THE BEGINNER'S GUIDE to DEEP UV

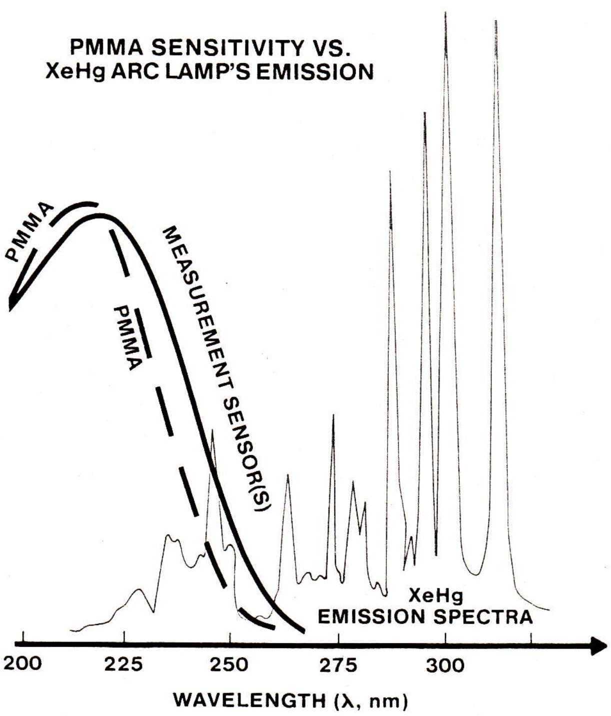
A Brief Review of DUV Exposure Technology

by Jerry Bachur, The Hybrid Technology Group, Inc., San Jose, CA

Very Large Scale Integration (VLSI) is receiving increased emphasis in the semiconductor industry today. A significant effort is therefore underway to improve the printing abilities of photolithographic systems.

Several approaches are being investigated, including Direct Stepping on wafers, Deep Ultra Violet, Electron Beam and X-Ray systems. Translated into investment dollars, Steppers cost in excess of $500,000. Electron Beam equipment requires $1.5 to $2 million and X-Ray more than $1 million. Deep UV (DUV) systems range from $15,000 (flood exposure system) to $500,000 (P.E.).

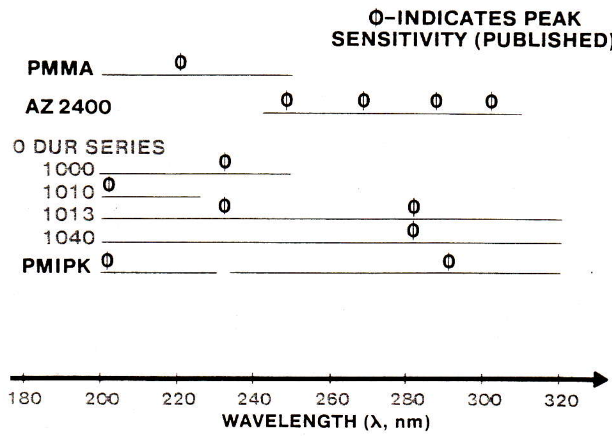
In this review, we concentrate only on the DUV exposure systems because they: 1) are an extension of today's ultraviolet exposure technology, 2) are commercially available and 3) offer the lowest cost approach to significant improvements in resoluton of optical photolithographic systems. DUV systems also afford solutions to various problems associated with certain mask levels of steppers and other types of mask aligners.



"Deep UV" is broadly defined as spectral energy between 1800 and 3300 angstroms, or 180 to 330 nanometers. ("Standard UV is accepted as falling between 350 and 450nm). Deep UV is further broken into three bands: 200 to 260nm, 260 to 285nm, and 285 to 315nm. These regions are associated with different photoresists providing spectral selectivity needed for specific processes.

Right now there are several photoresist formulations useful in the DUV region. PMMA has a sensitivity from 210 to 260nm with its peak about 220nm. PMIPK, covering 200 to 330nm, peaks around 190nm and again at 285nm. The AZ2400 Series displays sensitivity between 240 and 310nm with peaks at 248, 300 and 315nm. Finally, the ODVR Series covers from 200 to 315nm, peaking at 230, 280 and 300nm.

