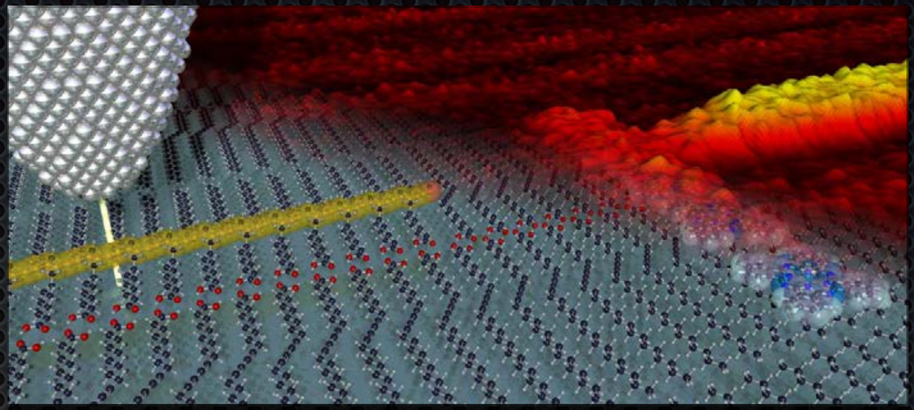

Room temperature electronic localization in a single graphene layer on sapphire by He-ion irradiation

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International Center for Materials Nanoarchitectonics (WPI-MANA), National Institute for Materials Science (NIMS), ***Japan***

Nanoelectronics Research Institute, AIST, ***Japan***

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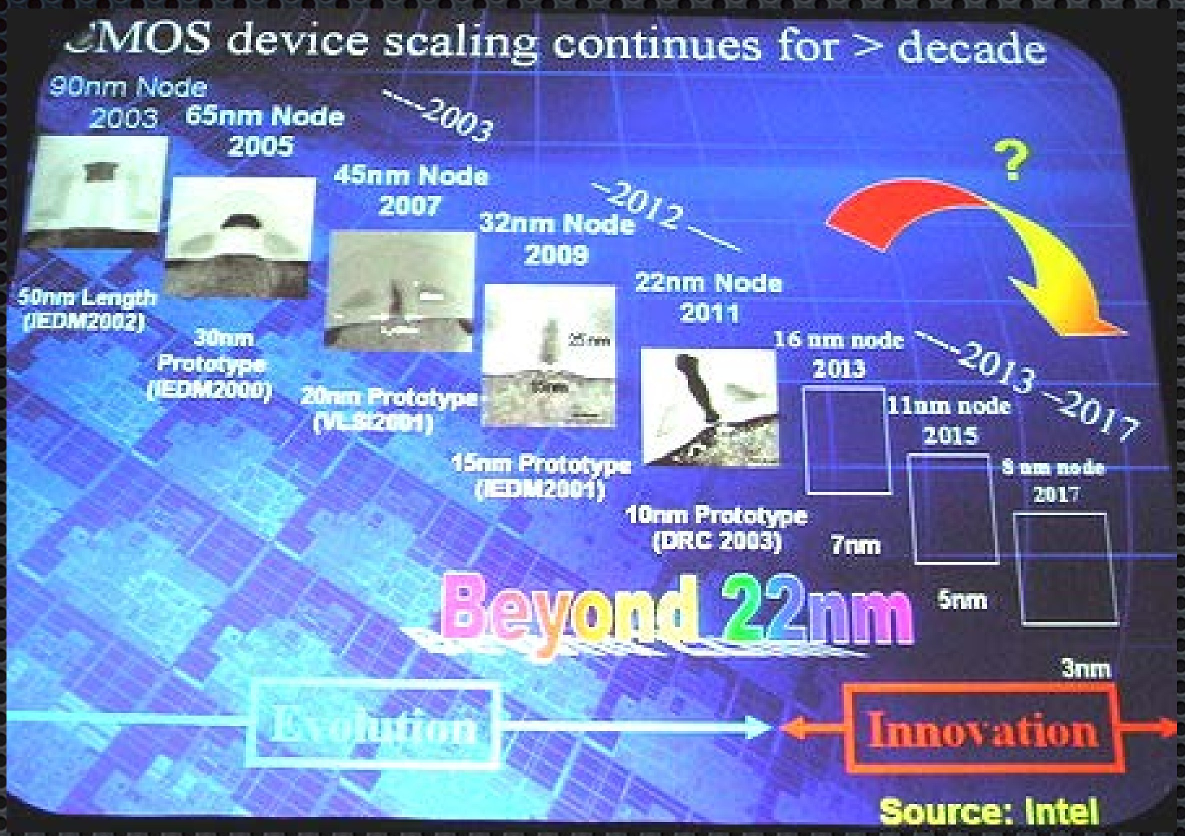
Outline

- Introduction
  - Current challenges in electronics
  - Molecular electronics
    - On graphene?
- Results and Discussion
  - Helium-ion beams as localization inducers on graphene
    - In-situ *I/V* measurements
  - Technological challenges
- Summary

Silicon driven to its limits



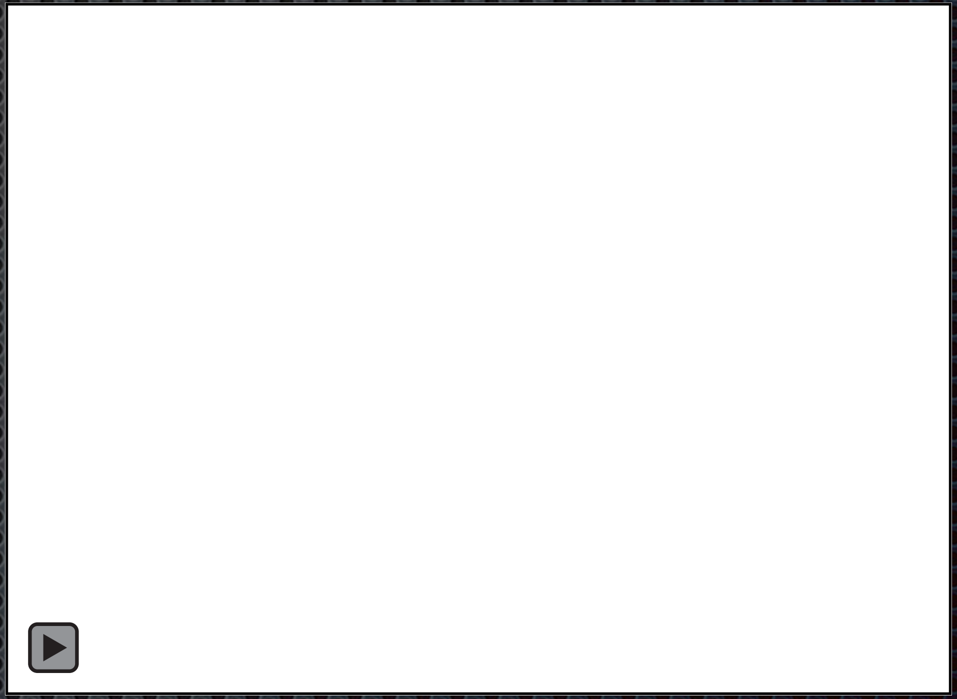
- Theoretical limit for silicon miniaturization is near
- Moore’s law still holds but development has slowed down
- Silicon fails to address various modern challenges (thermal dissipation, gate current leakage…)

➡ **Need for superior materials and/or methods to replace/complement Si**

Molecular Electronics

For novel nano-devices
beyond CMOS

Single functional molecules act as the basic component of electronic devices: rectifiers, transistors, switches, memories, photon emitters, ...

