SOURCES FOR THE PRODUCTION AND CONTROL OF DEEP ULTRAVIOLET RADIATION

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Abstract
Multi-level resist technology is rapidly emerging as a technique capable of significantly improving processes needed to acheive desired yeilds on VSLI products. For the multi-level resist technology to be successful, production-rated Deep Ultraviolet (DUV) exposure systems will be required.

Introduction
This presentation describes the two critical components of a Deep UV Exposure System: the source to produce the radiation; and the optical elements needed to collect, shape, and deliver the radiation to the wafer plane. For purposes of this discussion, I will primarily focus on radiation in the 200 – 315nm region and, in particular, the 200 – 260nm region where PMMA is used as a base resist.

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 can be made to handle more than 200W, deuterium cannot be seriously considered, except as an R&D tool.

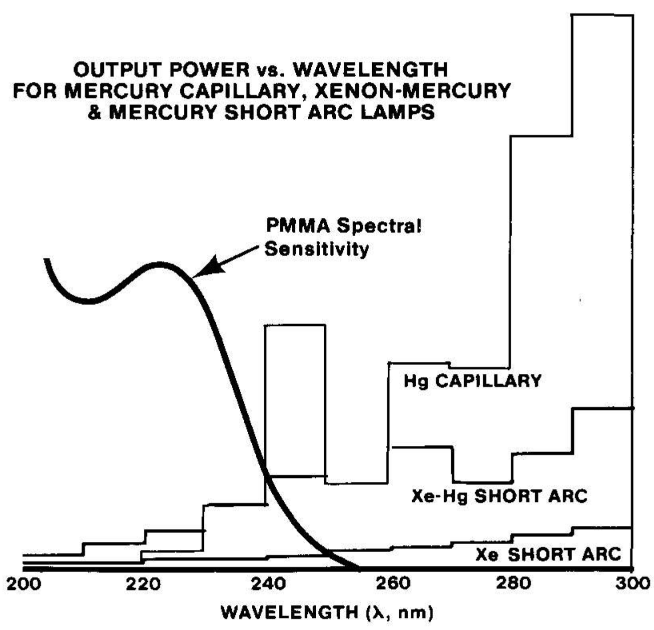

FIGURE 1

2) Hg (mercury): high-pressure, short arc lamps produce line radiation in the 200 to 315nm 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 285-315nm range. Super high-pressure Hg lamps (capillary types) can produce radiation at the shorter wavelengths; however, they perform best in the mid-UV range between 250 – 315nm (see Figure 1).

3) Xe-Hg (xenon-mercury): high-pressure, short arc lamps produce essentially a line structure on a low-level continuum from 210 to 315nm. Available in powers from 350W to 2000W, the Xe-Hg lamp is the best source currently used for most DUV applications (see Figure 1).

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 as it displays a strong continuum in the 200 to 300nm range when hit by these short, high-energy pulses. However, it suffers significant inconsistancies such as lacking repeatability and short life. Practical use is highly questionable.

5) Pulsed Sources (e.g. 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 wavelengths while maintaining acceptable lamp life.

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.

7) Lasers: some Eximer types emit radiation in the deep UV. Krypton-fluoride produces an emision line at 222nm. These lasers have not yet achieved the higher power levels needed to make them useful except for R&D purposes.

There are three sources which have the potential to be used for multi-level applications. These are Xenon-Mercury, low-pressure Cadmium, and pulsed Xenon.

