School of Physics, Peking University

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Helium-ion Microscopy *for Graphene Nanodevices*

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UCC
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EUROPEAN REGIONAL DEVELOPMENT FUND
HEA
Higher Education Authority
An tÚdarás um Ard-Oideachas

The Helium-ion “Microscope”

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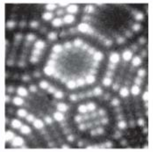
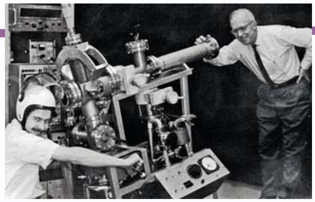
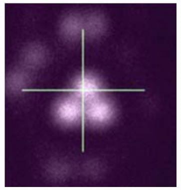
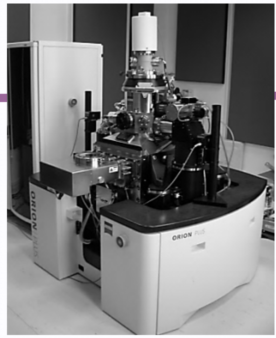
A suitable source for an ion microscope





1951
Field ion microscope





2006
Zeiss Orion

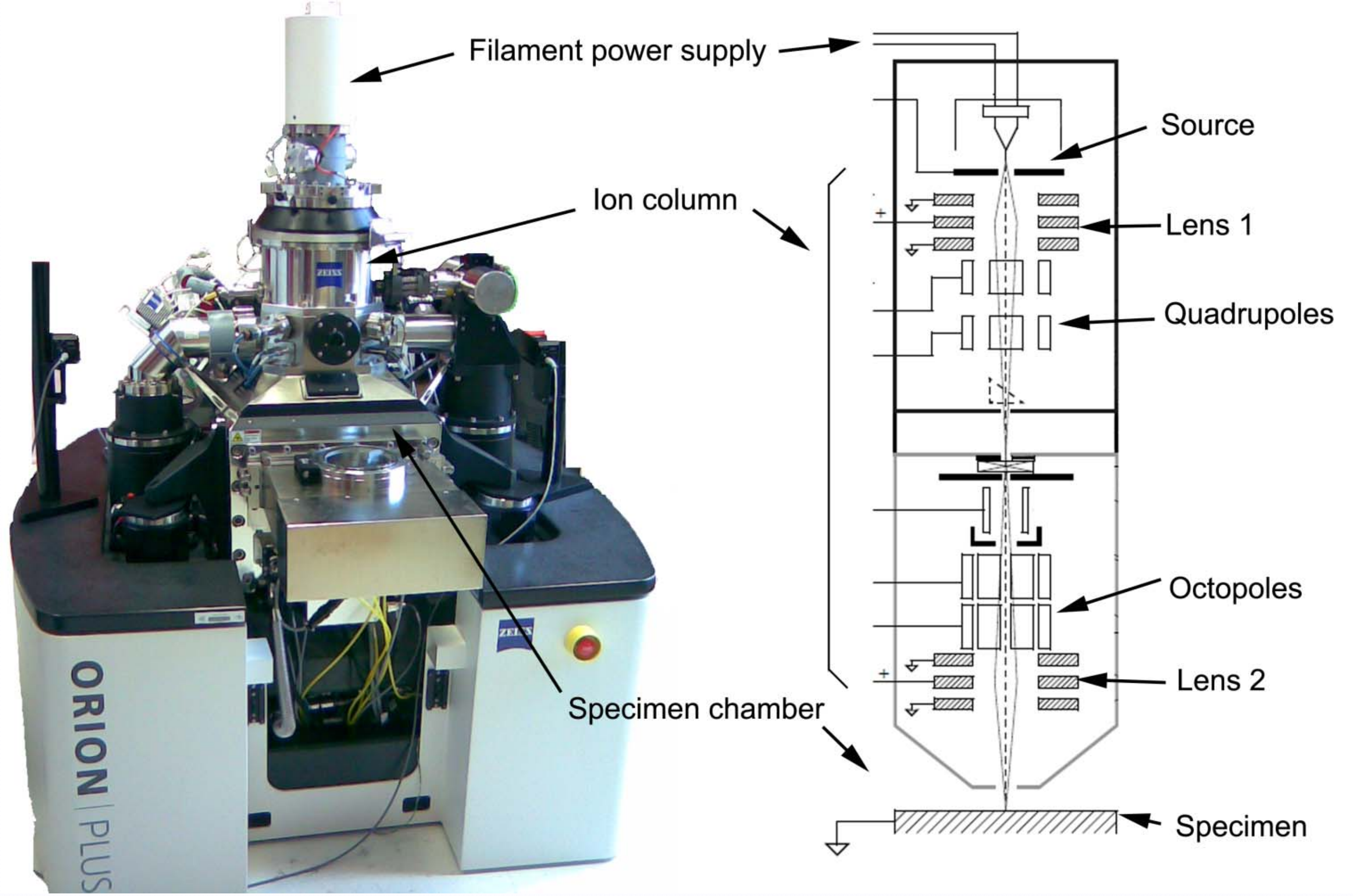
2009
Zeiss Orion Plus

Ga, Ne, He beams

2012
Orion Nanofab

Economou, N. P., J. A. Notte and W. B. Thompson (2012). "The history and development of the helium ion microscope." Scanning 34(2): 83-89.

How does the HIM works?



