Beam-induced damage to graphene in the helium ion microscope

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Graphene is currently attracting massive worldwide interest for its potential to be the foundation of a new generation of nanoscale electronic devices [1, 2]. This is owing to its remarkable properties that include very high carrier mobilities [3] and large current carrying capabilities which could enable the development of faster, less power-hungry devices, pushing the computer industry beyond what is possible with conventional silicon-based CMOS technology. One route for graphene-based electronic integration involves replacing the channel material in field-effect transistors with graphene, shaped into nanoribbons to open up a band gap. Alternatively, quantum dot structures fabricated in graphene could form the architecture for single electron transistor (SET) based electronics [4]. Both approaches require the development of patterning technologies to enable accurate nanoscale fabrication of graphene devices. Currently, the most established graphene device fabrication technique uses electron-beam lithography to pattern resist deposited on top of the graphene, followed by oxygen plasma etching [5,6]. However, the size of the patterns this process is capable of producing is limited by underetching of the resist. Recently, a new patterning technique based on direct milling of graphene using a focused beam of helium ions generated in a helium ion microscope (HIM) has emerged [7,8].

Helium ion microscopy (HIM) is a new surface imaging technique that involves scanning a focused beam of helium ions across a surface to generate an image from the resulting secondary electron (SE) emission, in a similar way to scanning electron microscopy (SEM) [9,10]. An atomically sharp and extremely bright source, combined with the larger momentum (and so smaller de Broglie wavelength) of helium ions compared to electrons, enables a sub-nanometer probe size at the sample surface and so high resolution imaging. Researchers have demonstrated that the tool can also be used to selectively sputter graphene to create intricate nanoscale designs, offering the potential of resist-free patterning of graphene on a finer scale compared to other techniques [11,12].

Patterning of graphene in a HIM involves firstly locating a suitable area on a graphene flake by imaging at a low magnification. The magnification is then increased and control is switched to a pattern generator to scan the beam in the required pattern. It is known that low energy ionic bombardment can cause damage to the graphene lattice [13] so it is important to establish whether HIM imaging to locate a suitable area for patterning can be carried out whilst avoiding damage to the graphene to the extent that the electronic properties are degraded.

Here we present Raman spectroscopy results of a graphene flake before and after exposure to the helium ion beam in a HIM at various ion doses. Damage to the graphene lattice manifests in a Raman peak at around 1350 cm^{-1} and the ratio of this D peak to the G peak, present in pristine and damaged graphene at around 1605 cm^{-1} provides a measure of the extent to which the lattice is damaged. An area of a pristine graphene flake is imaged in the HIM at a field of view (FOV) of 50 µm for 1 min giving a total dose of 1.59×10^{13} ions/cm^2. The FOV is reduced (magnification increased) and the exposure is repeated, resulting in overlaid areas exposed to increasing He ion doses (Figure 1 (a)). We then define a grid of pixels overlaying the exposed flake (b), and collect Raman spectra from each pixel, allowing the mapping of the D and G peak intensities (c). The average D to G ratios can then be plotted as a function He ion dose (d).

We will use this data to quantify the disorder induced in graphene through He ion bombardment which will enable an assessment of the extent to which imaging in the HIM can damage graphene and lead to guidelines on maximum ion doses to avoid substantial damage to graphene devices.

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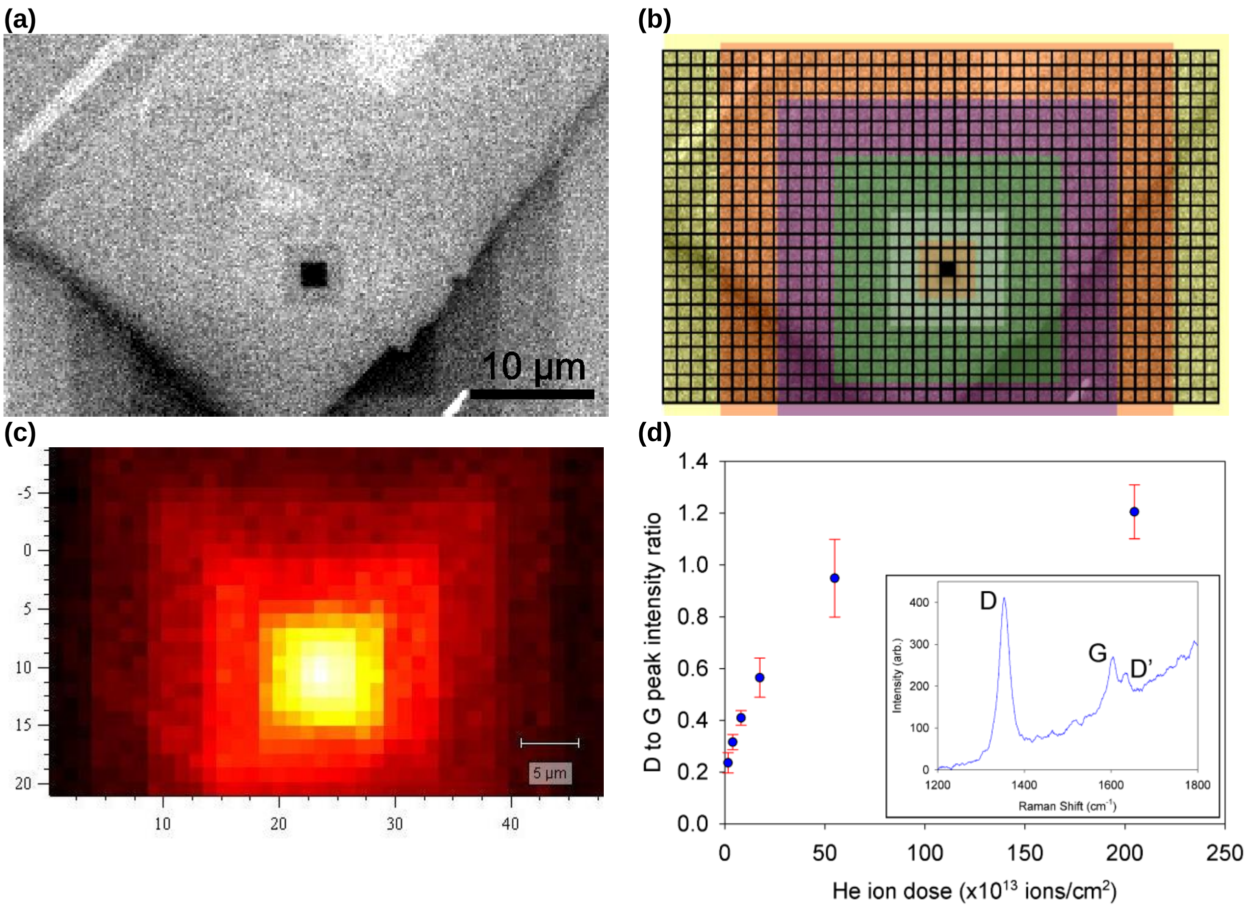

Figure . 1 (a) HIM image of exposed graphene monolayer, (b) overlay of Raman mapping grid and exposure areas, (c) Raman mapping of a region of graphene monolayer showing how the intensity of the D peak at 1353 cm-1 varies after exposure to the helium beam, (d) D to G peak intensity versus dose for exposure of graphene monolayer to 30 kV He ion beam, inset shows Raman spectrum for area exposed at a FOV of 5 µm.