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Distinguished Research Staff

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Education and Training

University of Illinois at Urbana-Champaign	Physics	Ph.D.	1987
University of Maryland, Baltimore County	Physics	B.S.	1978

Keywords

Laser interactions, laser ablation, carbon nanomaterials, nanomaterial growth mechanisms, *in situ* diagnostics, plasma diagnostics, optical spectroscopy, two-dimensional materials.

Funding

For more than 10 years have served as Group Leader for the Functional Hybrid Nanomaterials at the Center for Nanophase Materials Sciences at ORNL, managing a budget of ~ $3M for DOE BES SUFD, and was Principal Investigator of a DOE BES MSED project "Growth Mechanisms and Controlled Synthesis of Nanomaterials" with a budget of ~ 1.1 M$ until 2022.

Research and Professional Experience:

2007–p Group Leader, Functional Hybrid Nanomaterials, Center for Nanophase Materials Sciences, Oak Ridge, Tennessee

• Established and managed the Functional Hybrid Nanomaterials Group at the Center for Nanophase Materials Sciences that has focused on the nonequilibrium synthesis of nanomaterials and their optoelectronic functionality. The group established user facilities for the synthesis of nanomaterials both in areas for which they were world-recognized (including pulsed laser deposition and *in situ* diagnostics of PLD, and carbon nanotube synthesis by laser vaporization and chemical vapor deposition) but also in organic nanowires, hybrid perovskites, and 2D materials – all of which they have also become world-recognized – and all of which they offer to users. In all cases, the group has focused on understanding the link between the synthesis and structure of nanomaterials through time-resolved, *in situ* (principally optical) diagnostic techniques. The group also established a variety of optical and electrical characterization techniques for nanomaterials which they have developed as *in operando* measurements (principally optical spectroscopy) to not only characterize nanomaterials structure, but their functionality in operating prototype devices. At the inception of the CNMS, the group recognized the need for ultrafast laser spectroscopy and tunable Raman spectroscopy to unravel the energy landscape and the dynamics of excited states in (at the time) single-wall carbon nanotubes and hybrid composites with polymers, and they built laboratories for these purposes which have become indispensable and applied to a wide variety of hybrid systems involving polymers and inorganic nanomaterials – for which the group developed assembly facilities to fabricate solar cells and OLEDs. Lately, new specialized facilities have been developed for the characterization of two-dimensional materials, for example via low-frequency Raman spectroscopy (for stacking and layer number, in association with HRTEM and modeling), second harmonic generation, PL, and Raman mapping for multimodal characterization of properties. Most recently, the group has been working to combine the synthesis-to-structure-to-functionality loop using the combined *in situ* diagnostics during synthesis and *in operando* measurements of functionality using the novel sets of nanosecond, picosecond, and femtosecond lasers as both synthesis tools and as ultrafast diagnostics. The group is currently pursuing transformational new manufacturing approaches using artificial intelligence and machine learning. This idea - using the unique capability of pulsed lasers for synthesis, processing, and diagnostics with rapid AI/ML control – was included in a recent NSRC equipment proposal that brought $4M of equipment to the group at CNMS,

including a new automated PLD system and an ultrafast cathodoluminescence microscope (which will be ORNL's first foray into ultrafast electron microscopy) which are targeted toward establishing new capabilities for synthesizing/characterizing quantum materials for external users and ORNL efforts. The established group now consists of a relatively small and senior staff of world-renowned experts that each are experienced in not only the synthesis of (principally inorganic) nanomaterials, but the assembly of prototype devices, and the electrical and optical characterization of these materials over a wide range of time domains, including ultrafast. They are well-positioned and are actively moving efforts in the new laboratory directions of quantum materials and transformational manufacturing.

2001–p Distinguished Research Staff, Oak Ridge National Laboratory, Oak Ridge, Tennessee

• Served as PI on a BES-MSED FWP "*Growth Mechanisms and Controlled Synthesis of Nanomaterials*" that focuses on understanding how nanomaterials grow through the development of time-resolved, *in situ* diagnostic techniques. The work originated in thin films by pulsed laser deposition, developing gated ICCD-imaging, ion probe, and other laser spectroscopic or plasma diagnostic techniques to correlate film quality to growth parameters. The work then branched into carbon nanomaterials, especially single-walled carbon nanotubes, and the development of growth models both by laser vaporization and also chemical vapor deposition. The growth mechanisms of carbon nanohorns by laser vaporization were also studied, and then these materials were explored in a synergistic 5-year hydrogen storage EERE Center of Excellence for their tailored hydrogen storage physisorption. Pulsed CVD and optical reflectivity techniques were developed to understand and optimize the continued growth of vertically-aligned carbon nanotube arrays, and develop a predictive model of CNT growth based upon simple optical reflectivity measurements. Through these studies, and subsequent studies on the growth of graphene, an expertise in carbon nanomaterial synthesis was developed. With the advent of atomically-thin two-dimensional materials by CVD, this FWP has concentrated on understanding the synthesis of key 2D materials such as the transition metal dichalcogenides through the development and application of *in situ* spectroscopic measurements, as well as methods to characterize their properties, with the goal of forming a real-time optical spectroscopic control methodology.

1996–2001 Senior Research Staff, ORNL

1987–1996 R&D Staff, ORNL

• Initially worked on laser-assisted chemical vapor deposition, but quickly transitioned to pulsed laser deposition of high-T_c superconductors. Developed the first PLD system at ORNL in 1988, and specialized in the understanding of laser plasmas utilized for PLD film growth through the development of plasma diagnostics, intensified-CCD array photography, and laser spectroscopy.