Current status – General Information

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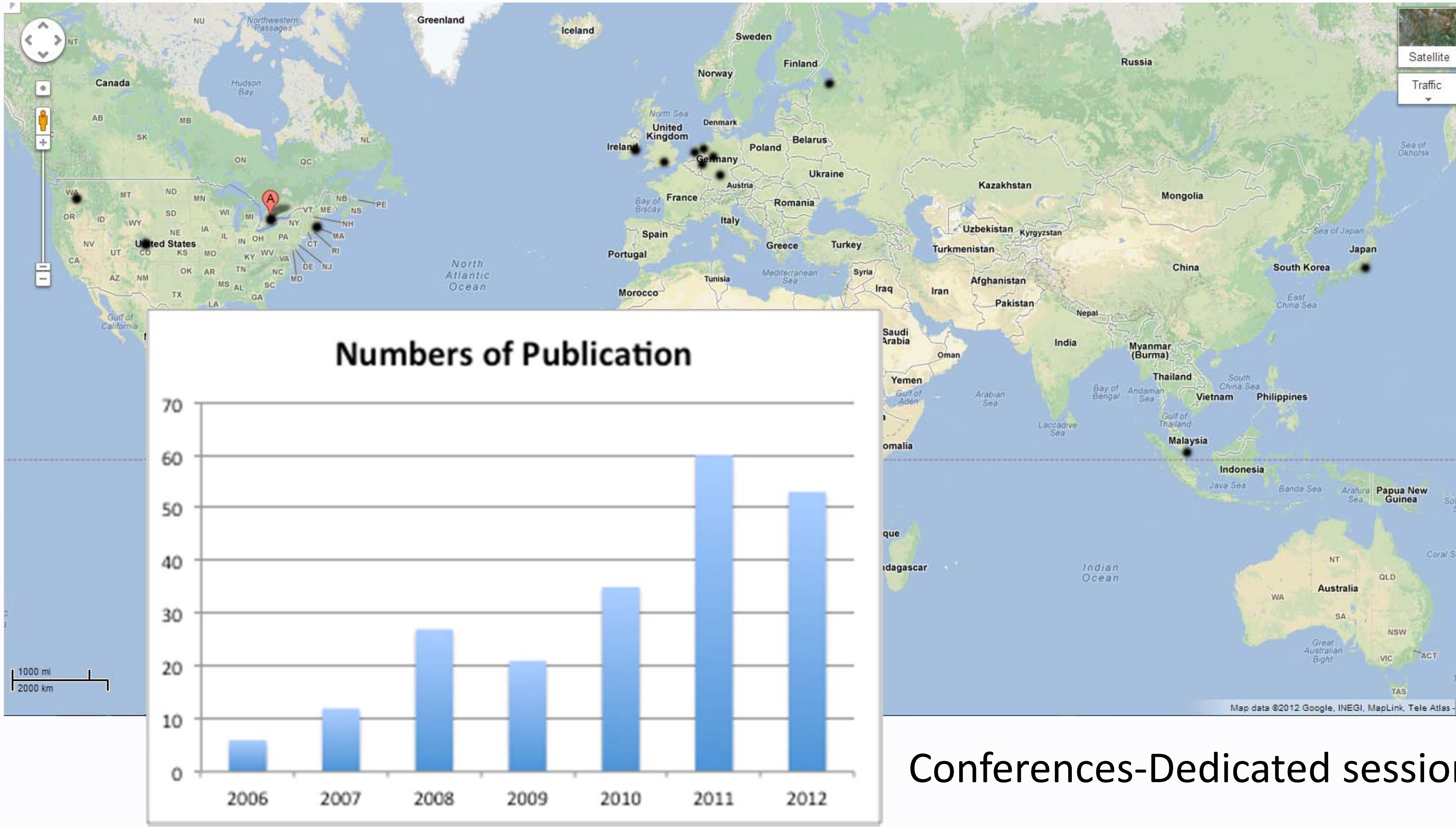
Labs equipped with HIM



Conferences-Dedicated sessions

What can it do? Better or worse?

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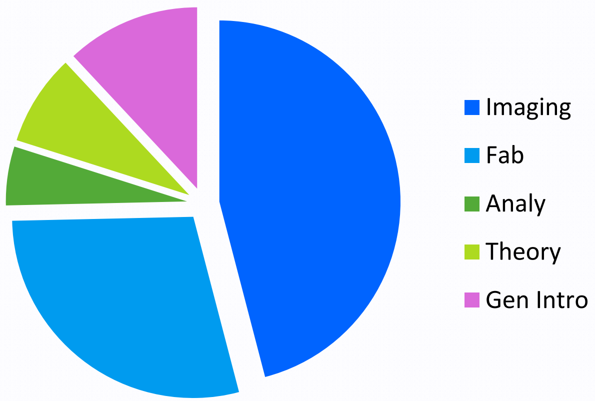
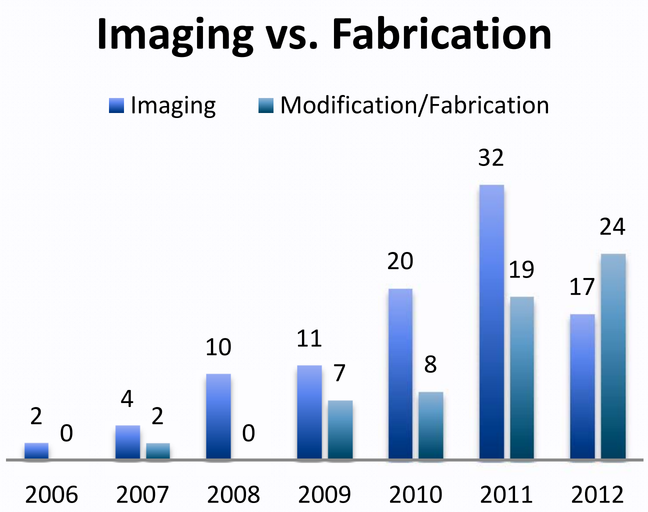
- **Resolution**
  < 0.4 nm at 35kV
- **Field of View**
  Variable from 1 mm to 200nm
- **Energy Spread**
  0.25-0.5 eV
- **Beam current**
  1fA – 100 pA
- **Sample size**
  50 mm in diameter x 25 mm thick
- **Detectors**
  - Everhart-Thorley secondary electron detector
  - Energy resolved backscattered ion detector
  - Spectroscopically resolved photon detector
  - Transmitted ion beam detector
  - SIMS
- **Attachments**
  - GIS system
  - Beam control system
  - Nanomanipulators