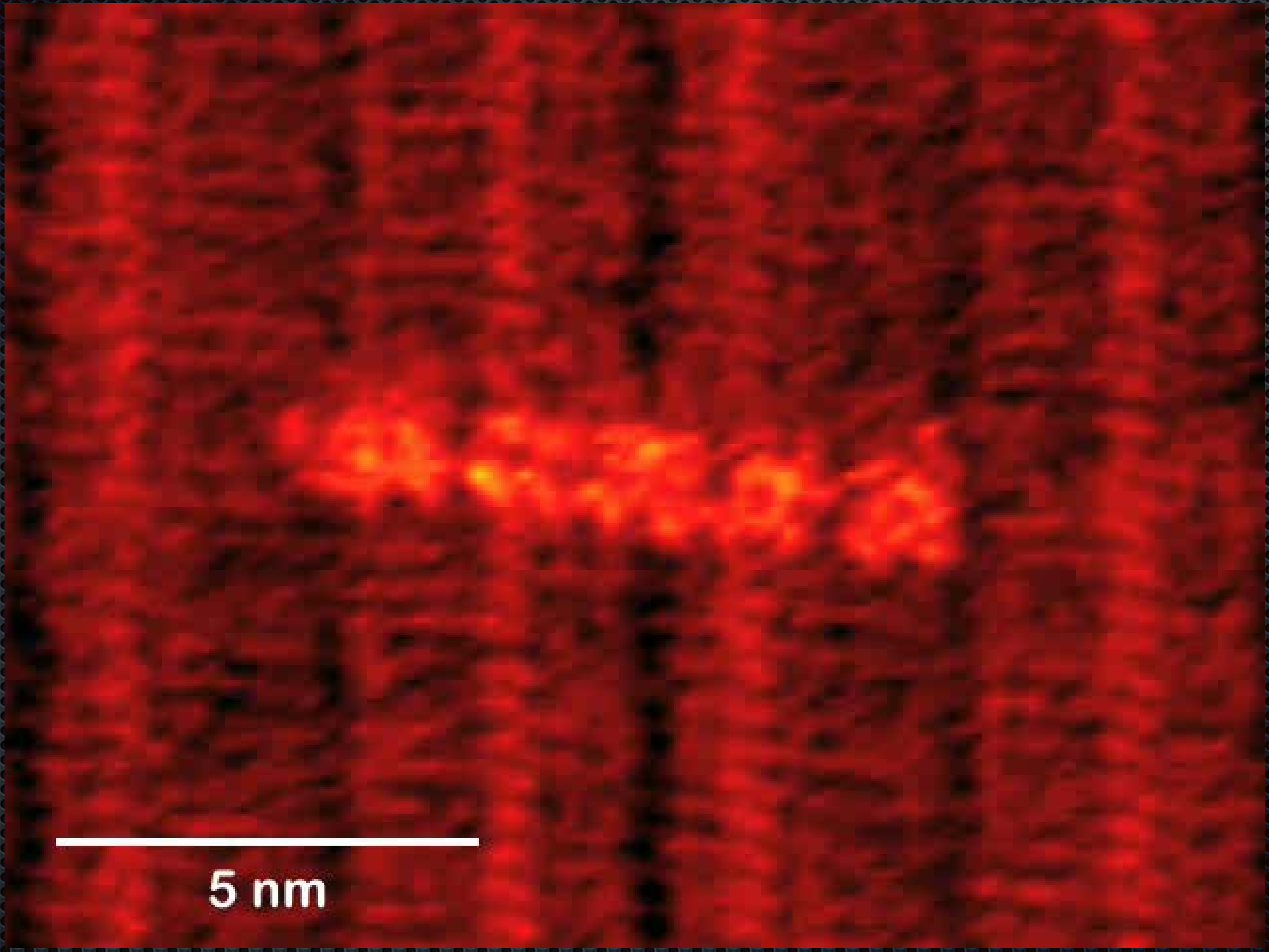


Single molecular rectifier

A. Aviram and M. A. Ratner, *Chem. Phys. Lett.* **29** (1974) 277

Many experimental and theoretical studies have been performed to realize single-molecule devices.
Not yet realized

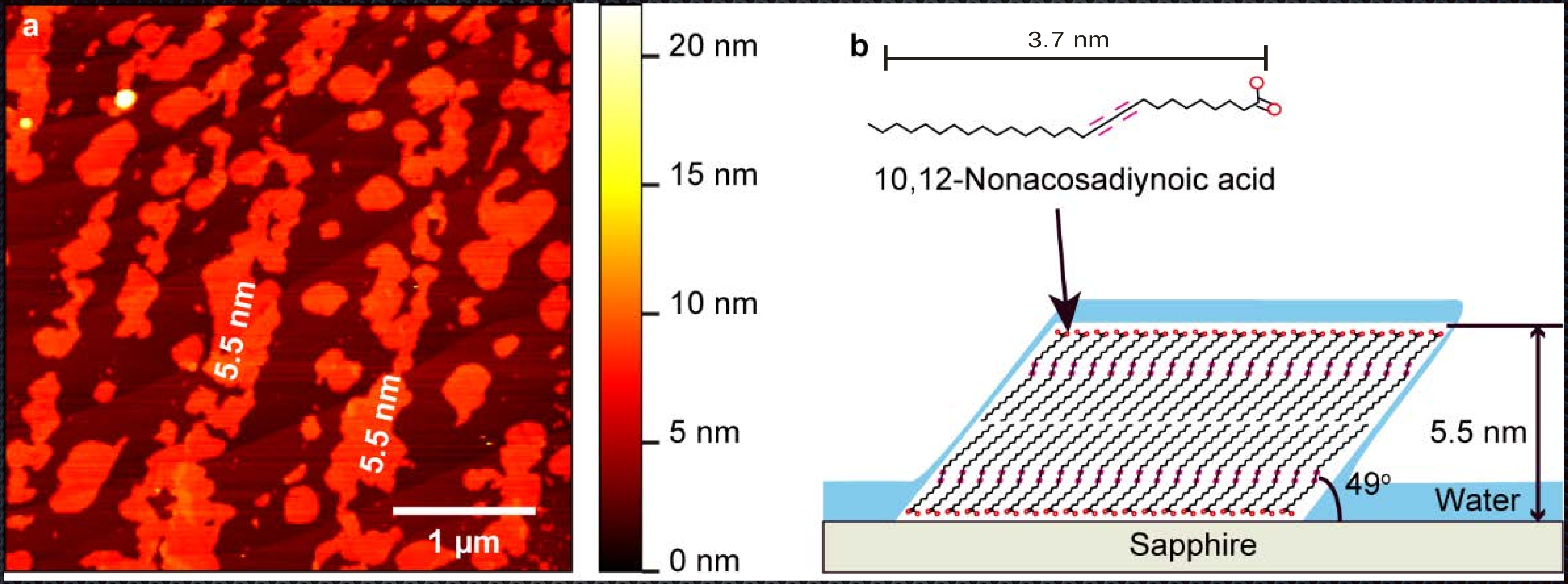
Nanoscale Control of Diacetylene Chain Polymerization **on HOPG**



Y. Okawa and M. Aono, *Nature* **409** (2001) 683

Need to replicate on <u>flat</u> insulators for usable electronic devices!