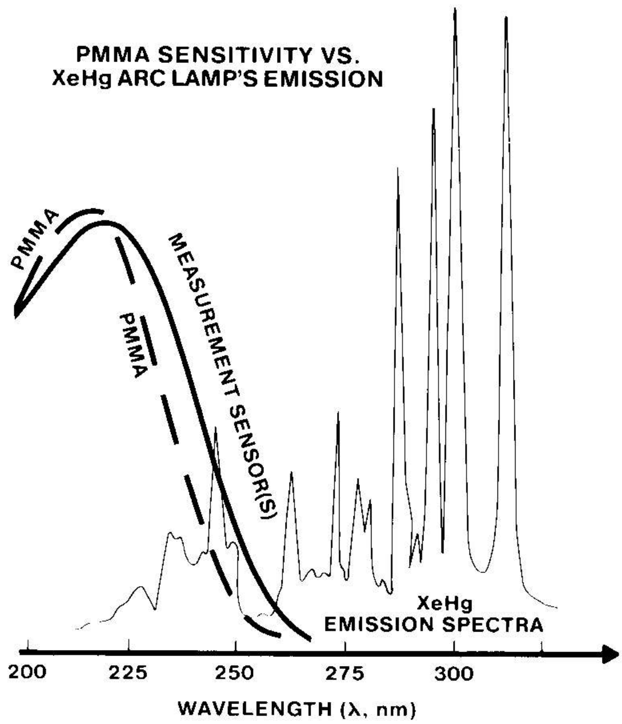

FIGURE 2

Xenon-Mercury Sources have been available for many years. Recently a significant amount of effort has been expended to improve its efficiency in the 200 – 260nm spectrum. By varying the pressure and adding an additional constituent, one manufacturer has achieved an improved Xe-Hg lamp for applications in the Deep UV. An Xe-Hg emission spectrum is shown in Figure 2.

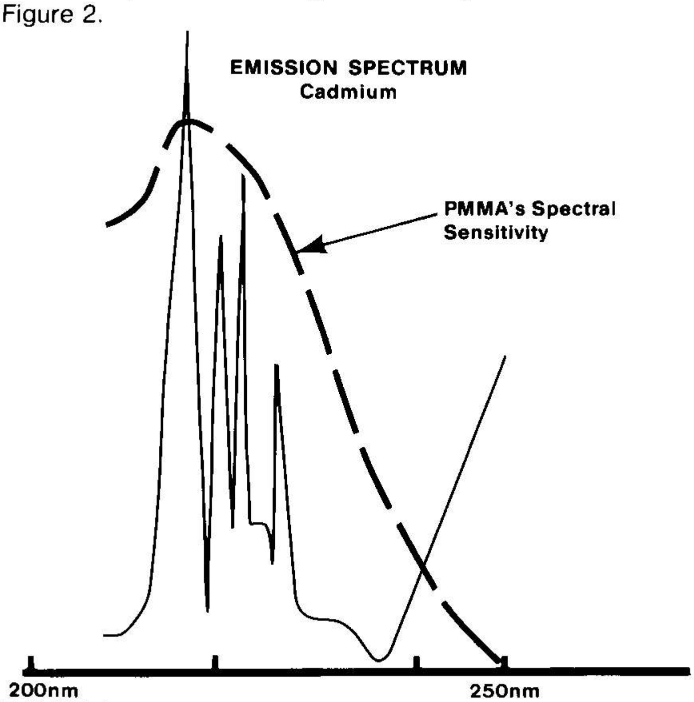

FIGURE 3

Low-Pressure Long-Arc Cadmium Doped Lamps offer the highest conversion efficiency. Claims of up to 10% have been reported by two reputable groups. The Cadmium dopant used produces significant levels of radiation in the 215 – 235nm spectral band, the ideal band for PMMA resist. The spectral output of a Cadmium doped lamp is shown in Figure 3.

Two different lamp approaches are being developed to produce a viable Cadmium exposure source. General Electric has concentrated on a low-pressure design which uses a linear tube. Heaters on both ends keep the Cadmium in vapor form and control overall vapor pressure within the lamp. G.E. reports successful application of this design in spite of its limited beam collimation and collection efficiency. Fusion Systems, on the other hand, has taken a more dynamic approach by exciting (pumping) their linear lamp with microwave radiation. By the use of microwave radiation to excite the bases and dopant, an electrodeless lamp can be employed. Fusion claims that lamp life will be good since there are no electrodes to deteriorate and degrade the lamp.

Although both approaches claim high conversion efficiency, neither will describe how they collect the radiation and produce the collimated beam desired for the multi-level resist process. Estimates on the *overall efficiency* of the exposure system have not yet been reported.

To circumvent the problems inherent in optics needed to collect and collimate energy from an extended linear source, Fusion Systems has initiated effort on a circular or disc-shaped source.

