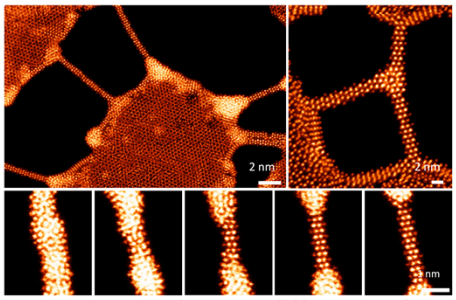
In-situ Fabrication of Ultrathin Metallic Nanowires from Semiconducting Monolayers



Z-contrast STEM images showing controllable patterning of a nanowire network (top left) and their Y-junction structure (top right). Each nanowire is sculpted individually using the e' beam. All the nanowires collapse into the same stable 3-atom-wide structure.

Scientific Achievement

***In-situ* fabrication and atomic resolution imaging of ultrathin flexible metallic nanowires and their Y-junctions from semiconducting two-dimensional (2D) monolayer materials.**

Significance and Impact

Our findings demonstrate an *in-situ* method to directly pattern lateral and conductive interconnects within the 2D circuit made entirely from monolayer materials, which is an important step towards the realization of a fully integrated atomic thin circuit.

Research Details

- Controllable fabrication of metallic nanowires with stable 3-atom width using electron irradiation.
- Electrical and mechanical measurements of the nanowires demonstrate they can serve as ultrasmall interconnect in future flexible electronics.

Electron microscopy performed as part of a user proposal at the Center for Nanophase Materials Sciences.

J. Lin, *et. al.*, *Nature Nanotechnology* **2014**
DOI: dx.doi.org/10.1038/nnano.2014.81

U.S. DEPARTMENT OF ENERGY | Office of Science | VANDERBILT UNIVERSITY | JST | THE UNIVERSITY of TENNESSEE KNOXVILLE | OAK RIDGE National Laboratory

Narrative Highlight Text: We show the fabrication of flexible metallic nanowires and their Y-junction structures from a semiconducting transition-metal dichalcogenide (TMDC) monolayer via electron irradiation in an aberration-corrected scanning transmission electron microscope. Bu using a combination of in-situ experiments and theoretical calculations, we were able to characterize the electrical properties and mechanical flexibility of the nanowires. TMDC materials have been considered as promising candidates for next generation ultrathin flexible electronics due to their semiconducting nature maintained at the atomic thickness. Our in-situ fabrication of ultrathin metallic nanowires connected laterally to TMDC monolayers serves as an important step towards the realization of a fully integrated atomically thin circuit. The nanowires provide flexible conductive interconnects between each individual component. Our in-situ study further reveals that the nanowires possess robust and self-adaptive junctions to TMDC monolayers, and remain conductive during severe mechanical deformations, both of which are important characteristics for potential applications in flexible electronics. Our study discovers a new route for direct fabrication of interconnects between TMDC monolayer devices, and opens up new possibilities for the large-scale production of monolayer circuits using other electron-beam-based technique.

Reference

"Flexible Metallic Nanowires with Self-adaptive Contacts to Semiconducting Transition-metal Dichalcogenide Monolayers"
Nature Nanotechnology **2014** DOI:10.1038/NNANO.2014.81

J. Lin,[1,2] O. Cretu,[3] W. Zhou,[2] K. Suenaga,[3] D. Prasai,[4] K. I. Bolotin,[1] N. T. Cuong,[3] M. Otani,[3] S. Okada,[5] A. R. Lupini,[2] J-C. Idrobo,[6] D. Caudel1,[7] A. Burger,[7] N. J. Ghimire,[2,8] J. Yan,[2,9] D. G. Mandrus,[2,8,9] S. J. Pennycook,[9] and S. T. Pantelides[1,2]
[1] Department of Physics and Astronomy, Vanderbilt University
[2] Materials Science & Technology Division, ORNL
[3] National Institute of Advanced Industrial Science and Technology (AIST), Japan
[4] Interdisciplinary Graduate Program in Materials Science, Vanderbilt University
[5] Graduate School of Pure and Applied Sciences, University of Tsukuba, Japan
[6] Center for Nanophase Materials Sciences, ORNL
[7] Department of Physics, Fisk University
[8] Department of Physics and Astronomy, University of Tennessee
[9] Department of Materials Science and Engineering, University of Tennessee

Acknowledgment of Support
The authors thank H. Conley for helping with the transfer of the samples, E. Rowe, E. Tupitsyn and P. Bhattacharya for early technical assistance on the samples, and R. Ishikawa, R. Mishra, B. Wang and J. Lou for discussions. This research was supported in part by the US Department of Energy (DOE; grant DE-FG02-09ER46554 to J.L. and S.T.P.), a Wigner Fellowship through the Laboratory Directed Research and Development Program of Oak Ridge National Laboratory (ORNL), managed by UT-Battelle, LLC, for the US DOE (W.Z.), the Office of Basic Energy Sciences, Materials Sciences and Engineering Division, US DOE (A.R.L., N.J.G., J.Q.Y., D.G.M., S.J.P., and S.T.P.) and through a user project supported by ORNL's Center for Nanophase Materials Sciences (CNMS), which is sponsored by the Scientific User Facilities Division, Office of Basic Energy Sciences, US DOE (J.C.I.). K.I.B. and D.P. were supported by ONR N000141310299. This research used resources of the National Energy Research Scientific Computing Center, which is supported by the Office of Science of the US DOE (contract no. DE-AC02-05CH11231). O.C. and K.S. acknowledge the Japan Science and Technology Agency (JST) research acceleration programme for financial support. N.T.C., M.O. and S.O. acknowledge support from the JST-CREST programme.