Stopping power and signal generation

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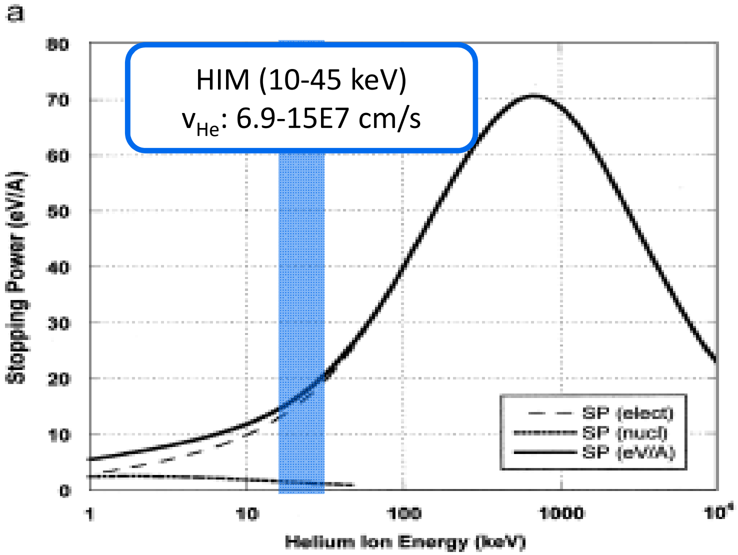
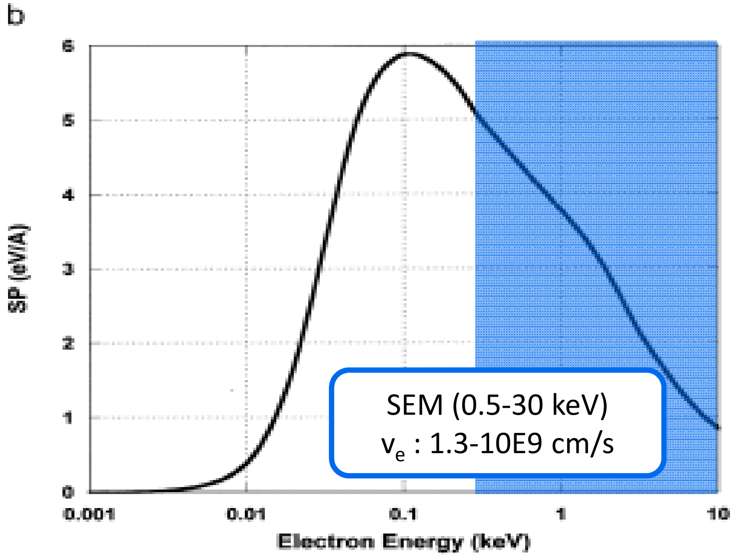
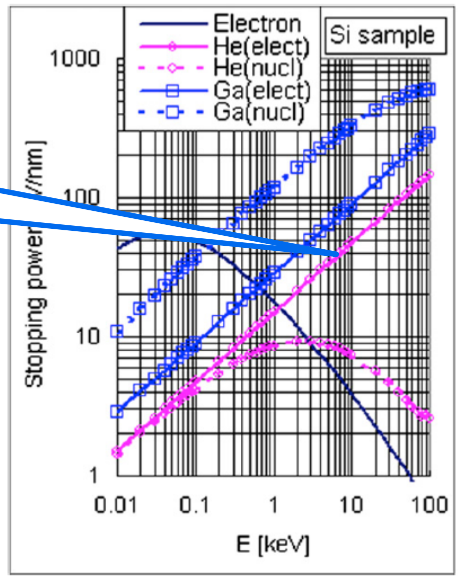




Yield of 2nd electrons

Larger Stopping power and thus Stronger interaction

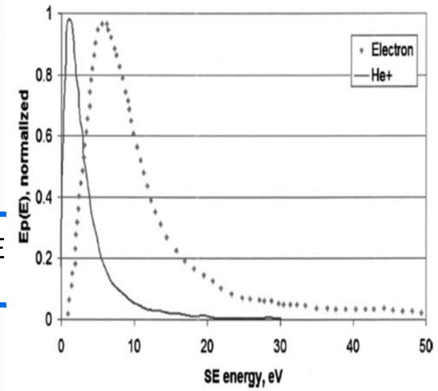


Energy spectrum of 2nd electrons:

Primary particles' energy decrease while they travel inside the sample

Electron: 2nd high E portion increase

HIM: 2nd high E portion decrease



Interaction between He^+ and Carbon

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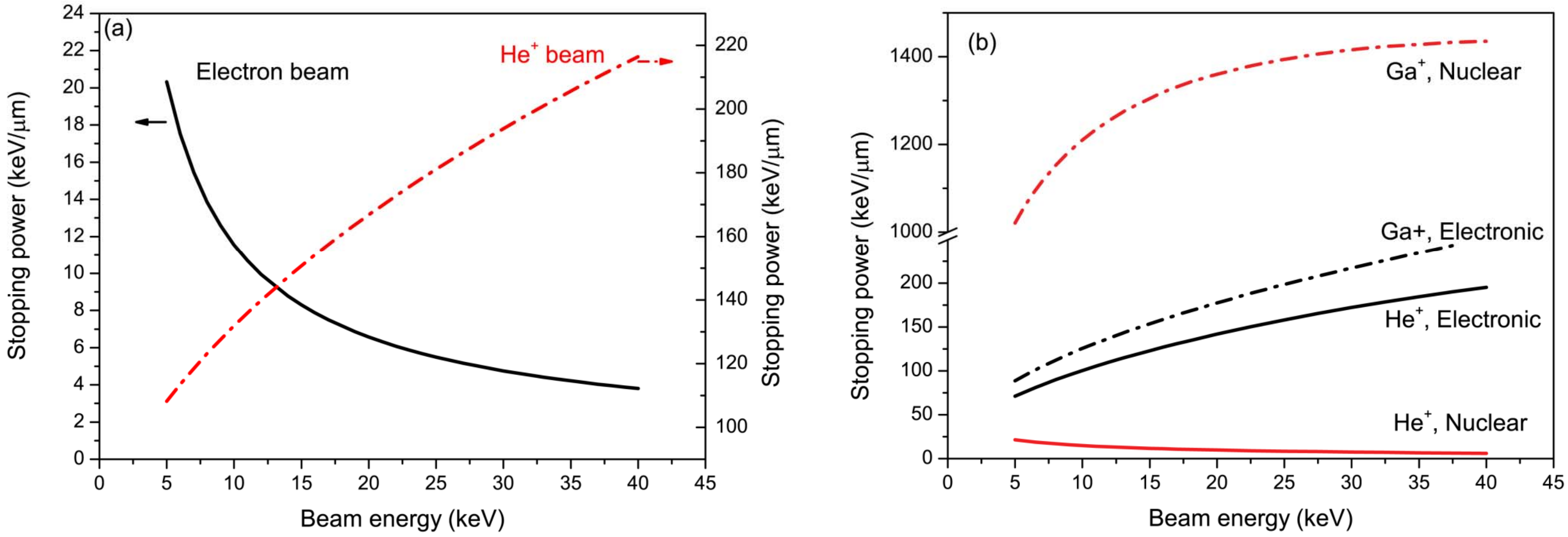

- Stopping power as a function of beam energy: He^+ beam (Dashed line) and electron beam (solid line). They follow opposite trends as the beam energy varies;
- The contributions of electronic and nuclear scattering to the stopping power: Ga^+ beam (Dashed line) and He^+ beam (solid line).

Interaction and information volume

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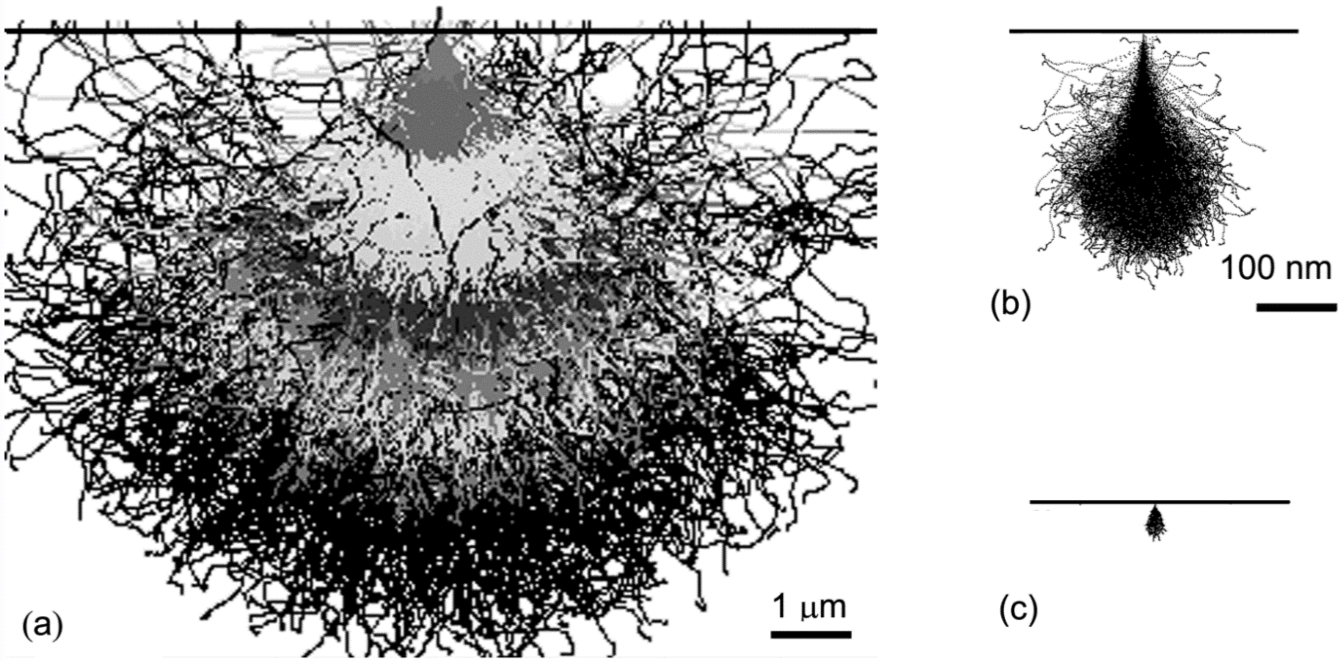

Simulated interaction volume of 30-keV charged particle beam with carbon: (a) the electron beam; (b) the helium-ion beam; and (c) the gallium-ion beam. Note the scale bars (b, c share the same) – the magnification for the He^+ and Ga^+ are 10 times larger than the electron.

