CHANNELING CONTRAST MICROSCOPY; A NEW TECHNIQUE FOR MICROANALYSIS OF SEMICONDUCTORS

J.C. McCallum* and J.S. Williams†

* MicroAnalytical Research Centre, School of Physics,
University of Melbourne, Parkville, Vic., 3052.

† Microelectronics Technology Centre,
Royal Melbourne Institute of Technology, Melbourne, Vic., 3000.

Abstract

The technique of channeling contrast microscopy has been developed over the past few years for use with the Melbourne microprobe. It has been used for several profitable analyses of small-scale structures in semiconductor materials. This paper outlines the basic features of the technique and examples of its applications are given.

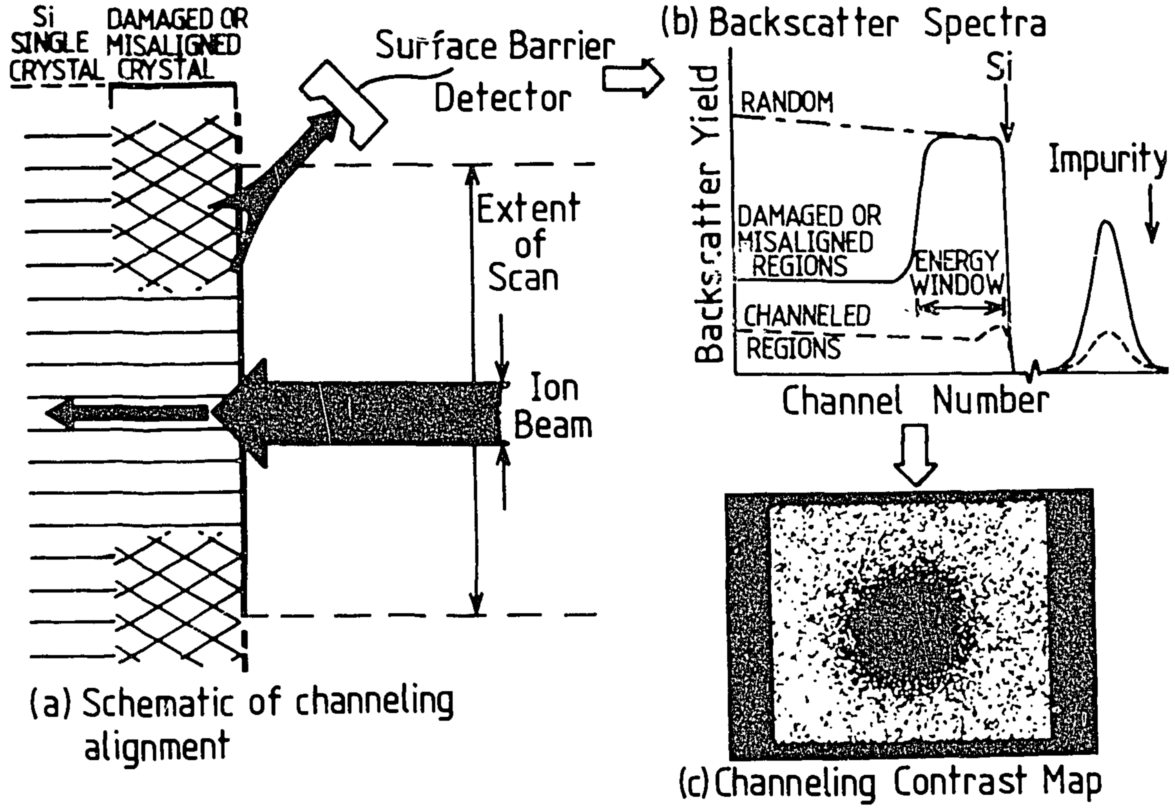
Introduction

The techniques of Rutherford backscattering (RBS) and channeling of MeV He^+ ions have long been recognised as valuable analytical tools in investigations of semiconductor materials and processes (1,2). However, in recent years, the study of micro-structures in semiconductors has become of increasing importance and hence probes with micron-dimensions are required. We have carried out such investigations by combining RBS and channeling with scanned He^+ microbeams produced by the Melbourne microprobe. Channeling contrast microscopy has evolved as a novel imaging technique due to our work in this area. It is sensitive in particular to (i) localised variations in crystal perfection and substrate orientation and (ii) variations in the location of impurities within crystal lattices and allows micron-sized structures to be identified. The technique has been successfully applied in investigation of locally laser-processed regions in silicon crystals (3) and to studies of individual grains in polycrystalline silicon.

