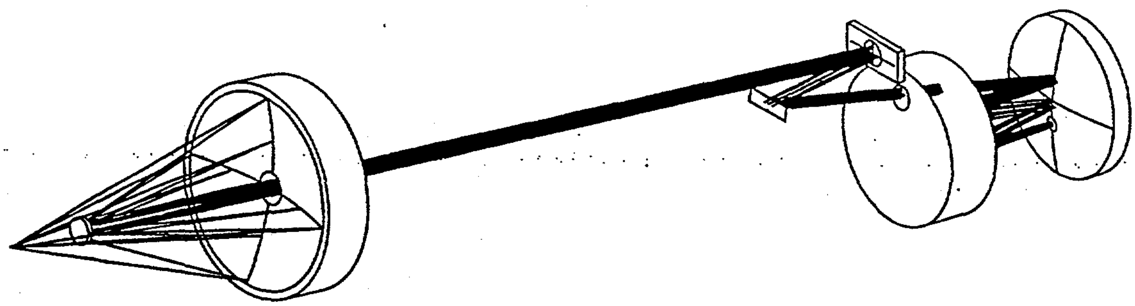


Figure 4: Critical illumination condenser in conjunction with LLNL imaging system.

A detailed analysis of the range of angles of incidence upon each mirror, for the full solid angle of incident radiation, is necessary to determine if the mirror coatings are realistic. Figure 5 shows a beam footprint at each mirror along with the radiation angles incident upon the surface. The footprint and angle analysis is accomplished by choosing 5 points at the source which are followed throughout the optical system to the image (mask) plane (see Figure 6). The third mirror in Figure 5 represents the footprint and angles for five source points. The dashed line represents the entire footprint from the 200μm source. In all cases, the variation of angles at each mirror is within the 8 degree spread.

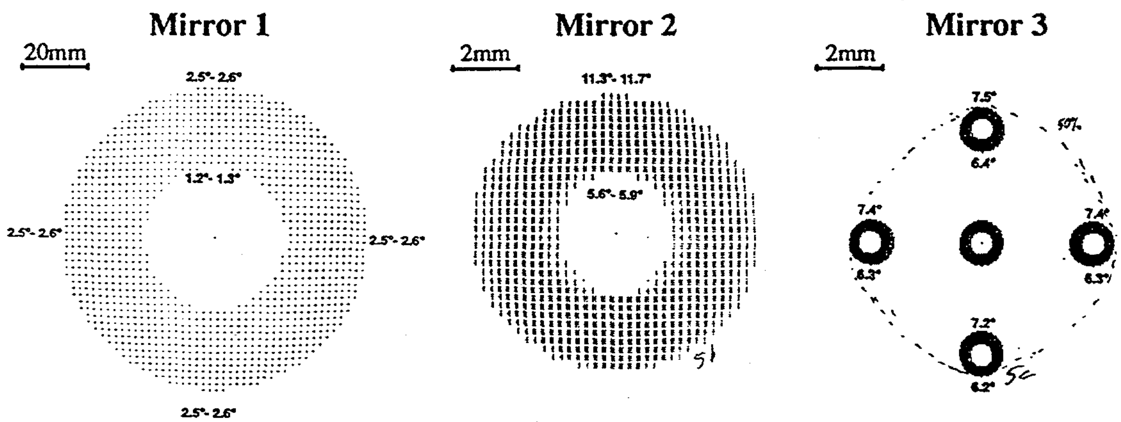


Figure 5: Radiaton footprints at each mirror along with angles of incidence.