2^{nd} iSE imaging: topographical contrast

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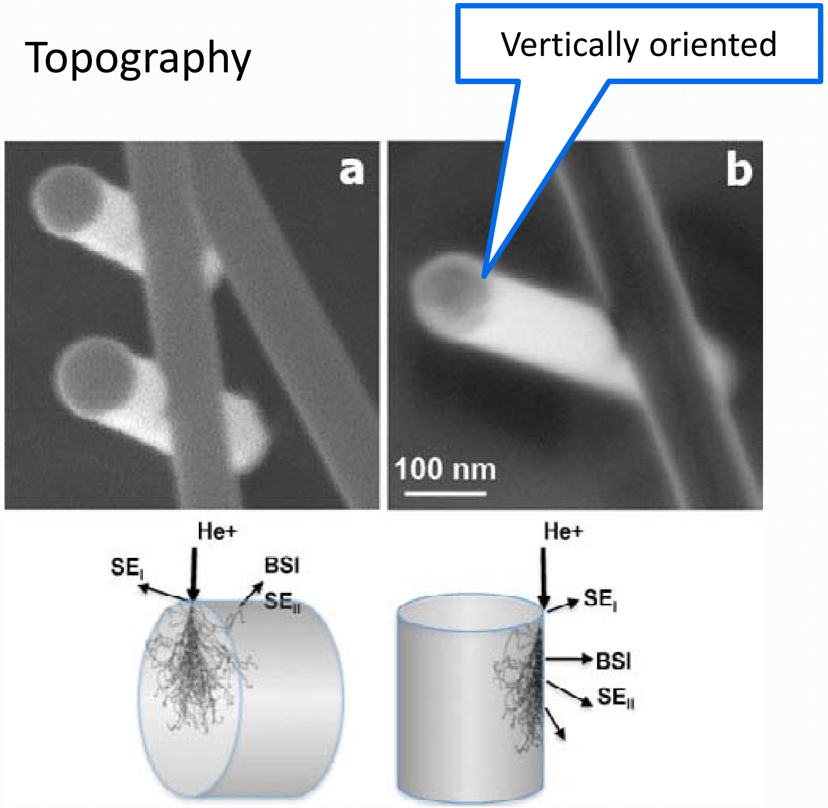
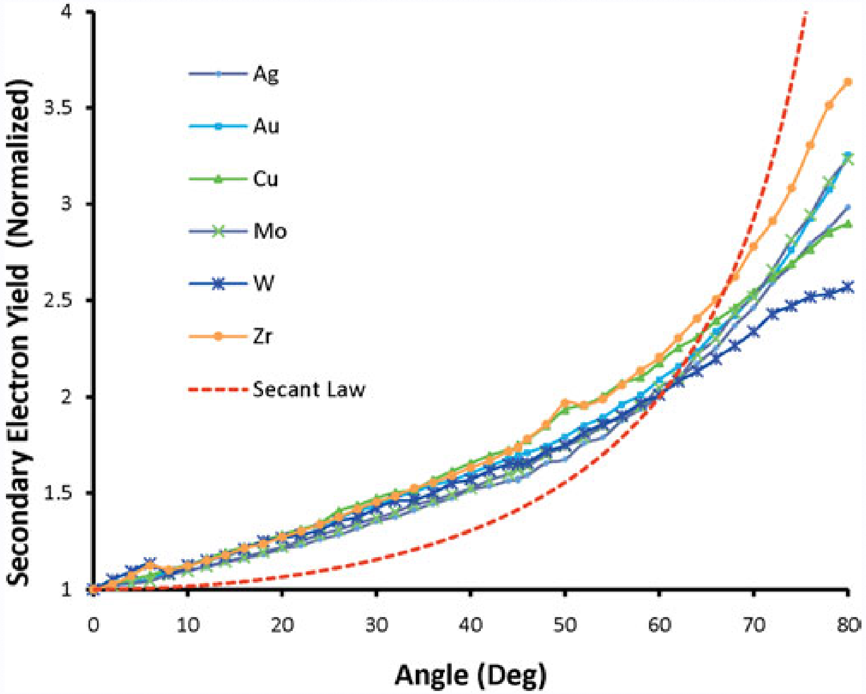
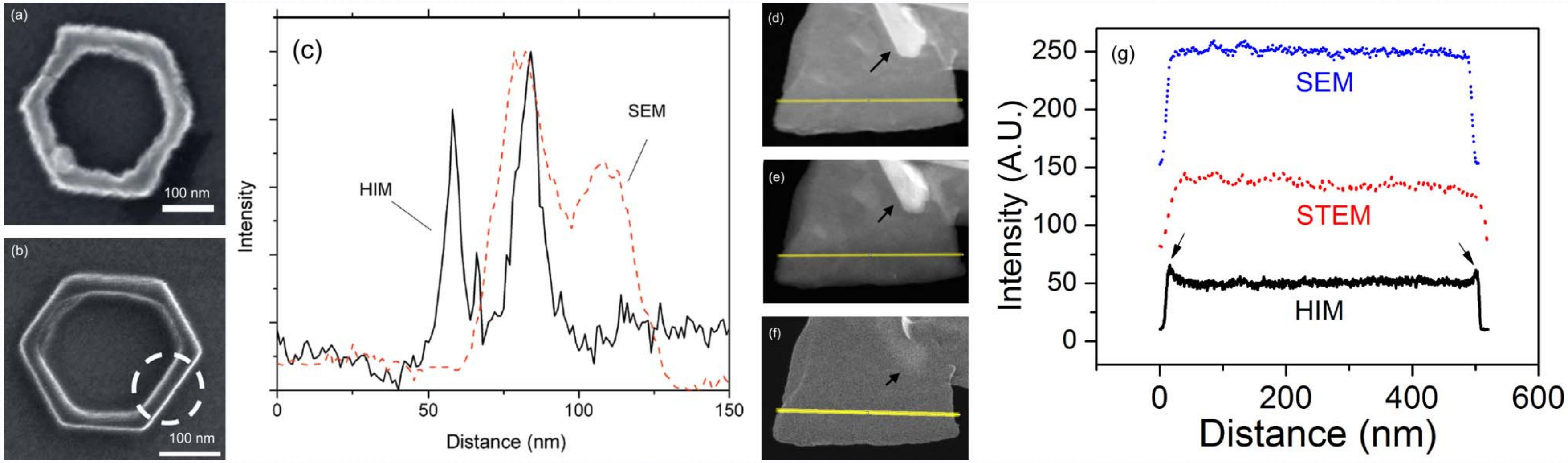
Topography



