Advantages of Energy Selective Secondary Electron Detection in SEM

C. Rodenburg,* M.A.E. Jepson,* and E. Bosch**

* Department of Engineering Materials, University of Sheffield, Mappin Street, Sheffield, S1 3JD, UK
**FEI Electron Optics, Achtseweg Noord 5, Acht, 5600 KA Eindhoven, The Netherlands

Recently, much emphasis has been placed on the development of scanning microscopes that provide smaller probe sizes which has led to Secondary Electron (SE) images with atomic resolution [1]. Less attention has been given to how the differences in detection of SEs can influence the information contained in an SE image, in spite of the fact that SEs of different energies have different escape depths [2], magnetization contrast [3] and dopant contrast (DC) [4] can be enhanced by SE energy selection (ES), and that material identification via finger-printing methods based on the SE spectra [5] has been suggested. This alone implies that a large amount of information and improved contrast (translating to better resolution) may be gained if the energy range of SEs used for image formation can routinely be adjusted in a scanning electron microscope (SEM) by the user.

In Fig1 we describe such a system that allows energy selection (ES) in a low voltage field emission SEM and present some of the characteristics, obtained from calculations, in Fig 2. Fig 2 describes the transfer of SEs of given energies when D (see Fig 1) is adjusted. It can be seen that for $D \leq 20V$ the energy cut off is shifted by 0.5eV per 1V increase in D. For larger D, a cut-off energy cannot be clearly identified (see D=60V trace in Fig 2). This causes some limitation as it only allows well specified ES for SE energies $\leq 10eV$. However, as the peak energy in the SE spectra of most materials is $< 10eV$ [5], this does not seem to be a severe limitation but explains the large differences in contrast obtained by standard SEM (D=60V) and ES selection when $D<20V$.

An example of the benefit of ES SEM is given for the mapping of doped regions in Si in Fig 3, when the Si surface is covered by a contamination layer as a result of prolonged (1 week) air exposure. ES (D=16V) imaging of this specimen gives double the contrast ($C_{pn}[\%]=200(I_p-I_n)/(I_p+I_n)$) with $I_{n,p}$ intensity of n-doped/p-doped region) values that can be obtained in standard SEM. This effect can be explained by the fact that the majority of low energy SEs (used to form the ES image) originate from a few nanometers below the surface (SiO_2: $\lambda_{esc}(3eV)\sim10nm$ [6]), whereas high energy electrons tend to stem from closer to the surface (i.e. from contamination layer and not silicon). Therefore by using ES to select SEs of appropriate energy, the detrimental influence of the contamination layers on contrast can be strongly reduced, resulting in enhanced DC. A particularly useful application is imaging of Focused Ion Beam (FIB) prepared specimens. For Si, a damage layer of ~10nm thickness for ion energies of 10keV exists [7] which leads to the loss of DC. This can be seen in Fig 4 which contains C_{pi} (contrast of p-type relative to intrinsic Si) plots obtained from a staircase structure for different combinations of sample preparation and SEM imaging conditions. There is no visible dependence of C_{pi} on dopant concentration in standard SEM of the FIB prepared specimen, whereas prepared by cleaving, the contrast clearly reflects the different dopant concentrations. However, if this damage layer of the FIB prepared specimen is oxidized (using an oxygen containing plasma) low energy SEs generated below the (now oxidized) damaged layer are able to escape. Therefore, the C_{pi} contrast profile obtained from the ES image of a plasma cleaned (for 10min) FIB prepared specimen is restored to that of a cleaved specimen for most doping levels.
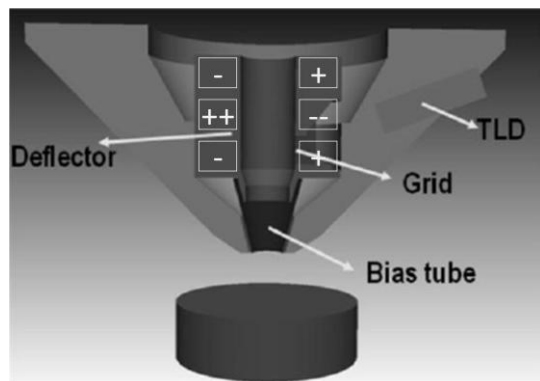
Fig 1 ES system consisting of a positively biased extractor to direct SEs to Deflector (three layers of electrodes of opposite potential). The lowest layer is to deflect SEs to detector (TLD). Deflection field strength is adjusted by changing the deflector voltage, D.
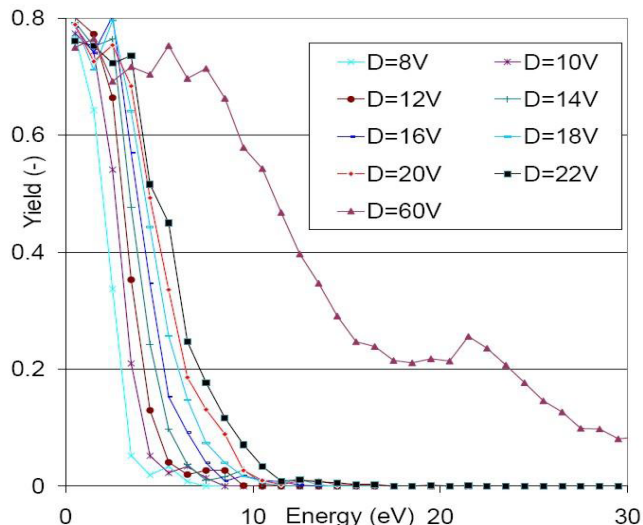