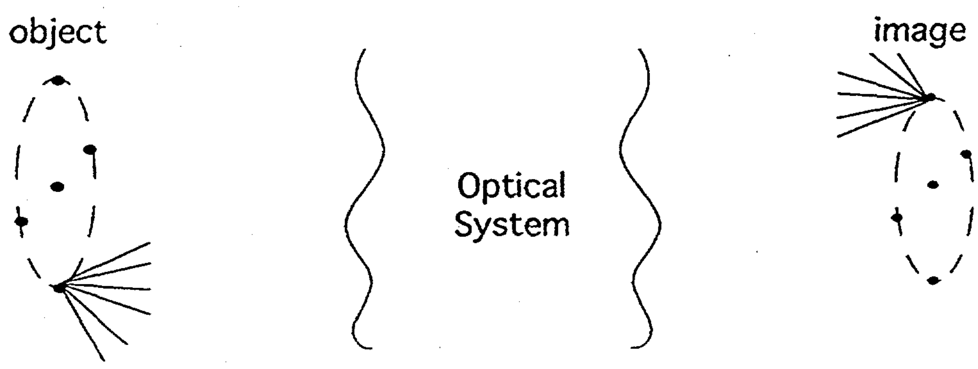


Figure 6: sketch portraying method of image analysis.

The mask is much larger than the image of the source created by the condenser optical system, which only illuminates a small portion of the mask. The EUV radiation must be scanned over the extent of the mask to illuminate its full width. Figure 7 is a schematic which illustrates the source being scanned and the resulting scan of the radiation across the mask and wafer plane. The mask is scanned across the ring field region of the imaging system. The 3 spherical mirror critical illumination condenser can scan by shifting the position of the laser driver on the plasma source (as illustrated in figure 7). Another way of accomplishing the same effect is by tilting the primary mirror of the condenser. Since the first mirror is the aperture stop of the system, tilting this plane will not shift the radiation at the critical illumination exit pupil plane which is also the entrance pupil for the imaging system. So, the EUV radiation can be shifted across the mask plane without moving in the aperture stop of the imaging system, consequently, the partial coherence of the imaging system is not affected. Figure 8 is a plot of the critical illumination condenser scanning radiation across the mask plane the mask plane (note the position of the radiation has shifted on the third mirror and the mask plane).

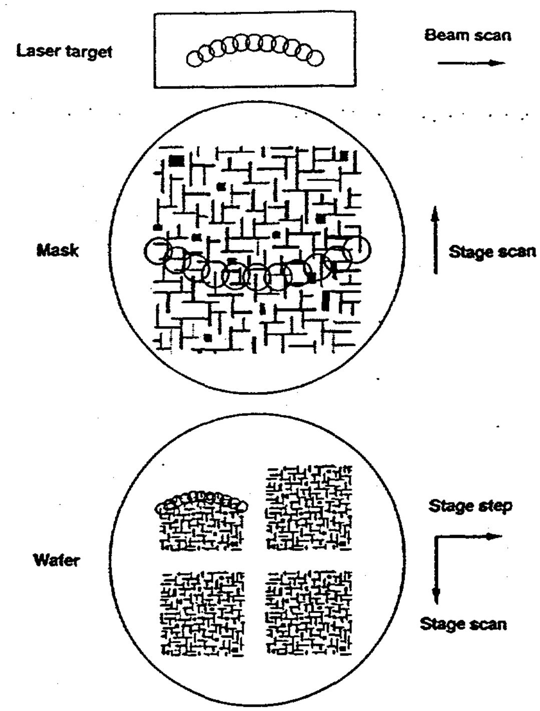


Figure 7: Laser is scanned on target to fill the ring field at the mask plane

The greater the extent of the scanning across the mask plane, the larger the incident angles will be on the second and third mirrors of the critical illumination condenser, however, the variation in these angles is less than a degree even over a 17mm mask.