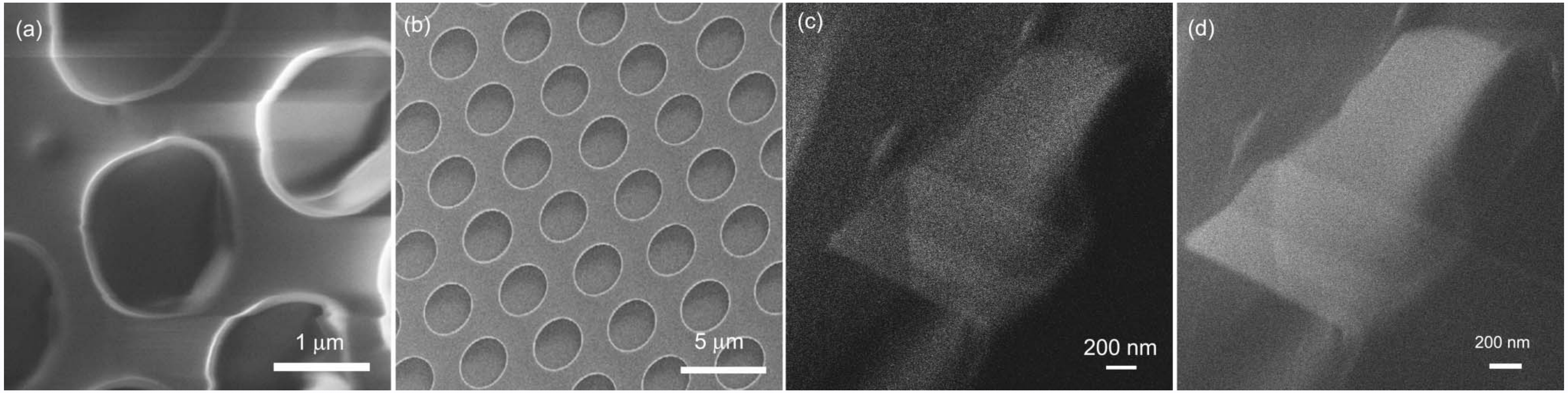


Metrology

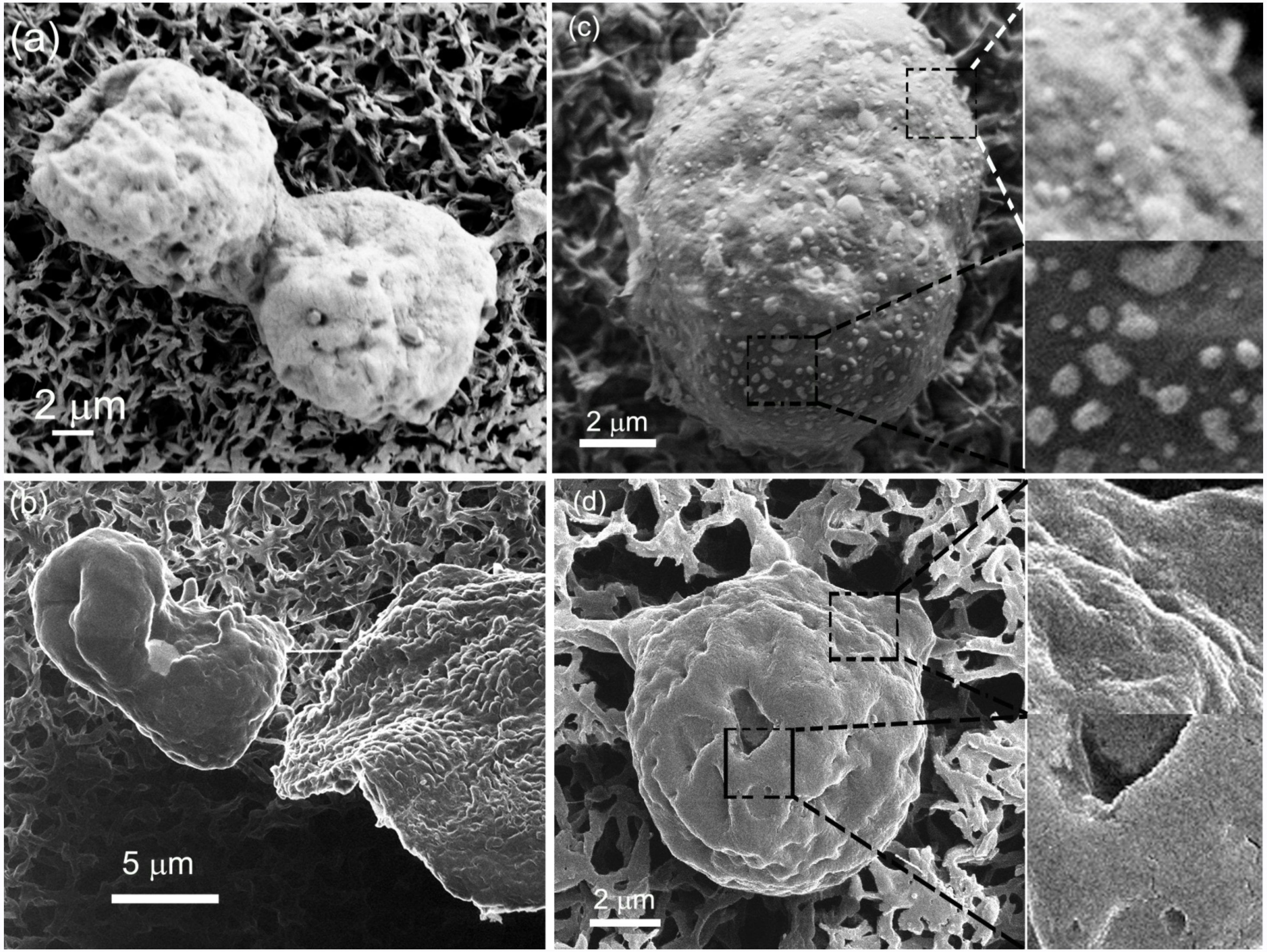


(a) and (b) are SEM and HIM images of a Ni/Co nanoparticles respectively. (c) the signal intensity was drawn as a function of the position along a line perpendicular to its side wall. (d-f) SEM, STEM, and HIM images of a graphene flake. The intensity along the line indicated in the images was drawn in (g).