Sapphire as support for diacetylene molecules

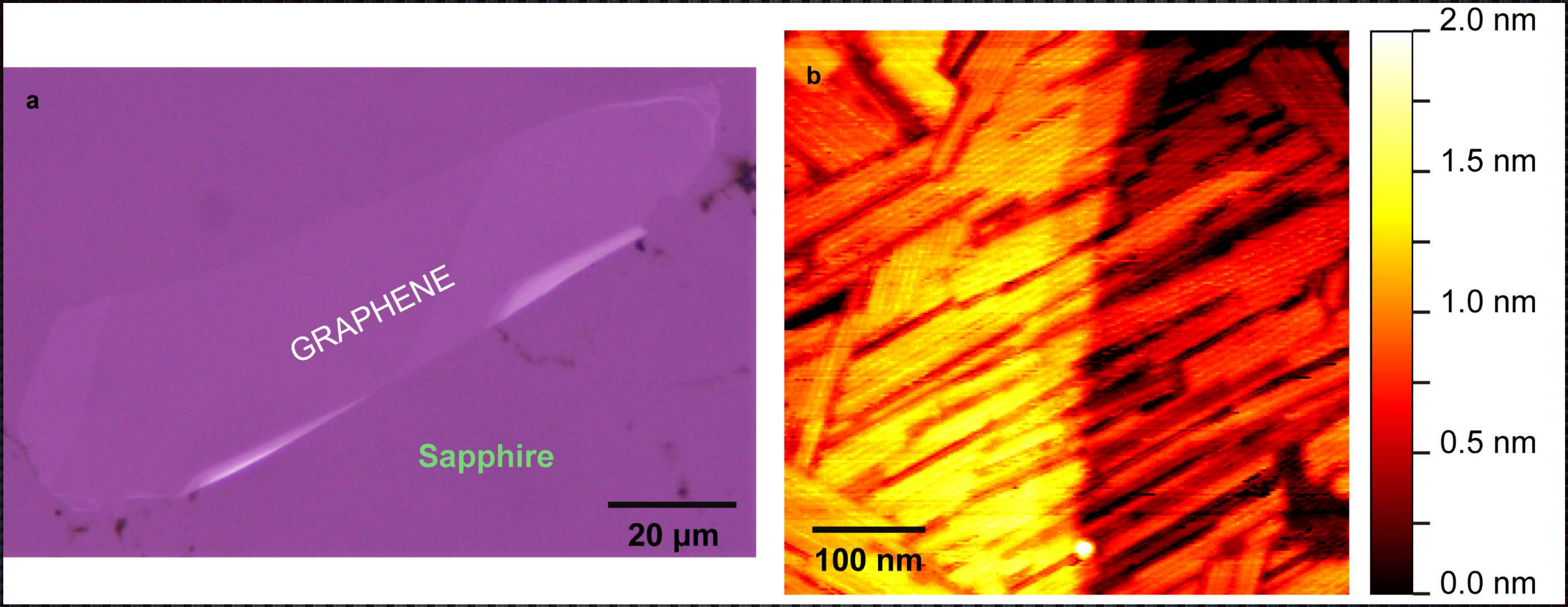


Molecules form standing bilayers!

We need them in a **planar** configuration

Substrate lattice structure is key

Molecular assembly on graphene



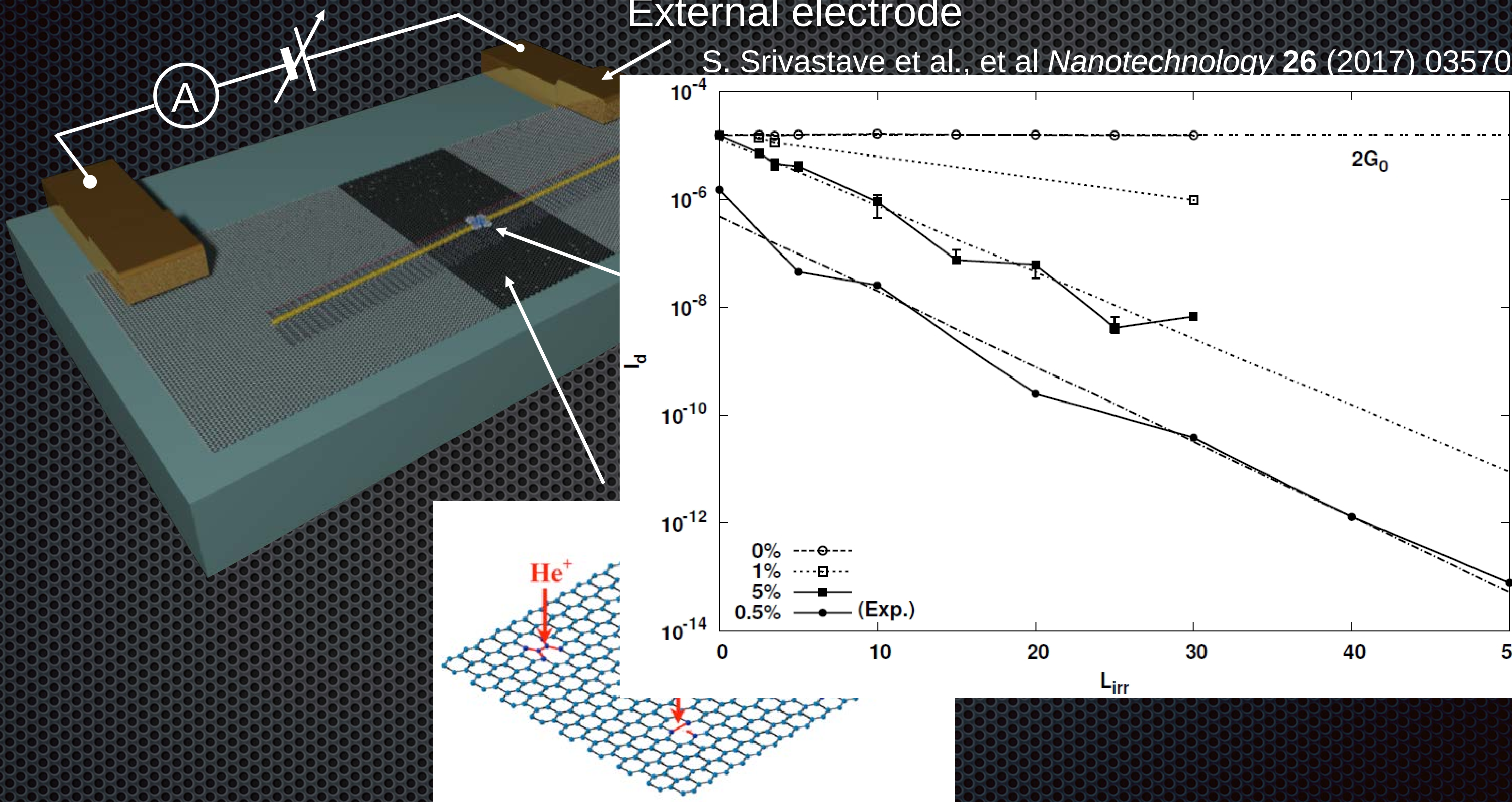
E. Verveniotis et al. Phys. Chem. Chem. Phys. 18 (2016) 31600

Underlying sapphire terraces visible in AFM

➡ Adhesion good

Diacetylene molecules assemble in a **flat-lying manner**!

