Scanning He Ion Beam Microscopy and Metrology

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ABSTRACT

Although the CD-SEM remains a powerful tool for metrology there is little scope for further enhancements in its performance. In contrast the scanning Helium Ion Microscope (HIM) offers a comparable or better level of imaging resolution as compared to the SEM, a much superior depth of field, and strong and interpretable topographic contrast [1]. The HIM gun is a high brightness field ionization source, utilizing helium gas, with a single atom effective source size, producing emission currents of several hundred pico-amps for energies between about 20 and 40keV. The column optics of the gun and lenses is similar to those of an SEM but all the elements are electrostatic rather than electromagnetic. The ultra-short ion wavelength (~ 100 femptometers at 30keV) eliminates diffraction limiting so the focused beam can be collimated to an angle α of the order of 100μrads. As a result spherical aberration - which varies as α^3 - is absent and chromatic aberration – which varies as α - is insignificant while the imaging depth of field, which varies as $1/\alpha$ is greatly enhanced. Consequently sub-nanometer resolution (0.7nm) can be achieved at 40keV even at working distances of 5mm or more.

The principal imaging mode of the HIM uses ion induced secondary electrons (iSE). The stopping power of ions in materials is much larger than that of electron beams of the same energy so the iSE yield is typically an order of magnitude higher than the comparable electron yield [2]. The increased stopping power also limits the range of the ion beam. In any given material the range of a He+ ion beam of some energy E(keV) is only about 1/E times the range for an electron beam of the same energy in the same material.. The iSE signal is therefore inherently richer in surface information at all beam energies than that from the SEM, and also provides strong chemical and crystallographic contrast. Topographic contrast – the variation of the iSE signal as a function of the angle of incidence θ of the incident beam to the specimen surface - is similar to but not identical with that observed in an SEM because both the magnitude and the form of the yield curve with incident angle depend on the chemistry of the sample. Modeling signal profiles for device metrology will therefore be more challenging than in the SEM case.

Helium ion beams do pose some special problems. Sample charging in the HIM is both more serious than in an SEM, and is always positive in polarity at all beam energies, with the result that the emission and collection of the iSE signal from insulators, oxides, etc is greatly affected. The best current solution is to periodically flood the specimen surface with a low energy electron beam to achieve neutralization although it is probable that operation in a “variable pressure” mode, as in the VPSEM, would be more satisfactory. The nature and severity of beam damage is also a consideration. Ions are more massive than electrons and so could cause significant damage through both sputtering and radiolysis. However sputter rates from He+ beams are only of the order of 0.1 events per ion and fall steadily with increasing beam energy. Radiolytic damage in typical resist materials with a 40keV He+ beam results in a few percent shrinkage a dose of about 10 ions/A^2 which is no worse than the corresponding damage from electrons. Because the iSE yield from the ion beam is both significantly larger than from an equivalent electron beam and rises with increasing incident energy the shrinkage for a given signal to noise ratio could be significantly lower than from an e-beam if ion energies in excess of 100keV were to be employed.

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