6.781
Homework Set #4

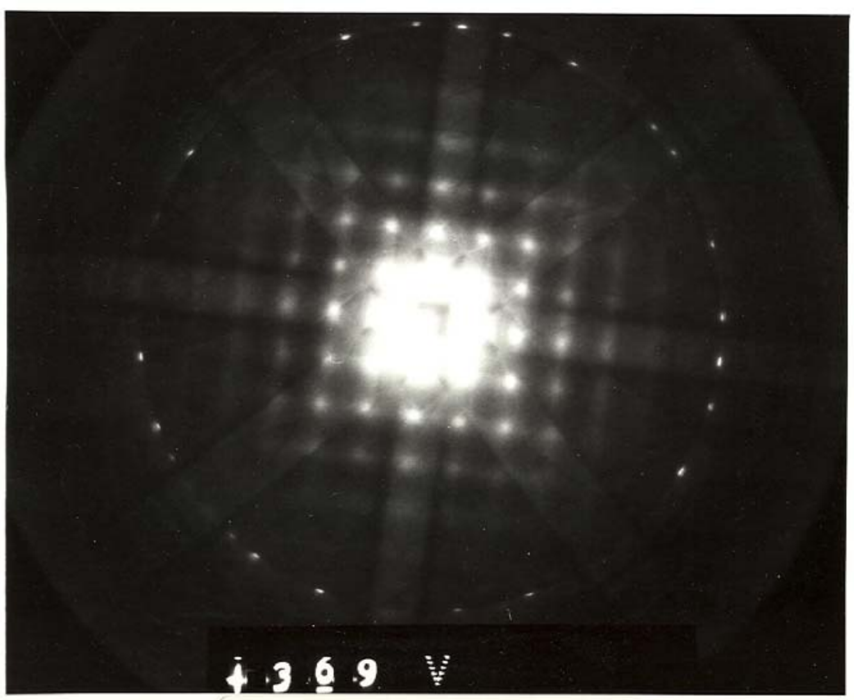
12. Calculate the deBroglie wavelength of an electron at 10 KeV, 100 KeV and 1000 kinetic energy, both classically and relativistically. In which of these regimes should you start to concern yourself with relativistic effects?

13. This problem is intended to clarify exactly what is meant by "elastic" collisions of electrons with a sample in electron microscopy.

    (a) Show that in any collision between an energetic light particle (e.g. an electron in an energetic beam) and a heavy particle at rest (e.g. a nucleus in a substrate) in which total energy and momentum are conserved, very little energy transfer occurs, and the collision can be considered "nearly elastic" from the point of view of the light particle.

    (b) Calculate the maximum energy lost in the collision of a 100-keV electron with a gold nucleus.

14. Here we show the electron-diffraction pattern for a 100 kV electron beam incident perpendicular to a thin film of (100) Si [i.e. 4-fold symmetry]. Note the large number of diffracted beams. The Si (100) sample can be considered a 2-dimensional grid of 0.54 nm period.



Transmission electron diffraction pattern from a thin film (~0.4μm) of (100) Si.

Within the acceptance aperture of the TEM there are diffracted spots out to 6th order.

(a) calculate the acceptance half-angle (i.e., α) of the TEM.

Consider an analogous optical diffraction pattern from a grid pattern.

(b) Assuming an optical wavelength of 400 nm, what grid period would give the same number of diffraction spots within an acceptance angle of 0.01 radians.

(c) What is the highest order of diffraction one could get from such a grid using the 400 nm incident radiation.

(d) X-ray diffraction analysis is normally done with an x-ray wavelength of 1.54Å (0.154 nm). For the above Si crystal, what is the highest order of diffraction that is possible?

15. (a) Calculate the resolution of an electron microscope operating at 100 KeV with an objective lens of 1 mm focal length.

(b) Do the same for 1 KeV and a 1 cm focal length.

(c) Give a rough estimate of how much the focusing current in the coil of the lens would differ in the two cases, assuming that the focal length of the lens is the same in the two cases (100 KV & 1KV). (i.e., factor of 100, $(100)^2$ etc.?)

16. The attached figures are taken from the book by R. B. Marcus and T. T. Sheng "Transmission Electron Microscopy of Silicon VLSI Circuits and Structures" John Wiley & Sons Inc. (1983).

In the Figures on pages 120 and 121 (upper) and 198/199 compare the appearances of oxide, poly Si and single-crystal Si. Why are there dark bands in the single-crystal Si but none in the oxide?

References

Problem 16

Marcus, R. B. and T. T. Sheng. *Transmission Electron Microscopy of Silicon VLSI Circuits and Structures*. New York, NY: John Wiley and Sons, Inc., 1983.
pp. 120-121, 198-199. ISBN: 0471092517.