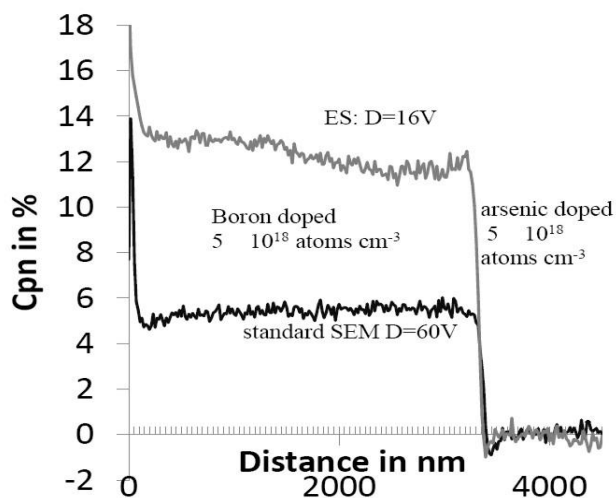Fig 2 Calculated change of cut off energy for various values of D.

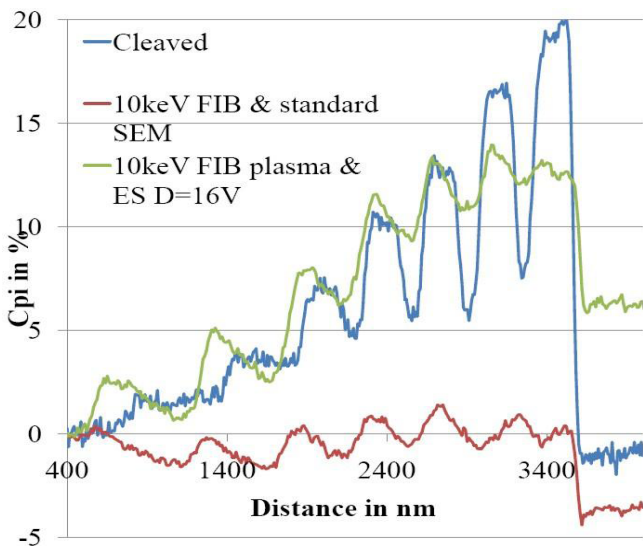Fig 3 C_{Pn} plots of p-n junction cross-section exposed to air for 1week, imaged by standard SEM and ES SEM (D=16V)

Fig 4 C_{pi} plots of staircase structure with Boron doped layers from left to right: $4x10^{15}$, $6.5x10^{16}$, $8x10^{17}$, $4x10^{18}$, $9x10^{18}$, $2x10^{19}$ cm^{-3}.

References
[1]   Y. Zhu et al., *Nature Materials* 8 (2009) 808
[2]   M.P. Seah, W.A. Dench, *Surface and Interface Analysis* 1 (1) (1979) 2
[3]   L. Reimer, *Image Formation in Low-Voltage Scanning Electron Microscopy*, SPIE OPTICAL Engineering press, 1993 p.117
[4]   C. Schönjahn, C.J. Humphreys, M. Glick, *Journal of Applied Physics* 92(12) (2002) 7667
[5]   D.C. Joy, M. S. Prasad, H. M. Meyer, *Journal of Microscopy, 215(1) (2004) 77*
[6]   E. Schreiber, H-J. Fitting, *J. Electron Spectroscopy and Related Phenomena* 124 (2002) 25
[7]   Z. Wang et al., *Appl. Surf. Sci.* 241 (2005) 80
[8]   C. Rodenburg thanks the Royal Society and EPSRC (EP/E030602/1) for funding this research.