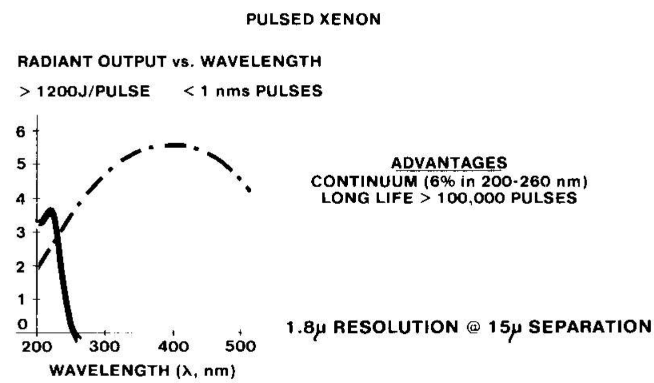

FIGURE 4

The third type of source which has the capability to produce short wavelength radiation is Pulsed Xenon. When pulsed at high energy (approximately 1200J) and short pulsewidth ($<50\mu$ second), a current density of 12,000 – 15,000 amp/cm^2 is achieved in a lamp less than 3 inches long. The radiation produced is a continuum, rich in short wavelength UV, yeilding about 6% conversion effiency in the 200 – 260nm spectral range. This lamp can be bent to form a circular shape which makes it easier to design with, from an optical design consideration. Its major drawback is the high levels of RFI produced whenever the lamp is pulsed. The RFI levels are sufficiently high to cause problems in surrounding equipment in which IC logic is used (see Figure 4). Note: Recent designs have reduced RFI to the point where pulsed sources are now being installed in increasing numbers.

All attempts to make an accurate comparison of the three lamp types described proved fruitless as little data has been provided. The only thing that can be said is that only Xe-Hg (plus) can be purchased off-the-shelf in both R&D and production intensity levels. Although promising, Cadmium doped lamps are not available in the industry. Pulsed Xenon has had limited test in the field; results from users are the only valid data so far.

As indicated prior, conversion effiency of the lamp is only one of two major factors that effect the energy delivered to the exposure plane. The second factor, which is at least equally important, is the collection and collimation of the emitted radiation to deliver a well-controlled beam to the wafer.

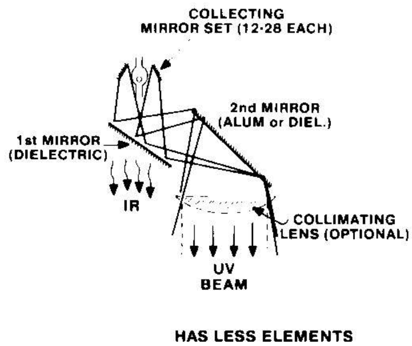

FIGURE 5

Two types of optical systems are currently used for DUV exposure systems. The first uses a series of small, flat mirrors to surround the lamp, reflecting radiation into an overlapping beam (see Figure 5). A collimating lens can be added to reduce divergence.

The second approach uses an elliptical collector with the source at the first focus. Energy is transferred to a second focus where it is blended by a multi-element optical integrator, producing a uniform pattern. The collimating lens then delivers the highly-collimated energy beam to the exposure plane.

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 much 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 feature is possible because lamp configuration is not restricted in size. Other approaches are under consideration, but none have yet been made commercially available.

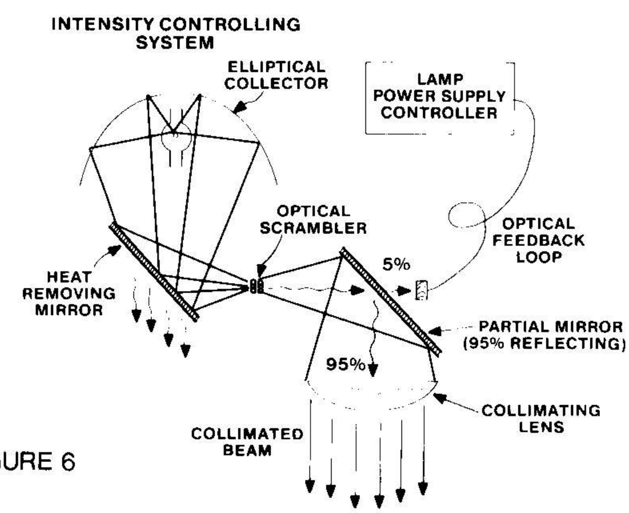

FIGURE 6

Lamphousing optics include both reflective and refractive elements. A typical optical system is shown in Figure 6.