Channeling Contrast

Channeling contrast imaging employs the versatile scanning and data collection facilities of the Melbourne microprobe (4,5). The basic principal involved in obtaining channeling contrast is illustrated in figure 1. Initially the sample alignment is adjusted via a two-axis goniometer until the He^+ beam is channeled in the crystal substrate. In this situation the yield of backscattered particles is sensitive to the rate at which the incident ions become dechanneled in the sample. Hence, with this alignment, as the beam is scanned over the sample the backscatter yield is highest, due to rapid dechanneling, in those regions where the crystal has been damaged or where the crystal orientation does not match that of the substrate. (In the illustration, such regions are indicated by cross-hatching.)

As shown in figure 1b, the Si backscatter spectrum from the regions of damaged or misaligned crystal will exhibit a high yield, approaching that of a random spectrum over the depth range of the imperfection. The spectrum from regions where the degree of crystal perfection and alignment match that of the substrate will exhibit a low yield, equivalent to the channeling yield from the substrate. By setting an energy window at a particular depth in the material (figure 1b) and displaying a two-dimensional map of backscattered particles from this window, a map which contrasts the channeled and non-channeled regions can be obtained (figure 1c). Regions where the beam is well channeled are indicated by a low density of backscattered particles (low density of points in the map).



(a) Schematic of channeling alignment

(c) Channeling Contrast Map

Figure 1: Schematic showing how channeling contrast images are obtained.

cw - Laser Annealed Silicon

The first demonstration of channeling contrast involved imaging of a locally laser-annealed region in ion-implanted Si(100) $^{(3)}$. Sb$^+$ ions were first implanted at 80 keV into Si(100) to a dose of 1 x 10^{15} Sb/cm^2, producing a surface layer of amorphised silicon. The sample was then locally annealed by a single pass of a laser beam, generated by a 10-W continuous wave (cw) argon ion laser. The backscatter analysis was carried out with a He$^+$ microbeam of lateral dimensions: 12 x 15 µm^2.

Figure 2 shows backscatter spectra generated from selected regions of equal area both within the laser stripe (region 1) and outside it (region 2). Comparison of the two spectra gives a channeling minimum yield of 4% for the recrystallised silicon within the stripe. This indicates that (i)good channeling has been obtained under the microbeam conditions employed in the analysis, and (ii) good epitaxial regrowth of the silicon has occurred during the laser anneal. The backscatter yield from within the indicated energy window (figure 2) was used to generate the channeling contrast map of figure 3a. The dark region (low backscattered yield) across the map clearly indicates the good crystal arising from the laser anneal. In figure 3b, the backscattered yield is plotted as a function of distance (at 4 µm steps) across the laser stripe at the position indicated by the window in figure 3a. The dip in yield has a full width at half maximum (FWHM) of 36 µm which corresponds well with the diameter of the incident laser beam.

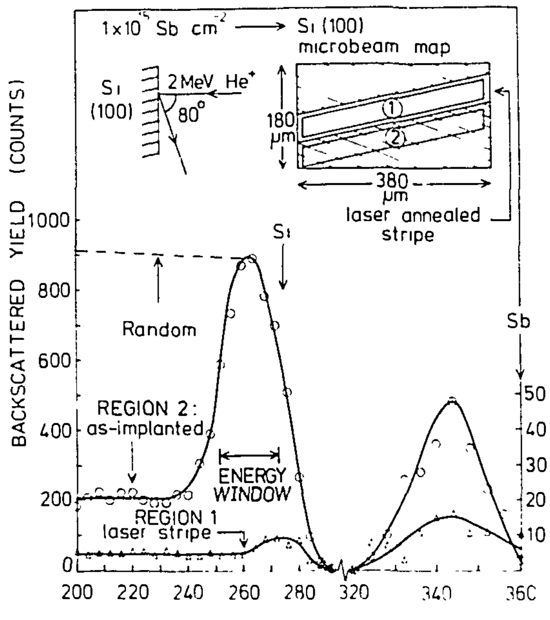


Figure 2: Selected area RBS/ channeling spectra taken from regions of equal area both within the laser stripe (Region 1) and outside it (Region 2).

