Atomic Membranes for 3D Systems

IRG-3

Atomic membranes are a new class of two-dimensional, free-standing materials only one atom thick yet mechanically robust, chemically stable, and virtually impermeable. The prototype atomic membrane is graphene, a honeycomb lattice entirely made of carbon atoms, but other emerging systems such as the III-V boron nitride (BN) materials offer exciting new properties. The central aim of this IRG is to extend miniaturization to its ultimate limit by creating atomically thin 2D "paper" materials that self-fold into incredibly responsive 3D structures with lateral features spanning the mm to nm scales.
To accomplish this goal, we will:

(i) synthesize and characterize novel 2D atomic membranes (2D-AMs), analogous to the different kinds of colored paper in origami,
(ii) develop approaches to bend and fold these 2D-AMs in response to environmental or external signals, and
(iii) elucidate general design approaches to create 3D structures that could ultimately be used for devices with novel physical, optical, electrical, and/or chemical functionalities.

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IRG NOTABLE PUBLICATIONS BELOW

Notable Publications

IRG-3 Atomic Membranes for 3D Systems

Bao, N.; Liu, Q.; Reynolds, M. F.; Wang, W.; Cao, M. C.; Muller, D. A.; Mavrikakis, M.; Cohen, I.; McEuen, P. L.; Abbott, N. L. Microactuation Using Kinetically Controlled States of Catalytic Surfaces. Science 2022 submitted.

A. J. Mannix, A. Ye, S. H. Sung, A. Ray, F. Mujid, C. Park, M. Lee, J.-H. Kang, R. Schreiner, A. High, D. A. Muller, R. Hovden, and J. Park, "Robotic four-dimensional pixel assembly of van der Waals solids", Nature Nanotechnology, DOI: 10.1038/s41565-021-01061-5 (2022).

Q. Liu, W. Wang, M. Reynolds, M. Miskin, M. Cao, D. A. Muller, P. L. McEuen, I. Cohen, "Micrometer-sized electrically programmable shape-memory actuators", Science Robotics 6, eabe6663 (2021) (Cover).

Lee, M., J. H. Kang, F. Mujid, J. Suh, A. Ray, C. Park, D. A. Muller, and J. Park. "Atomically Thin, Optically Isotropic Films with 3D Nanotopography" Nano Letters 21, (2021): 7291–7297. doi:10.1021/acs.nanolett.1c02478

H. Yu, J. I. Gold, T. J. Wolter, N. Bao, R. J. Twieg, M. Mavrikakis, N. L. Abbott, "Reversible switching of liquid crystals using surface-catalyzed reactions between H2 and O2," submitted (2022).

D. Varadharajan, K. Nayani, C. Zippel, E. Spuling, K. C. Cheng, S. Sarangarajan, S. Roh, J. Kim, V. Trouillet, S. Bräse, N. L. Abbott, J. Lahann, Surfaces Decorated with Enantiomorphically Pure Polymer Nanohelices via Hierarchical Chirality Transfer across multiple length scales. Advanced Materials, 34(9), 2108386. (2022)

S. Roh, J. Kim, D. Varadharajan, J. Lahann, N. L. Abbott, Sharing of Strain Between Nanofiber Forests and Liquid Crystals Leads to Programmable Responses to Electric Fields. Adv. Funct. Mater., in press (2022).

N. Bao, J. I. Gold, J. K. Sheavly, J. J. Schauer, V. M. Zavala, R. C. Van Lehn, M. Mavrikakis, N. L. Abbott, "Ordering Transitions of Liquid Crystals Triggered by Reactions of Sulfur Oxide Species with Metal Oxide Surfaces," J. Am. Chem. Soc. submitted (2022).

T. Szilvási, H. Yu, J. I. Gold, N. Bao, T. J. Wolter, R. J. Twieg, N. L. Abbott, and M. Mavrikakis, "Coupling the chemical reactivity of bimetallic surfaces to the orientations of liquid crystals," Mater. Horiz. 8, 2050-2056/1–7 (2021). http://dx.doi.org/10.1039/D1MH00035G

N. Bao, J. I. Gold, T. Szilvási, H. Yu, R. J. Twieg, M. Mavrikakis, and N. L. Abbott, "Designing chemically selective liquid crystalline materials that respond to oxidizing gases," J. Mater. Chem. C 9, 6507–6517 (2021). http://dx.doi.org/10.1039/D1TC00544H

S. Roh, J. Kim, D. Varadharajan, J. Lahann, N. L. Abbott, Sharing of Strain Between Nanofiber Forests and Liquid Crystals Leads to Programmable Responses to Electric Fields. Adv. Funct. Mater., in press (2022).

