Terahertz Scanning Tunneling Microscopy of Atomically Precise Graphene Nanoribbons

S. E. Ammerman[1], V. Jelic[1], M. Hassan[1], S. Adams[1], Y. Wei[1], V. N. Breslin[1], N. Everett[1], K. Cleland-Host[1], S. Lee[1], Q. Sun[2], C. Pignedoli[2], P. Ruffieux[2], R. Fasel[2,3] and T. L. Cocker[1]

[1] *Department of Physics and Astronomy, Michigan State University, East Lansing, MI 48824, USA.*

[2] *Empa, Swiss Federal Laboratories for Materials Science and Technology, 8600 Dübendorf, Switzerland.*

[3] *Department of Chemistry, Biochemistry and Pharmaceutical Sciences, University of Bern, 3012 Bern, Switzerland.*

hassan21@msu.edu

Next generation, atomically precise electronics operating at optical frequencies require tools that can characterize them on their intrinsic length and time scales to guide device design. Terahertz scanning tunneling microscopy (THz-STM) is a promising new technique towards this purpose [1]. THz-STM has been used to resolve the picosecond motion of single molecules [2] and extreme tunnel currents through single silicon atoms [3], among other exciting recent results [4]. Meanwhile, atomically precise graphene nanoribbons (GNRs) synthesized from molecular precursors [5] have garnered interest as a platform for future electronic and quantum information applications [6]. Here, we apply THz-STM to GNRs fabricated by bottom-up, on-surface synthesis [7]. THz-STM images recorded in an ultrahigh vacuum, low temperature environment reveal rich, Angstrom-scale electronic detail within single GNRs, including aspects that are not visible with conventional STM imaging. Height-dependent THz-STM measurements further probe GNR wavefunctions with sub-Angstrom vertical resolution, providing a new level of clarity. Finally, atomically resolved THz scanning tunneling spectroscopy of the GNRs advances THz-STM as a diagnostic technique for materials sciences [7,8]. Our experiments lay the groundwork to explore the ultrafast dynamics of single GNRs and GNR-based devices with atomic spatial resolution.

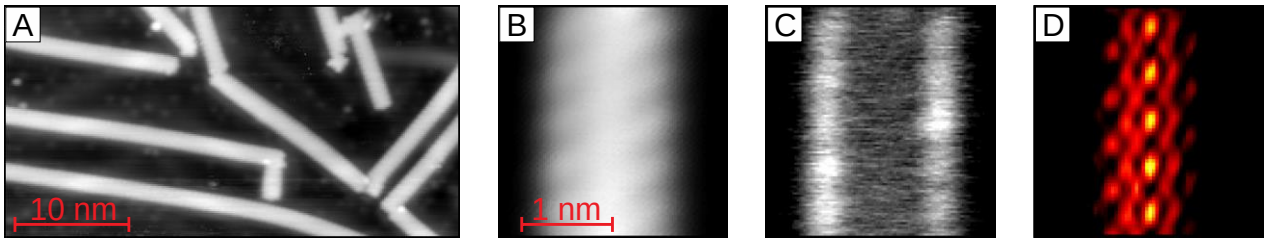

Figure 1: THz-STM of 7AGNRs. (a) Constant-current STM image of seven-atom-wide armchair graphene nanoribbons (7AGNRs) grown on Au(111) by bottom-up synthesis from molecular precursors. Bias = -1 V, setpoint = -50 pA. (b) Constant-height STM image and simultaneous (c) differential conductance showing the spatial distribution of the valence band local density of states. Bias =-1.2 V, Setpoint for tip height =-50 pA. (d) Constant-height terahertz scanning tunneling microscopy image of a 7AGNR showing the valence band local density of states at ultralow tip height. The scale bar is the same for (b)-(d).

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