Molecular device on functionalized graphene



S. Srivastave et al., et al *Nanotechnology* **26** (2017) 035703

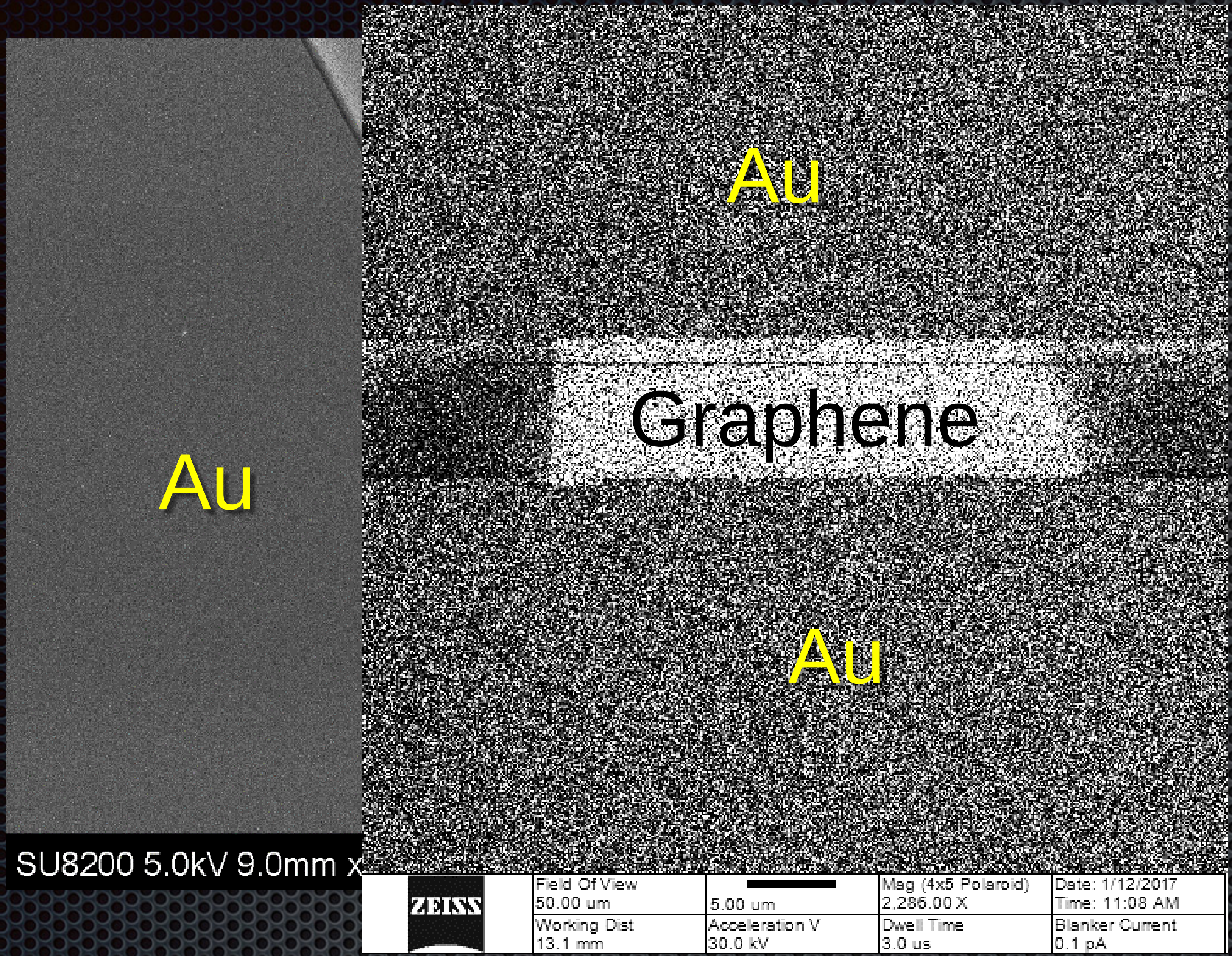
Defects induced in graphene → **Insulator**

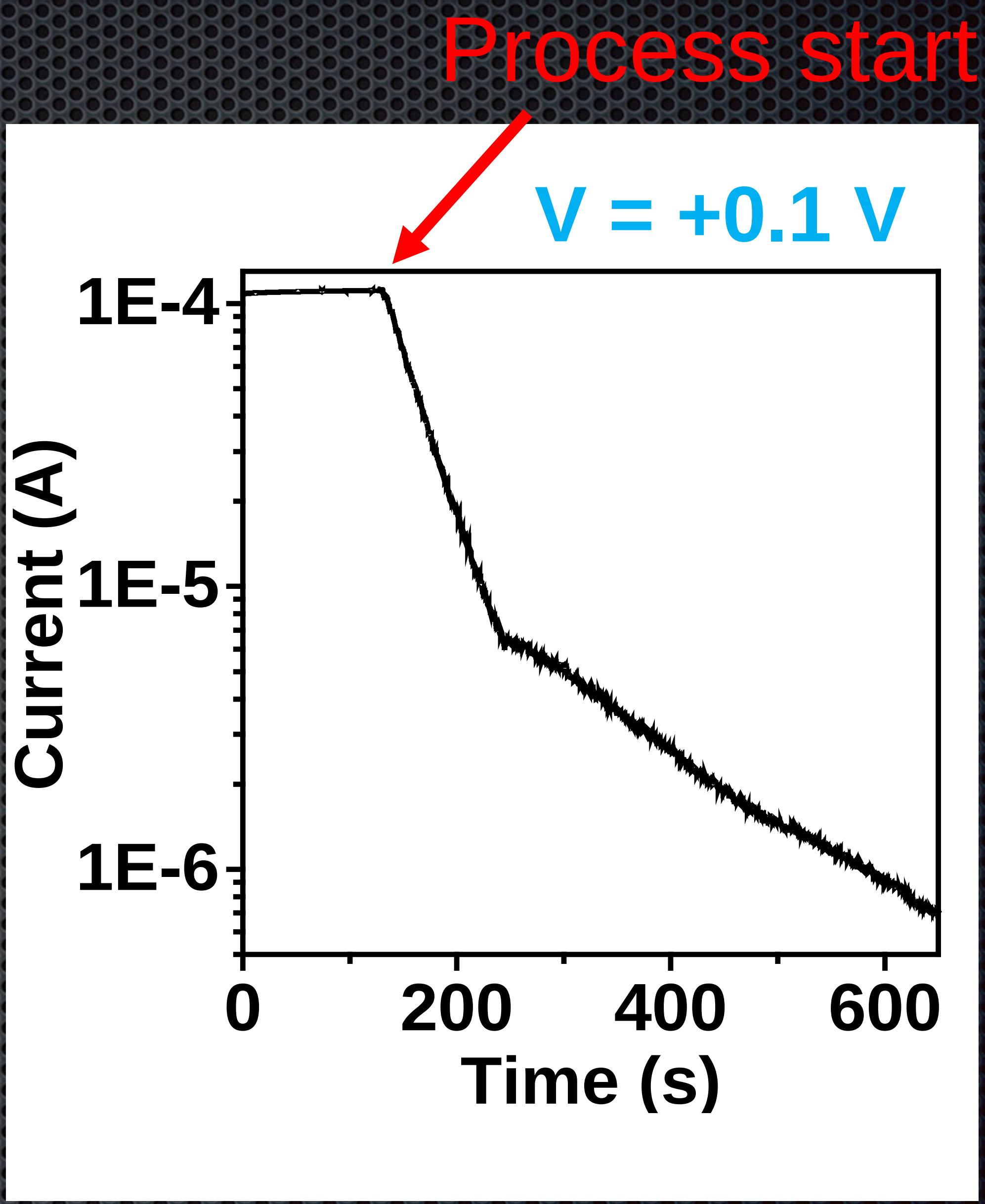
Possible with He-ion irradiation!