PHOTORESIST SPECTRAL SENSITIVITY CURVES



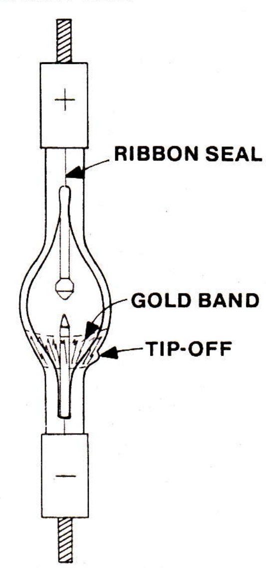
With a selection of DUV resists available, it might be easily assumed that switching your process to DUV technology should be simple . . . WRONG! Unfortunately, there are a limited number of exposure sources available with sufficient radiation in the 200 to 330nm range, especially the highly desirable 200 to 260nm region. To make matters worse, DUV resists offer low sensitivity to the radiation bands most generously produced by typical sources. Additionally, the broad-band output of the optical system must be limited to prevent the longer wavelengths from reaching the resist where they would impair resolution.

Sources that emit DUV radiation are:

1) Deuterium: although it produces a continuum in the region from 200 to 315nm, it finds limited application because of its low output levels. Until lamps of this material can be made to handle more than about 200 watts, it cannot be seriously considered, except for R & D purposes.

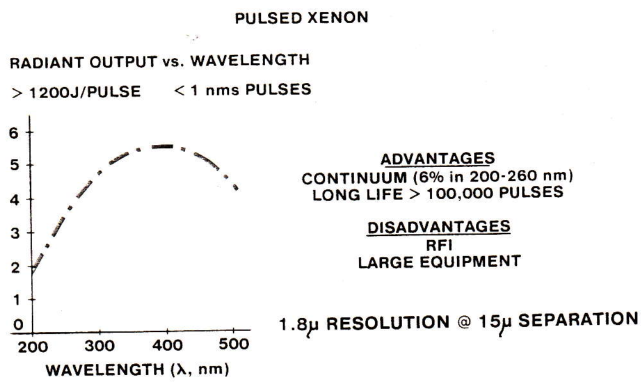
2) Hg (mercury): high pressure, short arc lamps produce line radiation in the 200 to 315(range. However, significant levels of energy are produced only at the 254nm line and around 300nm. This source has very limited use in other than the 285 to 315nm range.

XENON-MERCURY SHORT ARC

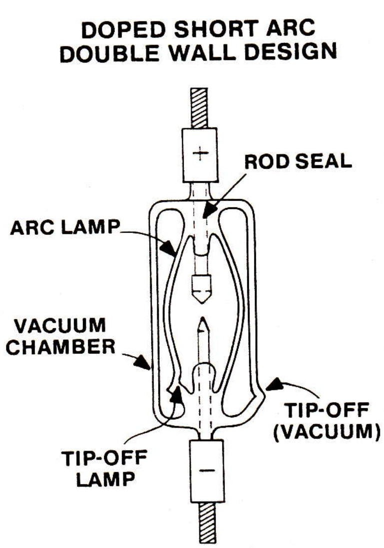


3) Xe-Hg (xenon-mercury): high pressure, short arc lamps produce essentially a line structure from 210 to 315nm. Available in powers from 350W to 2,000W, the Xe-Hg lamp is the source used currently for most DUV applications.

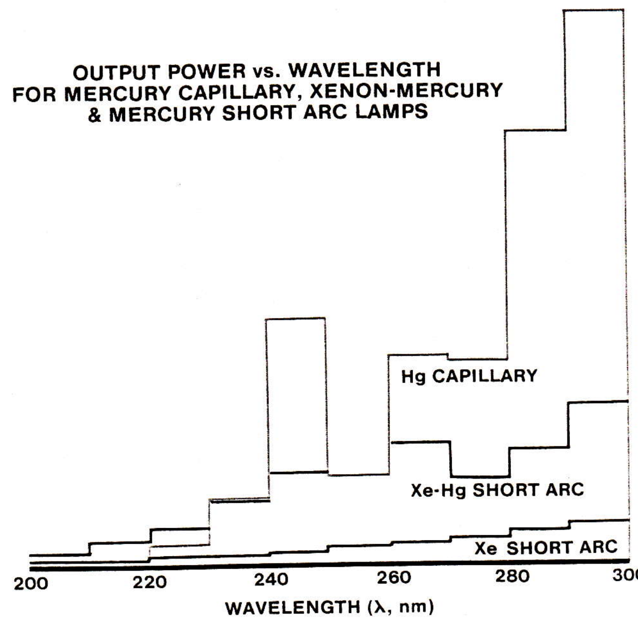
4) Pulsed mercury: high pressure, short arc lamps driven from idling power to high intensities with short, high-energy pulses. This source appears to have great potential. It displays a strong continuum in the 200 to 300nm range when hit by short, high energy pulses. However, it suffers significant inconsistancies such as lacking repeatability and short life. Practical use is questionable.