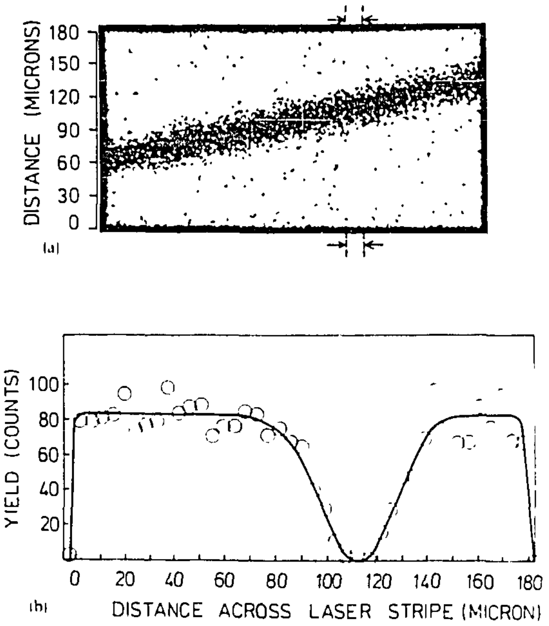


Figure 3: (a) Channeling contrast map showing the laser annealed crystal (dark region). (b) Backscattered yield as a function of position (4 µm steps) across the laser stripe. Statistics are integrated from within a narrow strips, as indicated in (a).

Polycrystalline Silicon

Channeling contrast microscopy has provided a unique way of examining impurity and damage distributions within individual grains of ion-implanted polycrystalline silicon (polysilicon). For this analysis a commercially produced polysilicon material with grain sizes ranging from a few microns to approximately 1 mm was implanted with Sb^+ ions and annealed at 650°C for 30 minutes. Channeling contrast analysis was carried out by aligning the sample so that the He^+ beam (unscanned) was channeled in a particular grain of interest. The beam was then scanned over a region containing the aligned grain.

Figure 4 is an optical micrograph of a scanned region and indicates the typical grain structure. A map generated using a Si energy window is shown in figure 4b and grains in which the beam is well channeled are clearly illustrated by the dark regions on the map (grains 1 and 2). A degree of partial channeling is also observed for grains 3 and 4 (as indicated by the medium point densities). The feature running diagonally across the lower half of the scan region is a scribed track used as a location marker. As expected, channeling is poor in the vicinity of this track and topographical effects such as shadowing are observed. The Sb map (figure 4c) shows two features of interest: (i) the Sb yield is lower (dark region) in the well channeled grains (1 and 2), indicating substitutionality of Sb, and (ii) the scratch contains bright areas which indicate segregation of Sb to this region. Selected area RBS/channeling spectra for the scanned region are shown in figure 5. The aligned spectrum was taken from grains 1 and 2, in which the beam is well channeled, and the non-aligned spectrum was taken from a region of equal area over the non-channeled grains. The area about the scribe mark was excluded from the spectra since it would introduce spurious topographical effects. Of particular interest in these spectra is the non-Gaussian shape of the Sb profiles which indicates redistribution of Sb during annealing. This movement of Sb was not observed for a similar region on the same sample indicating possible grain-orientation dependent redistribution effects.