I. Griniasty, C. Mostajeran, and I. Cohen, “Multivalued Inverse Design: Multiple Surface Geometries from One Flat Sheet,” Phys. Rev. Lett. 127, 128001/1–6 (2021). http://dx.doi.org/10.1103/PhysRevLett.127.128001

Kim, S. E., F. Mujid, A. Rai, F. Eriksson, J. Suh, P. Poddar, A. Ray, C. Park, E. Fransson, Y. Zhong, D. A. Muller, and J. Park. “Extremely Anisotropic van Der Waals Thermal Conductors” Nature 597, (2021): 660–665. doi:10.1038/s41586-021-03867-8

Wei Wang, Qingkun Liu, Ivan Tanasijevic, Michael Reynolds, Alejandro Cortese, Marc Miskin, Michael Cao, David Muller, Alyosha Molnar, Eric Lauga, Paul McEuen, and Itai Cohen, “Cilia metasurfaces for electronically programmable microfluidic manipulation,” Nature (accepted).

S. Xie, L. Tu, Y. Han, L. Huang, K. Kang, K. U. Lao, P. Poddar, C. Park, D. A. Muller, R. A. DiStasio Jr., and J. Park, “Coherent, atomically thin transition-metal dichalcogenide superlattices with engineered strain,” Science 359, 1131-1136 (2018). http://dx.doi.org/10.1126/science.aao5360

Y. Jiang, Z. Chen, Y. Han, P. Deb, H. Gao, S. Xie, P. Purohit, M. W. Tate, J. Park, S. M. Gruner, V. Elser & D. A. Muller, “Electron ptychography of 2D materials to deep sub-ångström resolution,” Nature 559, 343–349 (2018). http://dx.doi.org/10.1038/s41586-018-0298-5

Y. Zhong, B. Cheng, C. Park, A. Ray, S. Brown, F. Mujid, J.-U. Lee, H. Zhou, J. Suh, K.-H. Lee, A. J. Mannix, K. Kang, S. J. Sibener, D. A. Muller and J. Park, “Wafer-scale synthesis of monolayer two- dimensional porphyrin polymers for hybrid superlattices”, Science 366, 1379-1384 (2019). http://dx.doi.org/10.1126/science.aax9385

M. Z. Miskin, K. Dorsey, B. Bircan, Y. Han, D. A. Muller, P. L. McEuen, I. Cohen, “Graphene-based bimorphs for the fabrication of micron-sized, autonomous origami machines,” Proc. Nat. Acad. Sci. USA 115, 466 (2018). (Cover). http://dx.doi.org/10.1073/pnas.1712889115

M. Reynolds, K. McGill, M. Wang, M. Miskin, H. Gao, F. Mujid, K. Kang, J. Park, I. Cohen, P. L. McEuen, “Capillary Origami with Atomic Membranes,” Nano Letters 9, 6221-6226 (2019). http://dx.doi.org/10.1021/acs.nanolett.9b02281

B. Bircan, M. Z. Miskin, R. J. Lang, M. C. Cao, K. J. Dorsey, M. G. Salim, W. Wang, D. A. Muller, P. L. McEuen, and I. Cohen, “Bidirectional Self-Folding with Atomic Layer Deposition Nanofilms for Microscale Origami,” Nano Letters 20, 4850 (2020). http://dx.doi.org/10.1021/acs.nanolett.0c00824

M.Z. Miskin, A. J. Cortese, K. Dorsey, M. F. Reynolds, Q. Liu, M. Cao, D. A. Muller, P. L. McEuen, and I. Cohen, “Electronically integrated, mass-manufactured, microscopic robots,” Nature 584, 557–561 (2020). http://dx.doi.org/10.1038/s41586-020-2626-9