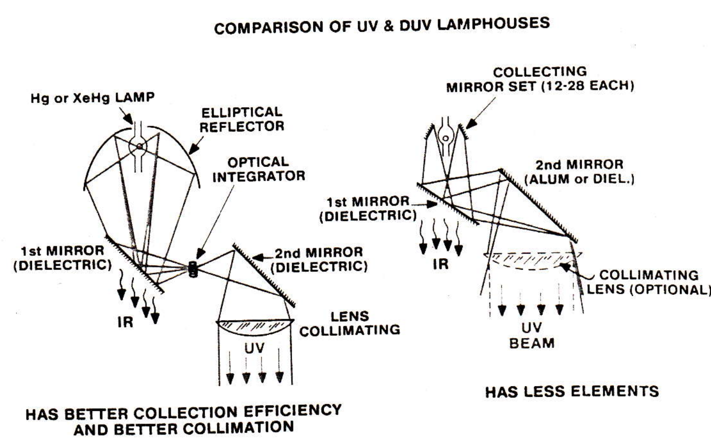
5) Pulsed xenon: low-medium pressure long arc flash lamps driven by very short, high energy pulses. This source delivers a continuum rich in content from 200 to 315nm. In fact, about 6% of the total emission is between 200 and 260nm. Most appealing of all, this source produces a repeatable continuum of short wave-lengths while maintaining acceptable lamp life. The chief disadvantage of this and all pulsed systems is RFI produced by high peak currents in short bursts.



6) Doped sources: past efforts have been made to enhance selected spectral emissions by doping lamp materials during their manufacture. Originally promising, practical results have been less than successful. Since most dopants are in salt form, it is difficult to get them to stay vaporized. Doped lamps are hard to build and tend to be inconsistent in output with short life spans. Nevertheless, several manufacturers are continuing development.



Two types of optical systems are in current use for DUV exposure systems. In the first, a series of small, flat mirrors surrounds the lamp to reflect radiation into an exposure beam. A collimating lens is added to reduce divergences. The second approach uses an elliptical collector with the source at the focus. Energy is transferred to a second focus where it is blended by a multi-element optical integrator. A collimating lens delivers the energy beam to the exposure plane, where it is at this point very well collimated and uniform.



The advantages inherent in the second of these approaches are: 1) the overall collection efficiency is much greater, producing higher intensities; 2) collimation is greater and the beam better controlled. Other advantages include increased reliability and more production life because critical elements of the system are less prone to damage from a catastrophic lamp failure. In addition, the system permits use of lamps with a more conservative, ruggedized design. This is possible because lamp configuration is not restricted as in approach one, above. Other approaches are under consideration, but none has yet made a commercial debut.

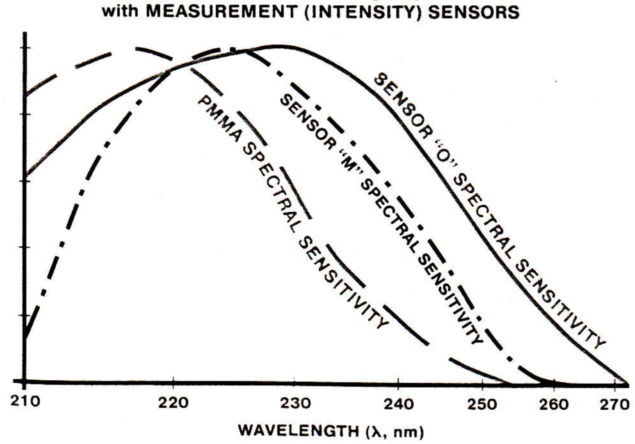
Of all the DUV lamps discussed earlier, only the Xe-Hg compact arc is useful for production work today. It delivers sufficient energy to be practical and is readily available. Several programs are underway to improve its efficiency. Most deal with dopants. Pulsed xenon is a real future possibility with tremendous potential. It is reportedly under development by at least one firm, however, progress is retarded by lack of customer interest.

Lamphousing optics include both reflective and refractive elements. Much work remains to improve the reflective elements, as they are the key to improved efficiency. Measurements from coated mirrors display a wide range of reflectivities with poor lot repeatability. As more systems are made and sold, these inconsistencies will become better understood and controlled. For transmissive elements, high-purity fuzed quarts must be used because of the absorption characteristics of regular quartz. This absorption is especially notable at the shorter wavelengths (200 to 250nm) where PMMA is used as the primary photoresist.

