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Flexible Metallic Nanowires with Self-Adaptive Contacts to Semiconducting Transition-Metal Dichalcogenide Monolayers

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Two-dimensional transition-metal dichalcogenide (TMDC) monolayers, most of which are semiconducting with direct bandgaps, are promising candidates for flexible nanoelectronics [1]. TMDC-based atomically-thin devices have inspired research on assembling them into circuits [2, 3]. As the TMDC-based devices scale down to tens of nanometers, flexible conducting wires with efficient and robust junctions are essential for connecting multiple components in a nano-circuit for flexible electronics applications.

Notably, one-dimensional ultrathin transition-metal chalcogenide nanowires have been predicted to be metallic. These nanowires could potentially serve as a better conducting interconnect for future TMDC-based flexible nanoelectronics since no extra elements are introduced, therefore, simplifying the fabrication process and providing reliable interconnections. Although such metallic nanowires have been synthesized individually, controllable connections of nanowires to the monolayers, an important step towards assembling them into devices, have so far remained elusive.

Here, we report direct electron-beam fabrication of such ultrathin nanowires, including their ramified junctions, connecting designated points within a semiconducting TMDC monolayer (Fig. 1). The controllable fabrication is performed in a scanning transmission electron microscope with 5^{th} order aberration corrector which simultaneously records the movements of the atoms during the fabrication. The sequential images reveal that the formation of the nanowires is a self-regulating and self-healing process that is insensitive to precise beam parameters. *In-situ* electrical measurements further reveal the nanowires are intrinsically metallic. The nanowires remain conducting and maintain structural integrity as they undergo continuous electron-beam-induced rotations and flexing, indicating their self-adaptive connections to the monolayers. The observed mechanical behavior is explained by density-functional-theory calculations, which further predict that the metal-semiconductor contacts could be Ohmic to ptype TMDC monolayers. These sub-nm-wide metallic nanowires can, therefore, serve as the ultimately small interconnects in future flexible nano-circuits fabricated entirely within a monolayer. [4, 5]

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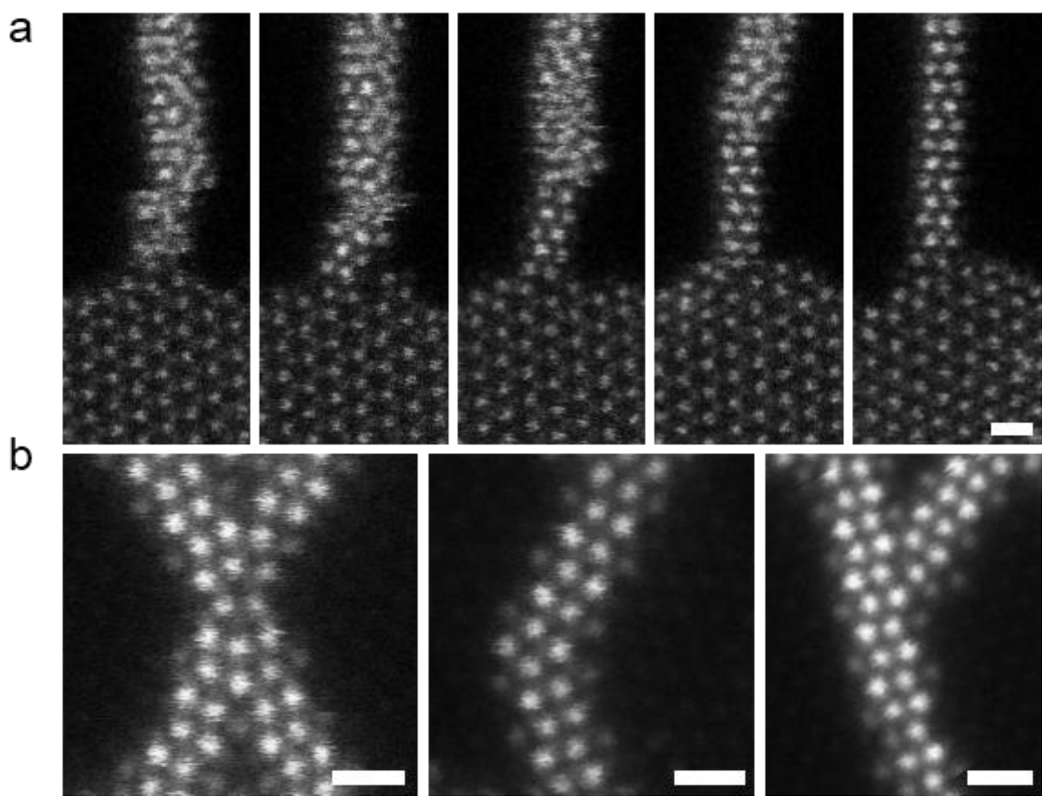

Figure 1: *In-situ* fabrication of nanowires from a TMDC monolayer and different types of junctions. (a) Sequential ADF images showing the fabrication process of an individual MoS nanowire entirely within a semiconducting MoS_2 monolayer. (b) ADF images of different types of nanowires and ramified junctions created by advanced control of the electron irradiation inside the STEM, demonstrating the diversity of building blocks made from these nanowires. Scale bars: 0.5 nm.

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