Defect density necessary < 5%

S. Nakaharai, et al *ACS Nano* **7** (2013) 5694

Graphene devices and He-irradiation





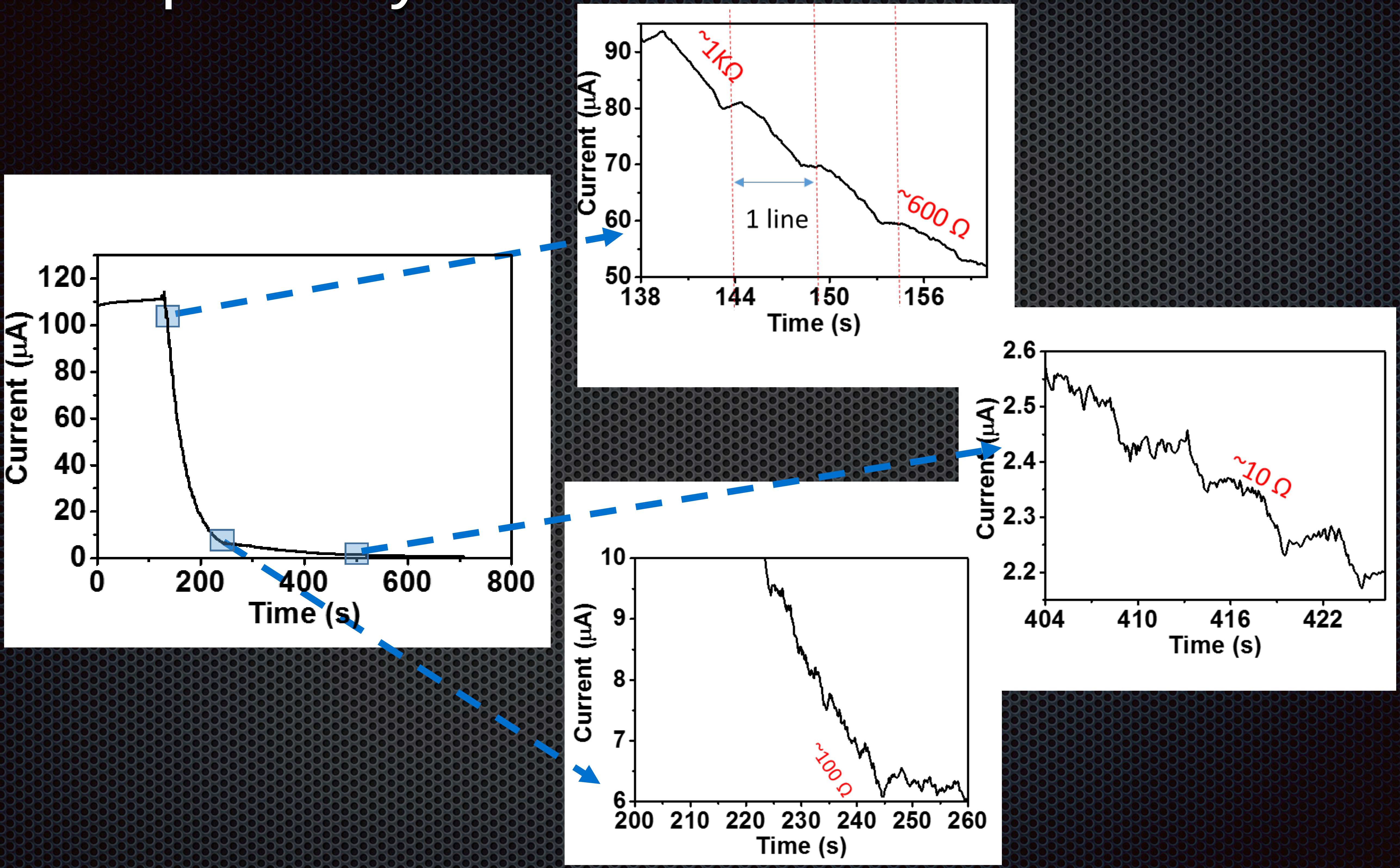
Irradiated a **100 nm-wide** band, in 1 nm steps, across the full graphene flake.

Dose tuned for inducing 1% of defects

Current decay due to defect introduction evident *in-situ*!

Localization slope is not maintained. Why?