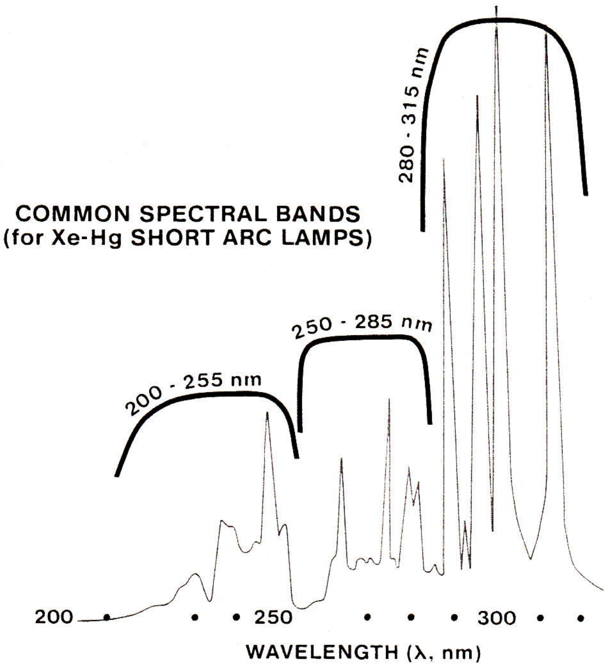
Much grief has been generated by the complete inconsistency of anti-reflective coatings on transmissive elements. A poor anti-reflective coating at these short wavelengths proves worse than no coating at all. When the problems of the optical coatings are finally controlled, it should lead to an improvement of 25 to 50 percent in output.

How do we measure the amount of radiation available at the exposure plane? Doing so is a key to developing a workable process and controlling it reliably. We must first decide what portion of the spectrum is to be measured. This is determined by the photoresist to be used. The sensor should be made to "see" the radiation as the photoresist does. This is not done easily, however. One approach would be a multi-channel analyzer programmed to the spectral sensitivity of the resist. Cost of such a device would be prohibitive, even if one could be purchased. Some other method must be used which can measure values meaningfully related to the spectral sensitivity of the photoresist.

COMPARISON OF PMMA SENSITIVITY
with MEASUREMENT (INTENSITY) SENSORS

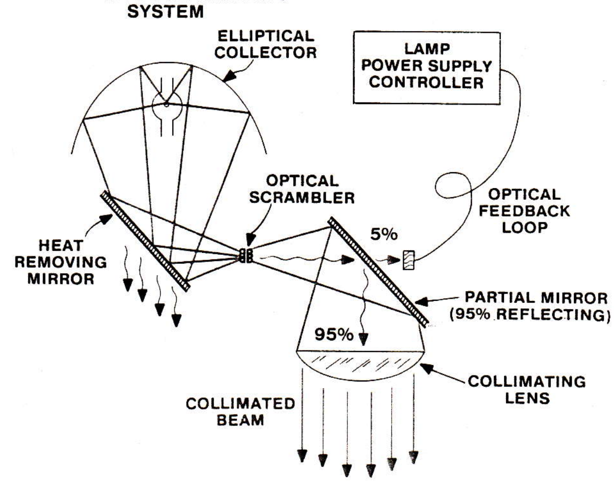


Several measurement systems exist. Although their spectral characteristics are slightly different, they produce measurements that are similar. These measurement systems are available for all spectrums of UV radiation. The spectral curve for a sensor useful with PMMA is shown.



It is extremely important that the intensity of the source can be measured as the source's output intensity decreases as the lamp ages. This intensity loss is most pronounced in the DUV region where absorption due to "aging" is quickly evident.

INTENSITY CONTROLLING SYSTEM



The key to maintaining a good exposure process is repeatability. The intensity/time function must be monitored constantly and adjusted to provide required energy (mj/cm^2) at the exposure plane. Intensity control is especially important in DUV work. Most exposure systems include intensity controlling capability. Such a control maintains a predetermined intensity level during the useful life of the lamp. There are three manufacturers of DUV intensity controllers at present. One offers 350W and 500W systems, another offers 350W through 2000W equipment. All use similar optical feedback techniques for monitoring and control functions.

