# Dynamics of Graphene Milling Using the Helium Ion Beam

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## Abstract

Graphene has been under intense exploration due to its excellent electronic, mechanical and thermal properties. This two-dimensional material can be controllably modified structurally, electronically and chemically, which can be utilized to design new functional devices. Advances in ion beam-based nanofabrication techniques have offered a pathway to precisely manipulate materials and develop new types of electronic devices. Helium ion microscope (HIM) offers "direct-write" capabilities, packaged in a machine capable of both imaging and nanofabrication, thus making it an excellent candidate for processing a wide range of materials. However, despite graphene's properties, and existing tools to take advantage of them; there are still challenges in the development of workflows that can yield high-performance graphene electronic devices; where the damage at edges and the basal plane is minimized during the milling process.

In this study, we explore graphene milling by the helium ion beam in order to control electronic and mechanical properties. We demonstrate the localized formation, growth and coalescence of nanopores, by investigating different levels of atomic-to-nanoscale defects in graphene using Scanning Transmission Electron Microscopy. Using advanced image data analytics, we illustrate the different dynamic behaviors of graphene milling depending on the material's initial conditions. This work provides in-depth understanding of the graphene milling as it occurs, laying a foundation to develop new pathways to manufacturing 2D material based electronic devices.

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