Application of High Pressure/Environmental Scanning Electron Microscopy to Photomask Dimensional Metrology

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Abstract. The application of high pressure or environmental microscopy techniques is not new to scanning electron microscopy. However, application of this methodology to semiconductor metrology is new because of the combined need for implementation of high resolution, high brightness field emission technology in conjunction with large chamber and sample transfer capabilities. This methodology employs a gaseous environment to help neutralize the charge build-up that occurs under irradiation with the electron beam. Although potentially very desirable for the charge neutralization, this methodology has not been seriously employed in photomask or wafer metrology until now. This is a new application of this technology to this area, but it shows great promise in the inspection, imaging and metrology of photomasks in a charge-free operational mode. For accurate metrology, this methodology affords a path that minimizes, if not eliminates, the need for charge modeling.

INTRODUCTION

The application of high pressure or environmental microscopy techniques is not new to scanning electron microscopy (SEM). This form of microscopy was originally proposed early in the development of SEM, has slowly developed and has been most recently been utilized in biological, food and chemical science applications. The application of environmental microscopy to production semiconductor metrology is new because of the need for the combined implementation of high resolution, high brightness field emission technology in conjunction with large chamber and sample transfer capabilities. This overall combination of technology has not been available until just recently.

High-pressure microscopy offers the advantage and possible application of higher landing energies or accelerating voltages, different contrast mechanisms and charge neutralization [2,3]. Higher landing energies mean higher resolution imaging is possible rather than at the lower accelerating voltages. This methodology employs a gaseous environment to help neutralize the charge build-up that occurs under irradiation with the electron beam. Although potentially very desirable for the charge neutralization, this methodology has not been seriously employed in photomask or wafer metrology until now. This is a new application of this technology to this area and much needs to be learned. But, this technology shows great promise in the inspection, imaging and metrology of photomasks in a charge-free operational mode. It has been reported that even at high accelerating voltage, injection of air of as little as 20 Pa (0.15 Torr) into the specimen chamber can reduce the charging potential of an insulator at the surface by as much as an order of magnitude [4]. In addition, this methodology affords a path that minimizes, if not eliminates, the need for charge modeling which is needed for higher accuracy measurements. The modeling of charging is exceptionally difficult since each sample, instrument and operating mode can respond to charging in different ways. Therefore, this methodology shows great potential if the optimal balance can be achieved in a reproducible manner. Further research is currently underway to understand the ways to optimize these operating conditions. This paper presents some new results in high pressure SEM metrology of photomasks.

PHOTOMASK METROLOGY

Photomask dimensional metrology, especially that associated with scanning electron microscopes, has not evolved as rapidly as the metrology of integrated circuit and resists features on wafers. This has largely been due to: 1) the distinct emphasis placed on the value of wafer production as opposed to mask production; 2) the fact that far fewer photomask metrology and inspection instruments are needed in production applications, 3) photomask metrology technology significantly leverages wafer metrology technology improvements and 4) the distinct technological advantage afforded by the 4x or 5x reduction used in the optical steppers and scanners of the lithography process and 5) there was previously a lesser need to account for the real three-dimensionality of the mask structures. Where photomasks are concerned, many of the issues challenging wafer dimensional metrology at 1x are reduced by a factor of 4 or 5 and thus have been swept aside - temporarily. This is rapidly changing with the introduction of advanced masks with optical proximity correction and
Typical SEM Chamber Pressure

FIGURE 1. Graphical representation of the approximate location of the environmental or high-pressure SEM operating conditions as compared to those of standard instruments. The most effective operational range is currently being investigated.

High pressure or environmental microscopy is an approach to photomask inspection that has until now not been fully explored [9,10]. The methodology employs a gaseous environment surrounding the sample to help neutralize the charge. Typically the gas used for photomask inspection is water vapor (although other gasses can be used). As shown in Figure 1, a typical SEM operates with a sample chamber pressure of about $6.7 \times 10^3$ Pa (5x10$^3$ Torr). For high-pressure microscopy work, the chamber pressure is allowed to rise to the realm of about 20 to 160 Pa by the injection of the water vapor (as compared to atmospheric pressure of 101,325 Pa). As shown in the figure, these operating conditions are magnitudes different than current standard SEM operating parameters.

The primary electron beam passes through the water vapor, interacts with it and creates positive ions. The primary electron beam continues on and strikes the surface of the mask and undergoes the typical sample/beam interactions. Electrons from the primary beam can create a negative charge on the insulating mask surface. The negative charge developed on the mask cause the positive ions from the gas interaction to drift toward the mask, neutralizing the negative charge on the sample. Concurrently, the signal electrons are accelerated toward the detector by an electric field. As they proceed, they also interact with and ionize additional water vapor, creating additional ions and electrons. This multiplication enhances both the charge neutralization process and the signal collected. Depending upon the design of the instrument either the secondary electrons, backscattered electrons or light is collected as the signal forming mechanism. The resulting process eliminates charging effects (beam
FIGURE 2. Scanning electron micrographs of binary photomask structures using the environmental SEM. (a) Image taken at 160 Pa (1.2 Torr) at 100,000x magnification showing the lack of sample charging at 10 keV accelerating voltage. (b) Micrograph of a single photomask line using high-pressure microscopy conditions showing the extent of the line edge roughness present.

distortion and shift) and can provide high quality images of dielectric samples as shown in Figure 2. Figure 2 shows two images of photomasks taken at high accelerating voltages with the pressure levels between 160 Pa (1.2 Torr) and 107 Pa (0.7 Torr).

For various technical reasons, high-pressure microscopy has mostly been employed on specimens of biological nature and not on many semiconductor samples. Although potentially desirable for charge neutralization, this methodology has not been seriously employed in photomask or wafer metrology until now. High-pressure microscopy offers advantages of the possible application of higher accelerating voltages and different contrast mechanisms [2]. This is a new application of this technology to this area, but it shows great promise in the inspection, imaging and metrology of the photomasks.

One significant benefit afforded by this technology is that for accurate metrology, this methodology affords a potential path that minimizes, if not eliminates, the need for charge modeling. The modeling of charging is exceptionally difficult since each sample, instrument and operating mode can respond to charging in different ways. This methodology shows great potential if the optimal balance can be achieved in a reproducible manner.

CONCLUSION

Environmental or high pressure scanning electron microscopy affords a new approach in to the accurate inspection and metrology of photomask samples. The minimization if not elimination of the charging currently limiting the inspection of photomasks in the SEM is a significant step forward for this work. Mask metrology has generally benefited from the advances made for wafer metrology. In this instance, the converse might eventually prove to be true if these methods can be successfully transferred to wafer applications. International SEMATECH and NIST are currently investigating the potential this affords to production photomask metrology.

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REFERENCES

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