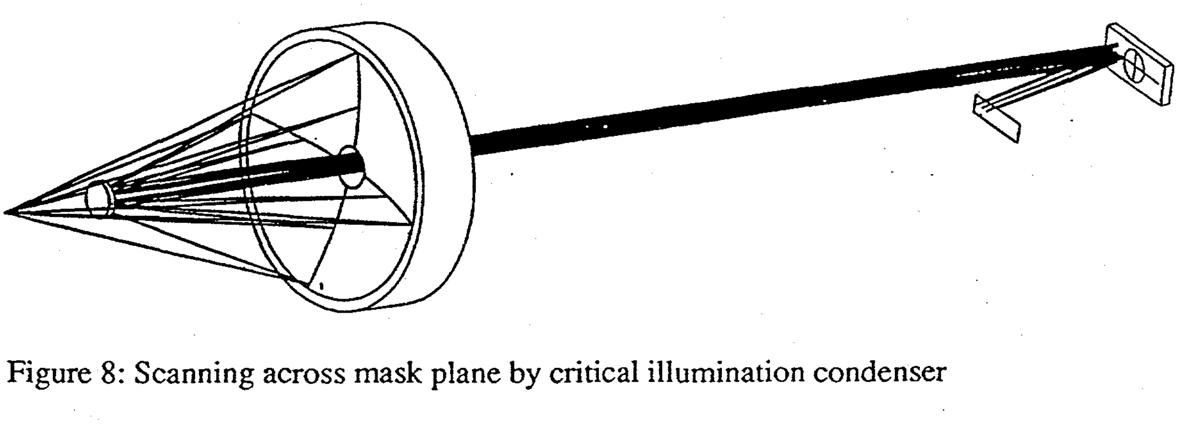


Figure 8: Scanning across mask plane by critical illumination condenser

The critical illumination condenser optical design is sufficiently versatile to be implemented into not only the current LLNL two element imaging system but also the AT&T/Sandia 5x, three aspheric mirror, imaging system. Figures 9a and 9b show the LLNL and AT&T/Sandia lithography systems with their front end critical illumination condensers. The same design format is used for each condenser. The mirror curvatures and spacings for the Sandia design have been optimized to work with the Sandia imaging system. The systems are shown at 1/12 scale. The AT&T/Sandia system has an overall length greater than 1.6m. The collection angle for the Sandia design is 0.5 radians (f/1) with a 60% linear obscuration, so the solid angle is 0.5 sr.

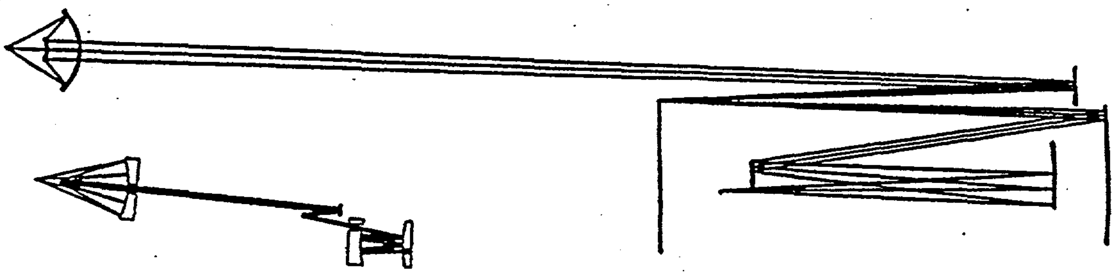


Figure 9a: The LLNL imaging system with its critical illumination condenser

Figure 9b: The AT&T/Sandia imaging system with the same type of condesner design

In a critical illumination condenser the uniformity of the source is an important factor which can affect the imaging of the mask onto the wafer. Since the source is imaged onto the mask plane in a critical illumination design, any non-uniformities in the source plane will appear at the mask plane and subsequently on the wafer. These non-uniformities will be source dependent and may be of concern. However, the potential advantages of the critical illumination system over a Köhler illumination condenser are quite dramatic. The critical illumination condenser can collect a much larger solid angle from the source than the Köhler design, and has an on-axis symmetric objective. In contrast, the Köhler illumination system is a non-symmetric, off axis design which is more challenging to align. Finally, the critical illumination condenser is more practical for scanning radiation across the mask. A Köhler illumination condenser can not be scanned by moving across the source, since this plane is re-imaged into the aperture stop of the imaging system and not the mask and wafer planes.

Conclusion

We have designed a three spherical mirror critical illumination condenser. This optical design satisfies the first order constraints of an imaging system and meets all the technical challenges associated with EUV projection lithography. The critical illumination condenser design is versatile enough to work with both the current LLNL and Sandia imaging systems. The design has a symmetric objective, can collect more radiation from the source than the Köhler design, and has the ability to scan over the extent of the ring field imaging system.

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Acknowledgements

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