Insulating samples

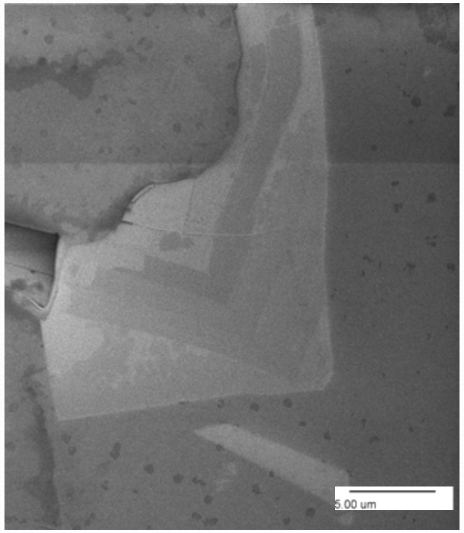


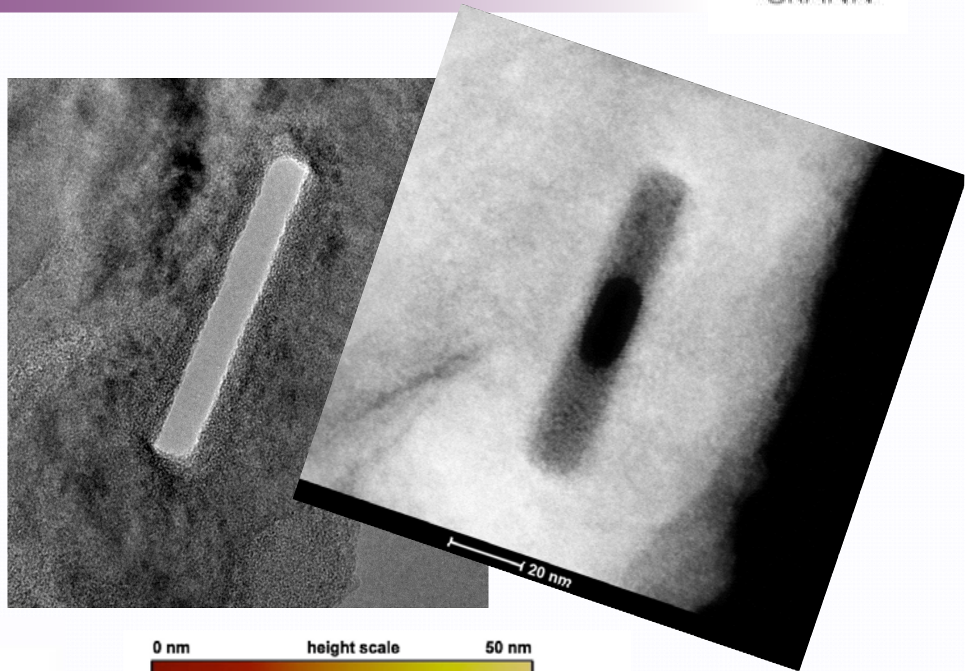
Charging effects and charging compensation in SEM and HIM. (a) An SEM image of micrometer sized pores in a polymer sample shows artifacts caused by the charging and (b) the HIM image of the same pores with charge compensator on reveal the surface clearly; (c) and (d) are HIM images of graphene embedded in insulting polymers without and with the flood gun, i.e. the charge compensator in the HIM.

