

# Formation Dynamics of Carbon Atomic Chain from Graphene by Electron Beam Irradiation

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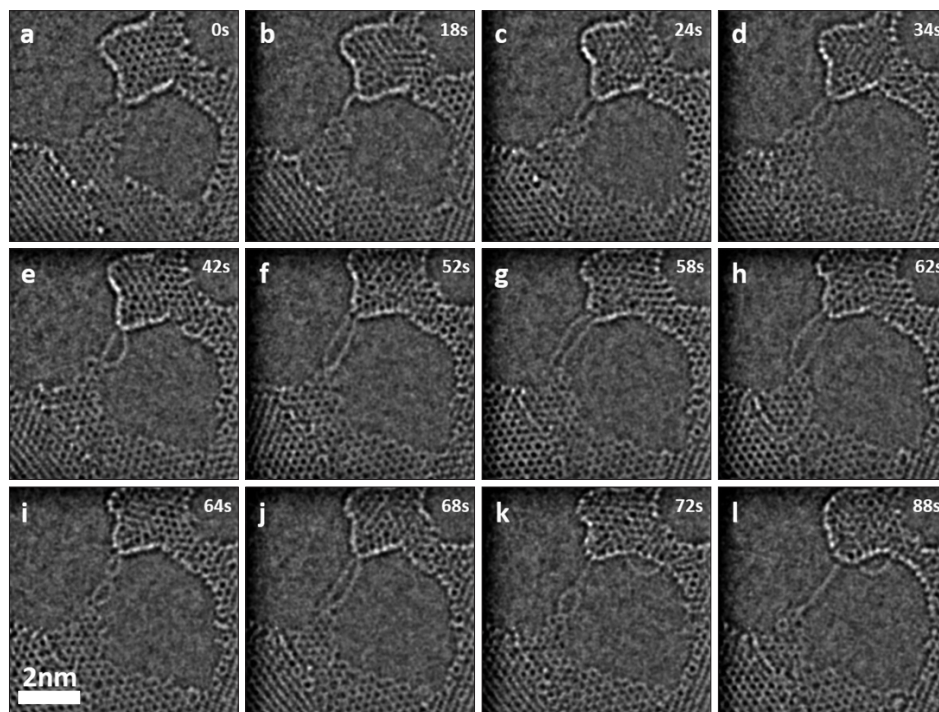
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Carbon has numerous allotropes and various crystalline forms with full dimensionalities such as diamond, graphite, fullerenes, and carbon nanotubes leading a wide range of applications. Since the emerge of graphene consisting of a single atomic layer of carbon atoms, a fabrication of all-carbon-based device with combination of one-, two-, and three-dimensional carbons has become a hot issue. Here, we introduce an ultimate one-dimensional carbon atomic chain. Carbon atomic chains were experimentally created by removing atoms from monolayer graphene sheet under electron beam inside transmission electron microscope (TEM). A series of TEM images demonstrate the dynamics of carbon atomic chains over time from the formation, transformation, and then breakage.

**Key Words:** Aberration-corrected transmission electron microscope, Carbon atomic chain, Graphene, Defect structure, Electron beam irradiation



Formation and dynamics of carbon atomic chains were investigated using an aberration-corrected transmission electron microscope (FEI Titan<sup>3</sup> G2 60-300) at 80 kV. Imaging condition was settled as  $-21 \pm 0.5$   $\mu\text{m}$  of spherical aberration ( $C_s$ ), around  $5 \times 10^5$   $\text{e}^- \text{nm}^{-2}$  of electron beam density. Time-lapse images were acquired over 88 seconds using Gatan DigitalMicrograph script and the atomic structures were analyzed frame-by-frame. Each of the images was acquired with an exposure time of 0.3 s, and the interval time between frames were 1.7 s.

The figure shows the formation, transformation and breakage of carbon atomic chain derived from monolayer graphene by prolonged electron beam irradiation. Firstly, carbon atoms were knocked off from a monolayer graphene sheet and graphene nanoribbon was formed (a). Additional ejection of atoms results in double-strand of carbon atomic chains (c~h). Temporal twist of double-strand was also observed (i). Finally, the end of one chain was detached from the graphene sheet and bound to the other chain (k) and then broken, leaving single carbon atomic chain (l). Although both carbon atomic chains were eventually broken by additional electron beam irradiation, they endured the intense electron beam over tens of seconds. This figure shows the carbon atomic chains are quite durable and flexible under electron beam (Banhart, 2015; Chuvilin et al., 2009; Jin et al., 2009).

## CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

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