The lamp is placed at the first focus of the elliptical reflector which collects approximately 75% of the emitted radiation. The energy is reflected off the first turning mirror, which is spectrally selective as well as heat removing, whereupon it is focused on the optical scrambler elements (the second focus of the ellipse). Energy passing through the optical scrambler (integrator) now has greater beam uniformity and a defined divergence. The collimating lense collects the energy from the "optical scramble" and delivers a well-collimated, uniform beam to the exposure plane.

To produce a useful level of energy in the Deep UV, all of the optical elements described have to have special qualities. The reflective elements (mirrors) must be designed for high reflectivity in the desired spectral region. This is a very difficult task as the selecton of coating materials is limited. The coating material must have a high index of refraction as well as good transmission for short wavelength UV. Materials which possibly are usable are sapphire, diamond, magnesium fluoride, and zirconium oxide. A few others qualify but are not mentioned as they are proprietary to the coaters.

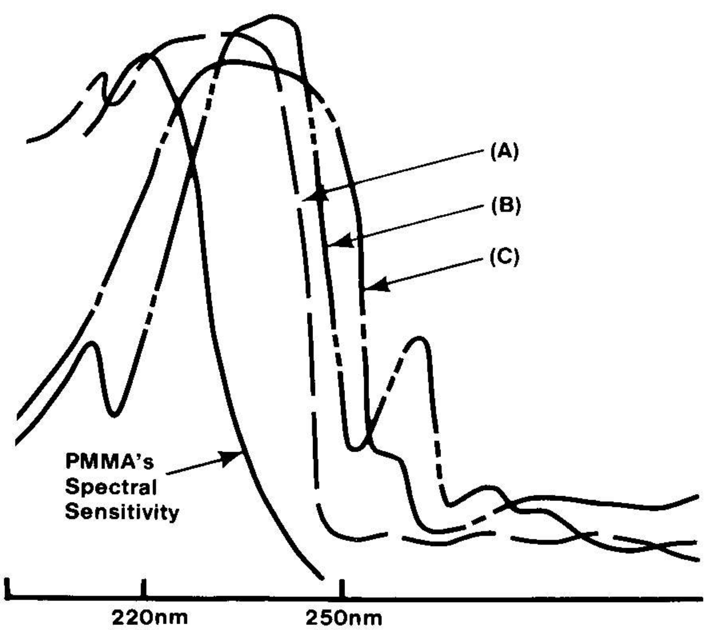

FIGURE 7

Measurements show that manufacturers of these DUV coatings have great difficulty repeating both the spectral shape and levels of reflectivity. Figure 7 provides the shape of the desired coating, curve A, while curves B and C show typical results from different runs made by the original and other coaters.

Curve B illustrates a coating which exhibits a series of secondary reflections. The longer wavelength reflections are particularly troublesome in multi-layer work as they can add long wavelength penetration through the upper layer of resist, causing a loss of resolution within the base resist.

Curve C shows another typical problem: a result of the coated layers not being accurately controlled in thickness. If the coater decides to save time by depositing a lesser number of layers, the reflectivity is usually lower.