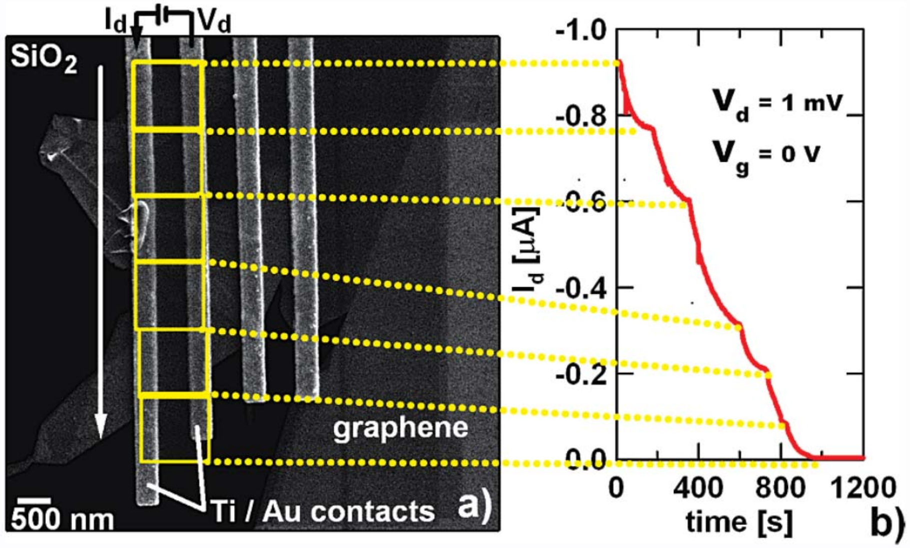


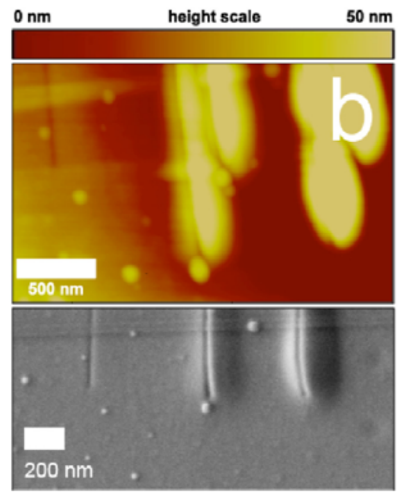
(a) SEM image of a coated Caco2 cells (b) HIM image of uncoated Caco2 cells. The effect of the large depth of the focus in the HIM can be seen from (c) SEM image and (d) HIM image of Caco2 cells.

Challenges – Contaminations and damage









large dose 20, 100, 200 nCcm-1

Acs Nano, 2009. **3**(9): p. 2674-2676.

Beam Deposition and Lithography

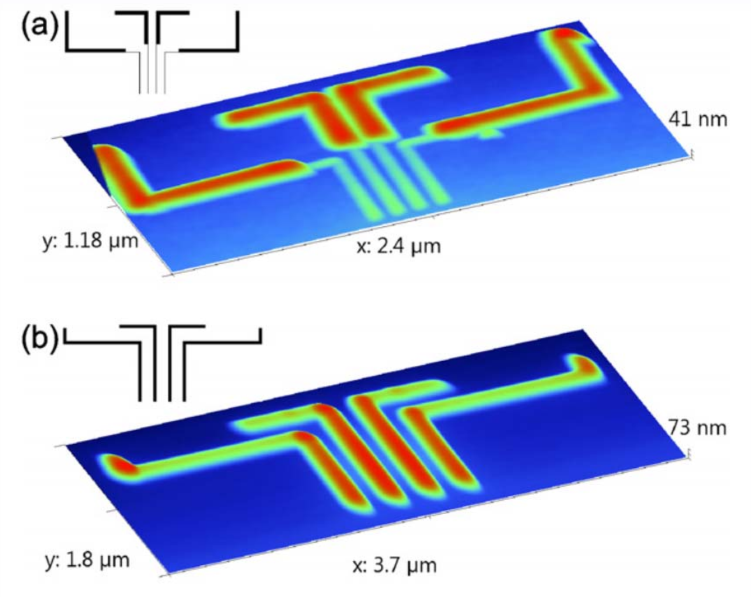


Fig. 4. AFM scans of examples of 4 point Hall bar contacts formed by He ion induced deposition of (a) platinum, (b) tungsten. The insets show the bitmap designs used by the pattern generator.

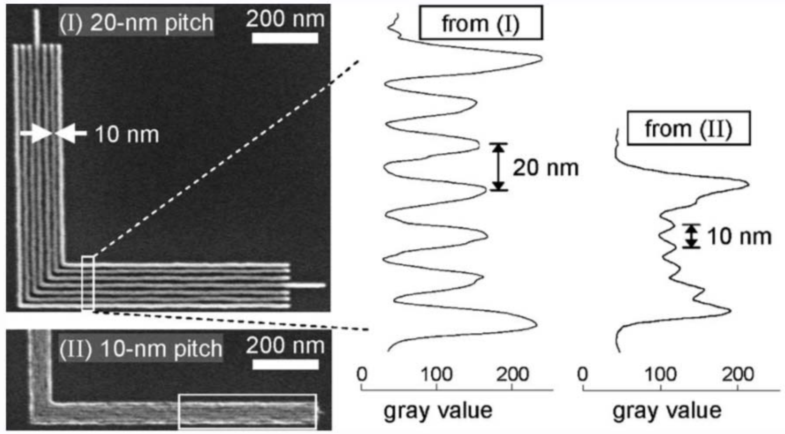


FIG. 2. (I) Scanning-electron micrograph of helium-ion-patterned, 20 nm pitch nested Ls of 25-nm-thick HSQ on silicon; line dose was 0.232 nC/cm (exposure step size was 1.25 nm and dwell time per exposure point was 104 μs). (II) A region of 10 nm pitch nested Ls at the same imaging magnification as (I); the line dose was 0.0834 nC/cm or ≈50 ions/nm (exposure step size was 1.25 nm and dwell time per exposure point was 37.3 μs). Averaging across each row of pixel values in the white-boxed areas obtained cross-sectional slices that show the modulation apparent in each nested-L structure. Both structures are from sample "B" (see text for processing details).

Boden, S.A., et al., *Focused helium ion beam milling and deposition.* Microelectronic Engineering, 2011. **88**(8): p. 2452-2455.

Winston, D., et al., *Scanning-helium-ion-beam lithography with hydrogen silsesquioxane resist.* Journal of Vacuum Science & Technology B, 2009. **27**(6): p. 2702-2706.

Graphene devices: the demands

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- **Characterization**
  - General morphology: smoothness, continuous, uniformity, size, thickness
  - Impurities and defects
    - Macroscopic wrinkles, ruptures, folds, voids
    - crystal quality and orientation, edge configurations
- **Modification**
  - Specific geometry: GNR
  - Chemical functionalization
  - Ordered structures (edges, arrays, defects)
- **Fabrication**
  - Nano-sized contacts
  - High density structures

We need:

- Reliable characterization methods
  - Dimension
  - Atomic resolution
  - Chemical analysis
  - Non-destructive
  - High throughput
  - High sensitivity
  - Low cost
- Highly-controllable modification/fabrication with desirable precision and accuracy

The Team

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TCD

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University College Cork, Ireland

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NDP
National Development Plan 2007 - 2013

SEVENTH FRAMEWORK PROGRAMME

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