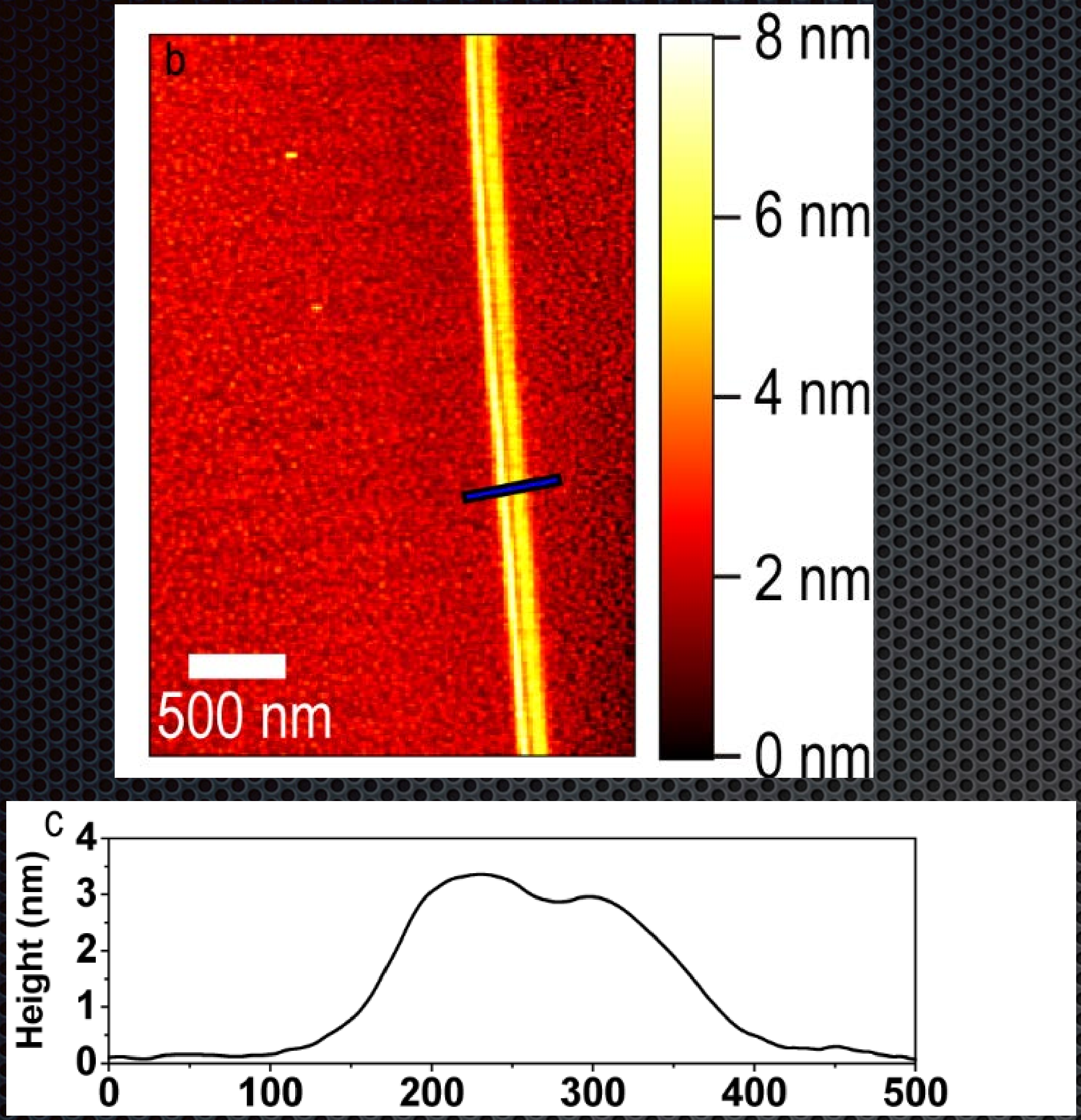
Slope analysis

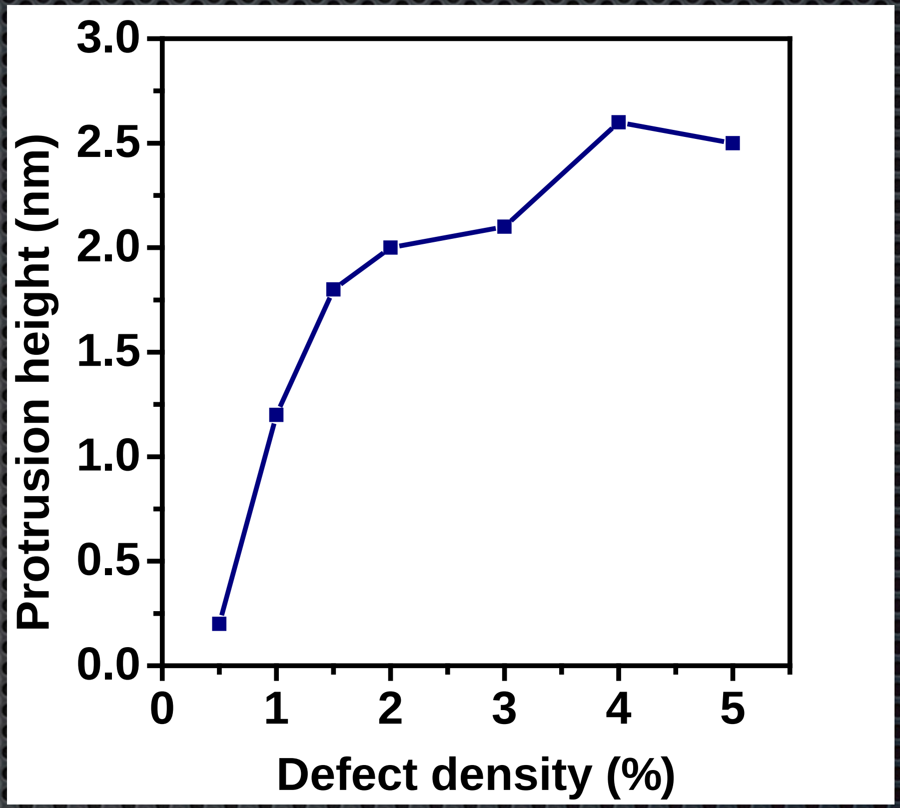


The current decay slope is constantly changing during the process!

Local heating?

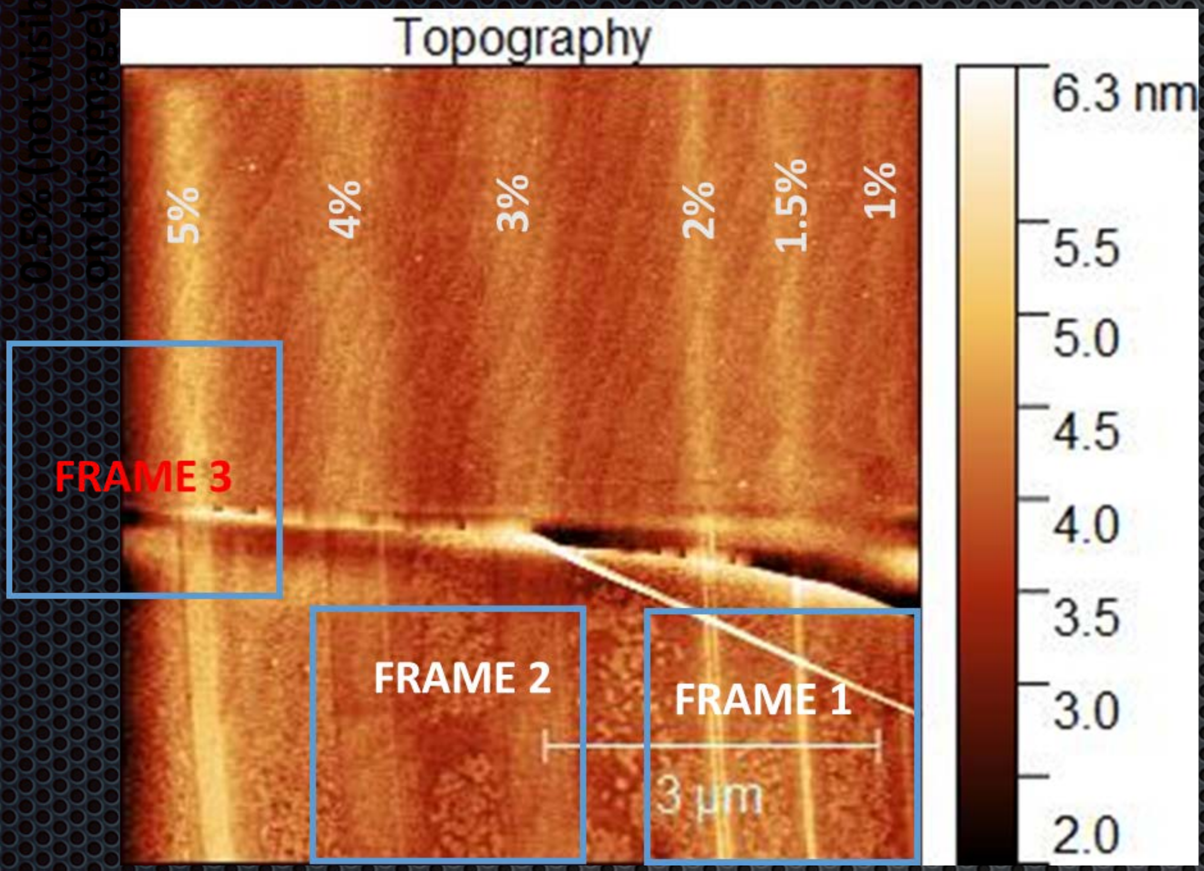
Further analysis-challenges



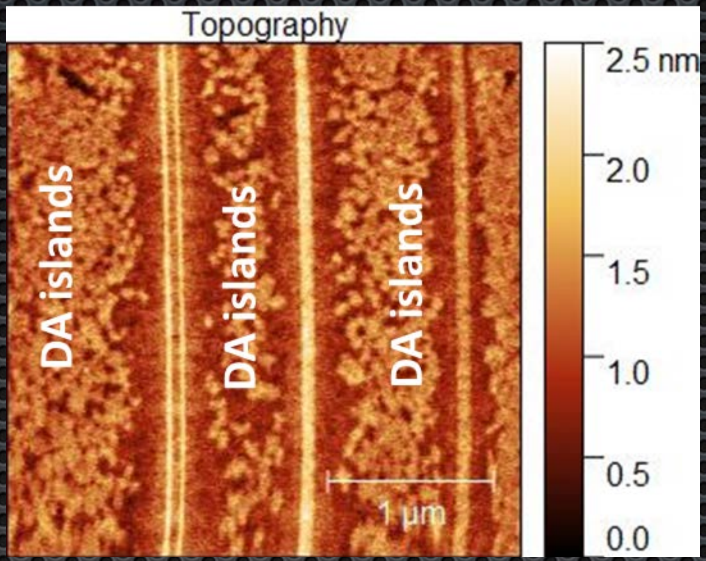


- AFM indicates differences of designed vs. irradiated band size
  - Band is inhomogeneous and protrudes ~3 nm off the surface (swelling)
  - Use free-standing graphene instead!
- Identical experiments always yield slightly different results-machine instability