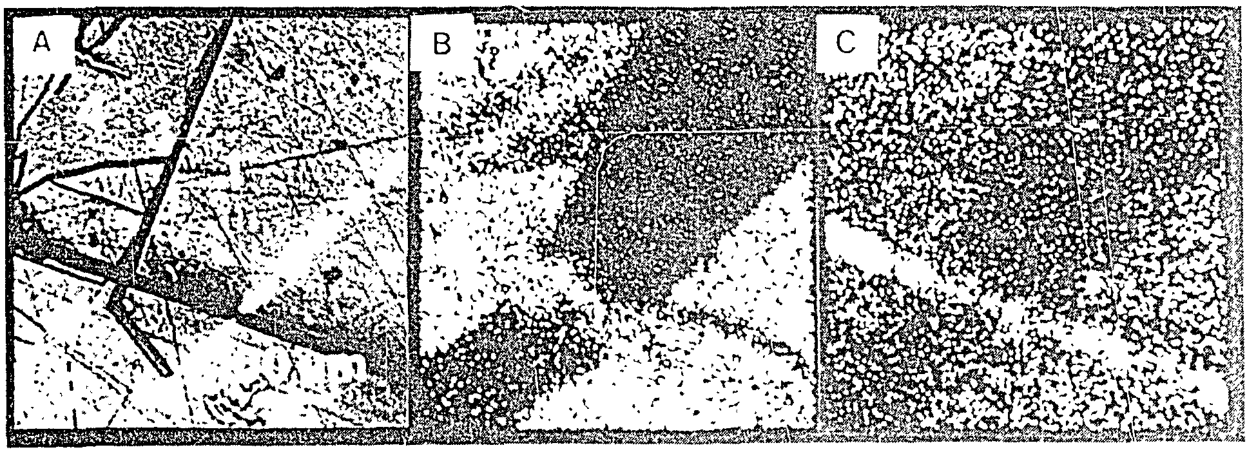


Figure 4: (a) Optical micrograph of region of polysilicon sample scanned with the microbeam. (b) Map generated from Si energy window. (c) Map generated from Sb energy window.

Pulsed-Laser Annealing of Silicon

The channeling contrast map shown in figure 1c illustrates a pulsed-laser annealed spot in a Si(100) sample which had been pre-amorphised and implanted with In^+ ions. The laser annealed region has a diameter of 50 microns and the map indicates good crystal regrowth within the spot. This is part of a study of implant redistribution effects during high temperature, short-time annealing of amorphous layers in silicon. Channeling contrast imaging has proved to be an invaluable aid in this work since it provides the only means of locating and analysing these laser-induced features.

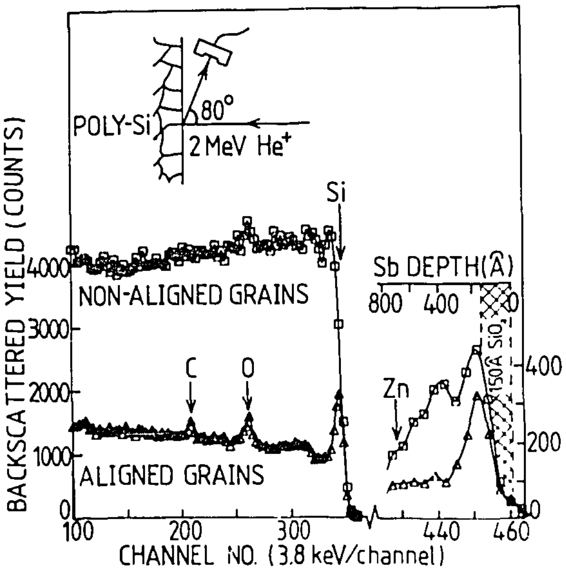


Figure 5: Selected area RBS/ channeling spectra from aligned grains (1 and 2) and non-aligned grains.

Conclusion

The technique of channeling contrast microscopy has been described and outlines of several applications have been given.

The Australian Research Grants Committee and the Commonwealth Special Research Centres Scheme are acknowledged for financial support of this project.

References

1. W.K. Chu, J.W. Mayer and M.A. Nicolet: Backscattering Spectrometry, Academic Press (1978).
2. L.C. Feldman, J.W. Mayer, S.T. Picraux: Materials Analysis by Ion Channeling, Academic Press (1982).
3. J.C. McCallum, C.D. McKenzie, M.A. Lucas, K.G. Rossiter, K.T. Short and J.S. Williams, Appl.Phys.Lett. 42, 827 (1983).
4. G.J.F. Legge and I. Hammond: Journal of Microscopy 117, 201 (1979).
5. R.A. Brown, J.C. McCallum, C.D. McKenzie and J.S. Williams: Proceedings of the MRS Spring Meeting (April, 1985).