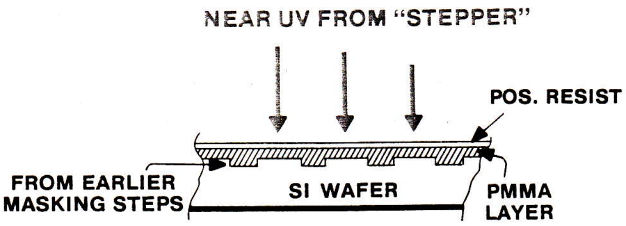
We've discussed how DUV radiation is produced, collected, shaped, measured and controlled. Let's proceed to the use of DUV and problems associated with it as an exposure technique.

Currently there are two ways in which DUV is used for exposure purposes.

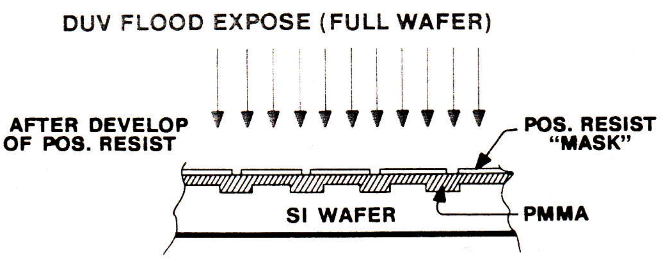
1) Alignment and exposure and 2) Flood Exposure (no alignment required).

The alignment and exposure mode is very similar to that used on all optical photolithography systems, except that the mask must be made of a DUV-transmitting material, such as quartz (fused silica) or sapphire. The standard mask materials absorb the radiation allowing little or nothing to expose the DUV-sensitive photoresist. For sub-micron resolution, the mask must be in intimate contact with the substrate. Additional very high magnification alignment optics (400 to 1000X) and ultra-fine X,Y and θ motions must be used to produce the ultra-precise registration.

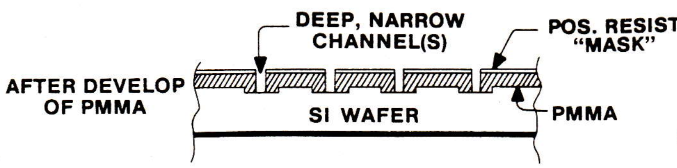
The other technique, flood exposure, is fast becoming a highly useful approach. It has been developed because of the great difficulty of reproducing very fine structures over and in deep depressions on partially processed wafers. This process, called the "multi-level resist technique," as it uses both a DUV and a standard UV resist. The DUV resist is spun directly onto the wafer, filling in all the voids, leaving a flat (planar) surface onto which the second, thinner layer is spun. (The second layer is usually a positive resist, such as KTI's 809 or AZ1470.)



The upper layer of resist is exposed in the normal mask alignment mode on a stepper or other high-resolution mask aligner, then developed out, leaving a "conformal" mask on top of the DUV resist. No further mask alignment is needed, since the upper resist acts as a mask by being opaque to the DUV radiation.



The wafer with its portable conformal mask (PCM) is then exposed to the DUV source and processed. The end result is very high resolution lines and spaces in topography which would otherwise create a difficult, low-yield situation.



One of the most annoying and costly problems of working in DUV is the length of exposures required to completely polymerize the photoresists. This is the result of several factors: 1) the low sensitivity of the resists, 2) the relatively low percentage of DUV content from the lightsource and 3) the spectral mismatch of the two. The shorter the wavelength, the more noticeable the problem becomes. It is not uncommon to encounter exposures requiring three to ten minutes on thick PMMA.

Recent measurements from a production-related DUV lightsource significantly exceeded 50mW/cm² (UV-220) within a 4.5" (10.3 cm²) diameter, highly collimated beam.

A word of caution: it should be noted that it is easy to be confused or mislead by intensity figures quoted for DUV lightsources. Many factors must be considered to understand and properly compare sources. These include:

1) What is the output spectrum of the source?
2) What is the beam size and how uniform is its intensity?
3) Is the beam collimated (by lens) or converging (no lens)?
4) What kind of lamp is used?
5) What is the input power required by the lamp?
6) What is the measurement system, its spectral range and wavelength peak of the sensor?
7) What is the intensity at a fixed power input (i.e. 350W, 500W or 1,000W)?

IN CONCLUSION

This report is intended as a primer for those people thinking about using DUV as an exposure source AND for those who wish to know more about DUV capabilities, potentials and problems.

The author would be pleased to provide additional detail about DUV technology, including the available and soon-to-be-available, or future equipment. Some items, however, are of a proprietary nature, so their discussion would be necessarily limited.