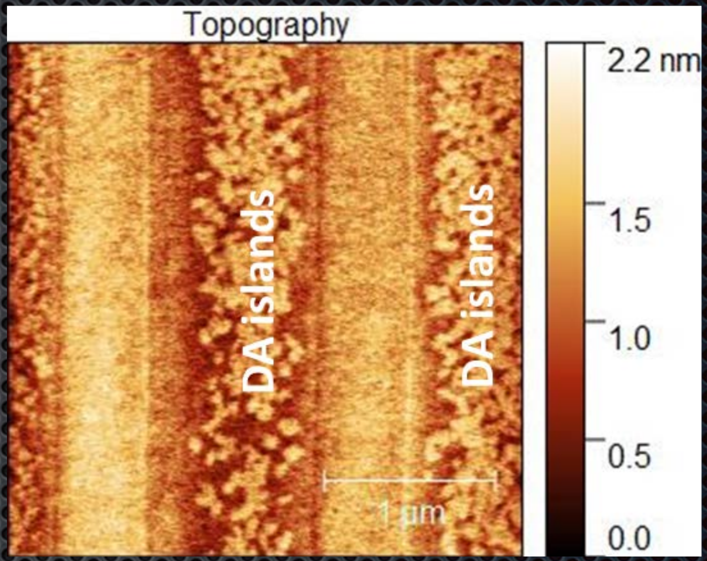
Preliminary results - molecular deposition



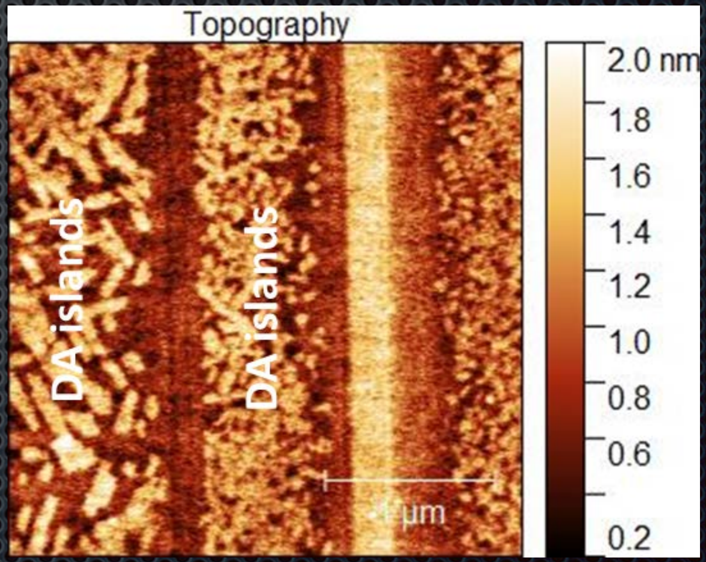
FRAME 1



FRAME 2



FRAME 3



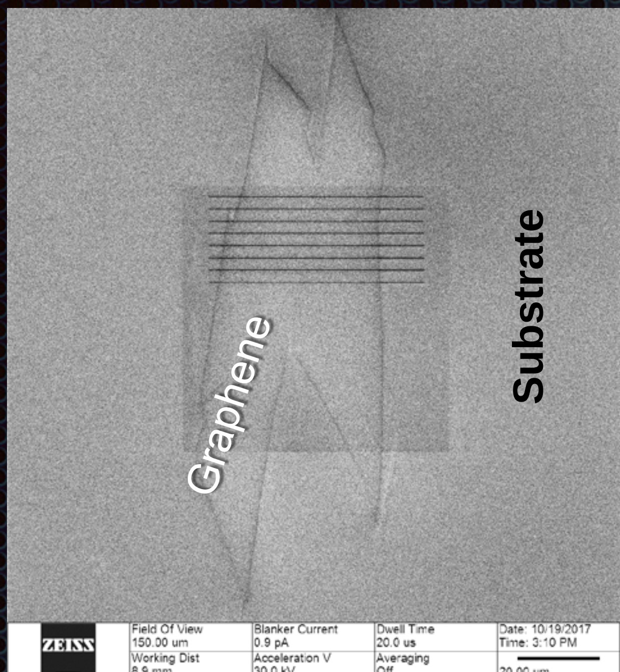
Typical patches of molecules seen only away from the irradiated lines!

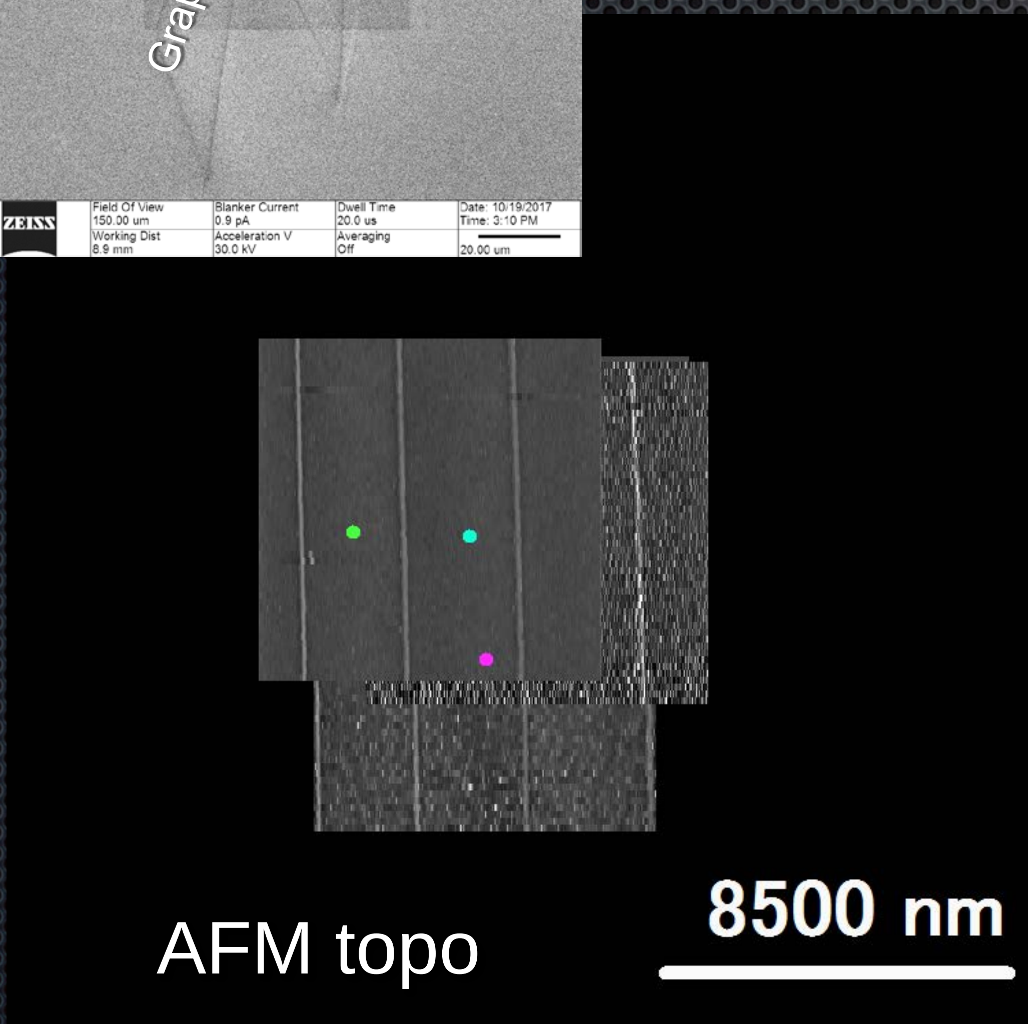
Molecules are repelled from all irradiated areas regardless of He dose!