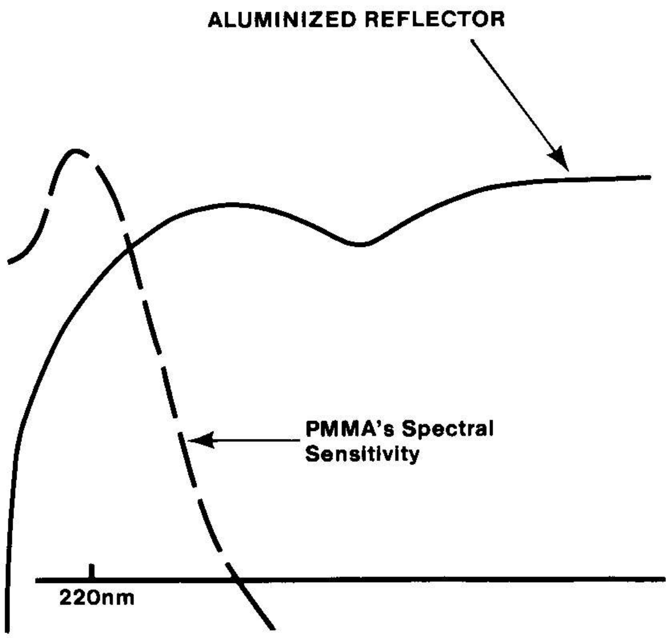

FIGURE 8

Aluminum coatings are useful with the wideband reflectors for the DUV region (Figure 8) since they can deliver reflectivities of greater than 90%. Their major problem is that they deteriorate too rapidly for long-term use. Even when undercoated, aluminum mirrors exhibit limited useful life. They also reflect the IR (heat) radiation which can be a significant problem in some processes.

The reflective efficiency of mirrors is very significant, as the system employs *three* mirrors. A variance of 5% in reflectivity (from 90% to 85%) can result in a change loss of 15% in throughput. Reflectivity is, therefore, a key factor in the system's efficiency.

Spectrum control is the other major concern since a mismatch between the source and reflector can produce an undesirable spectrum, thereby passing radiation which can play havoc with the process.

The refractive elements (lenses) are also critical, as they directly affect the output spectrum and the intensity of the system.

To produce DUV radiation, the refractive elements cannot have significant transmission losses. These losses can occur in three ways: (1) absorbtion within material, (2) surface reflections, and (3) scatter.

To minimize absorbtion losses, materials such as quartz must be used — *not ordinary quartz,* but a special optical grade which has maximum transmission down to 200nm. If a lesser grade is used, a sizeable loss of energy will be observed at the shorter wavelengths.

Sapphire offers better transmission characteristics; however, its cost (through fabrication) makes it economically unfeasible for industrial usage.

Surface reflection is dependent on the material's refraction, the wavelength of the radiation, and its angle of incidence to the material. Losses due to surface reflection are significant, especially as the typical optical system has at least six transmissive elements. The problem is greater at shorter wavelengths. Typical losses in a six-surface DUV optical system are in the 20% range. Generally, anti-reflection coatings can reduce these losses significantly. However, experience has already shown that the yield is so low that uncoated elements became acceptable for most applications. (A poor coating in the DUV region creates substantial transmission losses when compared to what is gained by a good coating.)

Scatter: this is not as severe as first thought. Initially, it was proposed that scatter due to surface imperfection was a major contributor to a significant loss of intensity through the refractive elements. Tests recently performed show that the surface finish of most lenses is of high enough quality that scatter is now a second-order problem.

It should be understood that scatter is a much more severe problem in short wavelength radiation optics. Concern about scatter is justified when lens design is initiated for DUV optics.

CONCLUSION

We have now pretty well covered the two major factors that can affect the performance of DUV lightsources: the source (lamp) and the lamphouse optics. As you can see from this discussion, there is still much room for improvement in both areas.

Development is continuing with much of the lamp effort directed toward optimizing the lamp's design and internal fills with the goal of improving the effiency as well as the life of the lamp. A significant amount of effort is also being applied toward the improvement of coatings used on reflective and refractive elements. Gradual improvements are expected to continue.

Even though much of todays multi-layer effort is developmental, DUV systems are available off-the-shelf which can be used in a production environment. Flood exposure has already been interfaced on wafer track systems. Retrofit lamphouses are available for mounting on Kasper, Cobilt, Canon and Karl Suss mask aligners.

In spite of the slowdown in the semiconductor industry, efforts to improve and expand the capabilities of DUV exposure systems continue at a rapid rate.

ACKNOWLEDGMENTS

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