Chapter 7
Ion-Generated Damage

It has to be expected that both ions and electrons will damage specimens under examination to a greater or lesser degree. Electrons are low in mass but can travel at velocities which are a significant fraction of the speed of light. In general, electrons do not significantly damage metallic or inorganic specimens, but even relatively low doses of electrons can be expected to chemically alter or destroy organic materials such as polymers and biological samples. The threshold dose above which damage can be expected is typically as little as one to two electrons per square angstrom and may result in mass loss of the target, or to the removal of a high fraction of certain chemical components such as hydrogen or phosphorus. Knock-on damage, in which an incident electron releases an atom from its surrounding so leading to large-scale damage of crystals, depends directly on beam energy, so, for example, the damage threshold for carbon (atomic number 6) is 85 keV, but is 240 keV for Si (atomic number 14).

Ions are at a minimum from 5,000× to 500,000× times heavier than electrons and so inflict significantly more damage. In addition, the nature of ion damage is more varied in form than that for electrons (Benninghoven et al. 1987) because ions can generate point defects such as vacancies and interstitials within the materials that they attack. The effects of such damage depends on the binding energy of atoms in crystal lattice, and on the displacement which they undergo. Typically, the displacement becomes negligible for energies above 100 keV. However, the sputter yield rate at such energies is still high enough—typically 0.1 atoms/per ion at 30 keV—to allow Helium ions to pattern, materials such as graphene sheets. A study by Livengood et al. (2006) showed that, while the damage caused to wafer silicon by 30 kV He^+ ions was negligible, at higher energies and/or when subjected to significantly larger beam doses, even materials such as gold nanospheres and carbon nanotubes could be damaged by the He^+ beam. Consequently, the absence of significant damage at one energy and dose cannot always be taken as being evidence of a similar outcome at some higher energy. On the other hand for those materials which can readily be sputtered, He^+ ions are ideally suited for patterning as the ions suffer little lateral scatter and so are capable, for example, of precisely cutting holes, or fabricating slots, no more than a few nanometers in diameter and spacing.

D. C. Joy, *Helium Ion Microscopy*, SpringerBriefs in Materials,
DOI: 10.1007/978-1-4614-8660-2_7,