Atomic-level manipulation of two-dimensional materials through electron and ion irradiation

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Despite the great promise of two-dimensional materials due to their exciting properties, they are not always directly suitable for applications. One way to tune the material properties is to manipulate the atomic structure using particle irradiation. However, as one might expect, this is challenging to do in the case of extremely thin materials, where careful control over the irradiation energy and solid understanding of the underlying atomic-scale phenomena are required.

Despite the challenges, electron and ion irradiation have recently evolved into powerful techniques to manipulation the atomic structure of two-dimensional materials. At the same time, the recent advancements in aberration-corrected transmission electron microscopy both provide means to directly image the manipulated structures but also to fine tune them by inducing local structural changes and even to move defects and impurity atoms.

In this presentation, I will describe the advances in manipulating graphene with electron irradiation (e.g., Ref. [1]) and overview our latest progress in using ion irradiation at a large energy scale to implant foreign atoms into graphene [2], moving impurity atoms and defects at will (e.g., Refs. [3,4]), creating nanopores into graphene [5] and MoS2, patterning graphene with gratings and two-dimensional amorphized areas [6,7] as well as other recent results.

If time allows, I will also describe our new experimental setup (to be finished in 2017) combining low-energy ion irradiation line in the same vacuum as a state-of-the-art aberration-corrected scanning transmission electron miroscope fitted for in situ manipulation during imaging.

[1] Susi et al., *Nat. Commun.* **7**, 13040 (2016).
[2] Susi et al., *ArXiv* 1610.03419 (2016).
[3] Kotakoski et al., *Nat. Commun.* **5**, 4991 (2014).
[4] Susi et al., *Phys. Rev. Lett.* **113**, 115501 (2014).
[5] Emmrich et al., *Appl. Phys. Lett.* **108**, 163103 (2016).
[6] Kotakoski et al., *Nano Lett.* **15**, 5944 (2016).
[7] Brand et al., *Nat. Nanotech.* **10**, 845 (2015).