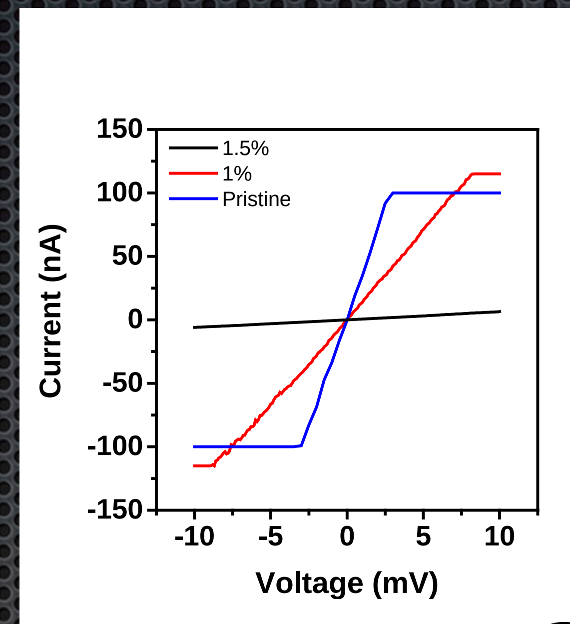
Need to compensate for the accumulated charge in the substrate

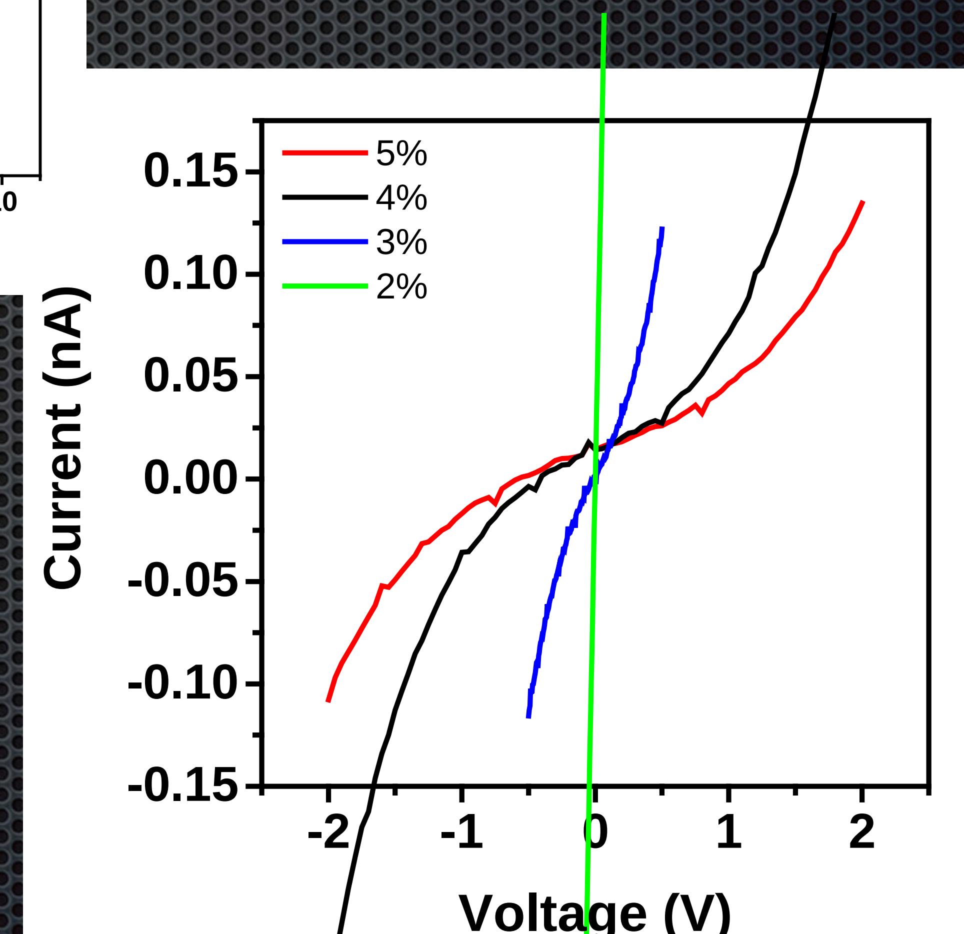
I/V characteristics using multi-probe SPM

HIM micrograph





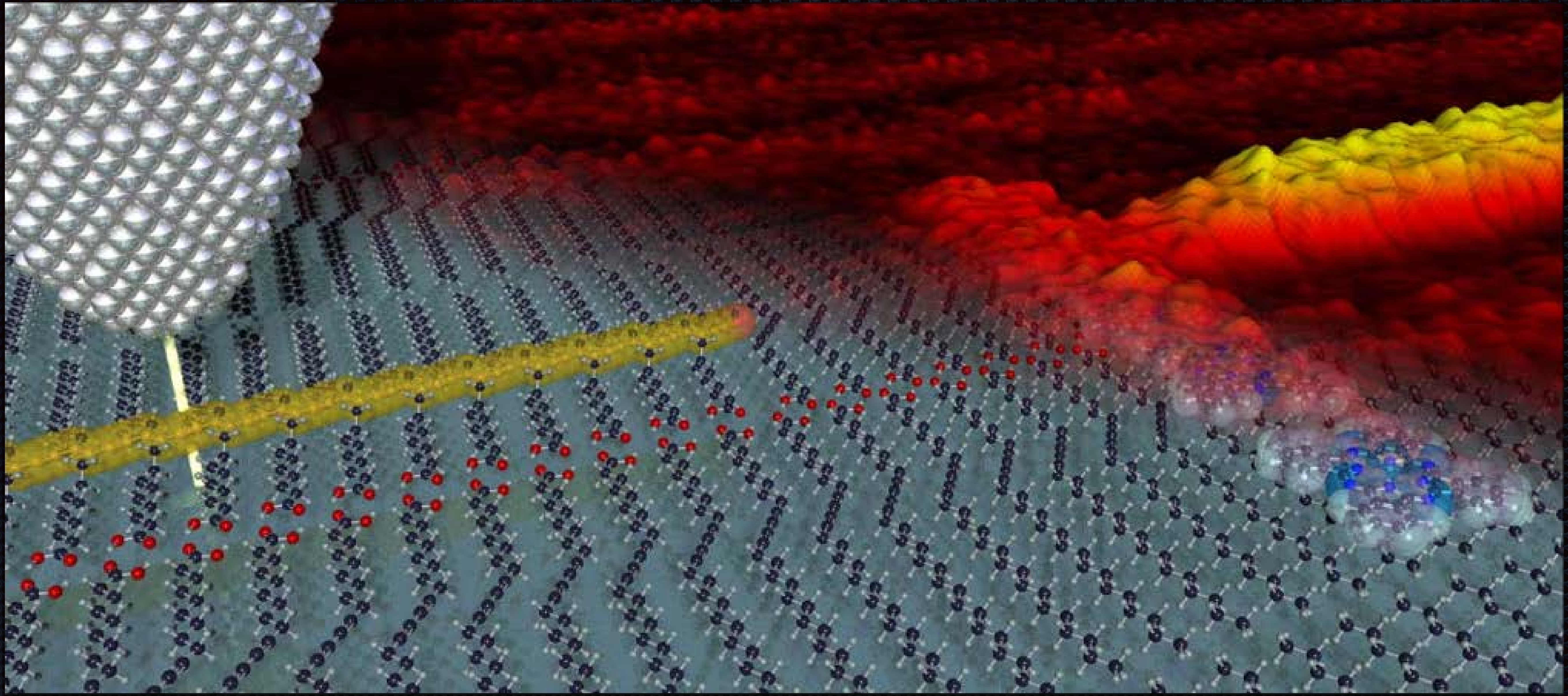




To avoid metal deposition altogether!

Summary and future work

- Helium-ion microscopy can be used for tuning graphene conductance
  - Technology challenges-machine stability
  - Need to maintain current decay slope for efficient localization
  - Use free-standing graphene to avoid rumples caused by substrate swelling
- Fabricate true molecular electronic devices!



Thank you

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JSPS KAKENHI (21310078, 24241047 and 16H03829)