1986–1987 Postdoctoral Associate, Electrical and Computer Engineering, University of Illinois at Urbana-Champaign (UIUC)

• In graduate work at UIUC, performed mainly gas phase laser spectroscopy on rare gas halides and rare gases that were relevant to excimer laser kinetics and loss processes, including multiphoton ionization, photoassociation, trimer formation (e.g., Kr_2F or Xe_2Cl), radiative collisions, and ion pair formation. The work involved the measurement of electron densities via microwave attenuation, and nanosecond pulsed lasers in pump-probe geometry.

• As a postdoc at UIUC, work transitioned to excimer laser photodissociation of molecules such as GeH_4 or Ge_2H_6 for the growth of germanium thin films, and similar efforts for silicon.

Selected Publications as of 2020: (>280 refereed publications, 7 book chapters, 15 issued U.S. patents, >10,900 citations, h = 61 (Web of Science), h = 73 (Google Scholar)).

The following publications reflect examples of personal research interests in non-equilibrium synthesis techniques and *in situ* diagnostics. Most recently, PLD of 2D materials including novel hyperthermal implantation replacement of chalcogens[1,6] for the formation of Janus structures[1] and simple *in situ* characterization of PLD growth by optical reflectivity.[2] Understanding how nanomaterials grow, and the development of simple diagnostics that can be used to build growth models, has crosscut materials systems such as carbon nanotubes, nanohorns, graphene, and now metal chalcogenide 2D materials that ORNL synthesizes and offers at the CNMS.[9-13] The work has focused on understanding the building blocks of nanomaterials[5,7,8], and how their assembly guides functionality, primarily through

laser-based spectroscopy and processing.[4]

1. Yu-Chuan Lin, Chenze Liu, Yiling Yu, Eva Zarkadoula, Mina Yoon, Alexander A Puretzky, Liangbo Liang, Xiangru Kong, Yiyi Gu, Alex Strasser, Harry M Meyer III, Matthias Lorenz, Matthew F Chisholm, Ilia N Ivanov, Christopher M Rouleau, Gerd Duscher, Kai Xiao, David B Geohegan, "Low Energy Implantation into Transition-Metal Dichalcogenide Monolayers to Form Janus Structures", *ACS Nano* **14** (4), 3896 (2020). 10.1021/acsnano.9b10196
2. Alexander A Puretzky, Yu-Chuan Lin, Chenze Liu, Alex M Strasser, Yiling Yu, Stela Canulescu, Christopher M Rouleau, Kai Xiao, Gerd Duscher and David B Geohegan, "In situ laser reflectivity to monitor and control the nucleation and growth of atomically thin 2D materials", *2D Materials* **7** (2) 025048 (2020). 10.1088/2053-1583/ab7a72
3. Kai Wang, Alexander A Puretzky, Zhili Hu, Bernadeta R Srijanto, Xufan Li, Nitant Gupta, Henry Yu, Mengkun Tian, Masoud Mahjouri-Samani, Xiang Gao, Akinola Oyedele, Christopher M Rouleau, Gyula Eres, Boris I Yakobson, Mina Yoon, Kai Xiao, David B Geohegan, "Strain tolerance of two-dimensional crystal growth on curved surfaces", *Science Advances* **5**(5) (2019). 10.1126/sciadv.aav4028
4. David B Geohegan, Alex A Puretzky, Aziz Boulesbaa, Gerd Duscher, Gyula Eres, Xufan Li, Liangbo Liang, Masoud Mahjouri-Samani, Chris Rouleau, Wesley Tennyson, Mengkun Tian, Kai Wang, Kai Xiao, Mina Yoon, "Laser Synthesis, Processing, and Spectroscopy of Atomically-Thin Two Dimensional Materials," pp. 1-37 in: Ossi P. (eds) *Advances in the Application of Lasers in Materials Science*. Springer Series in Materials Science, vol 274. Springer, Cham. (2018). 10.1007/978-3-319-96845-2_1
5. Masoud Mahjouri-Samani, Mengkun Tian, Alexander A. Puretzky, Miaofang Chi, Kai Wang, Gerd Duscher, Christopher M. Rouleau, Gyula Eres, Mina Yoon, John Lasseter, Kai Xiao, and David B. Geohegan *"*Nonequilibrium Synthesis of TiO_2 Nanoparticle "Building Blocks" for Crystal Growth by Sequential Attachment in Pulsed Laser Deposition*" Nano Letters* **17** (8), 4624 (2017). 10.1021/acs.nanolett.7b01047
6. Masoud Mahjouri-Samani, Ming-Wei Lin, Kai Wang, Andrew Lupini, Jaekwang Lee, Leonardo Basile, Abdelaziz Boulesbaa, Christopher Rouleau, Alexander Puretzky, Ilia Ivanov, Kai Xiao, Mina Yoon, David Geohegan, "Patterned arrays of lateral heterojunctions within monolayer two-dimensional semiconductors", *Nature Communications* **6,** 7749 (2015). DOI: 10.1038/NCOMMS8749
7. Masoud Mahjouri-Samani, Mengkun Tian, Kai Wang, Abdelaziz Boulesbaa, Christopher M. Rouleau, Alexander A. Puretzky, Michael A. McGuire, Bernadeta R. Srijanto, Kai Xiao, Gyula Eres, Gerd Duscher, and David B. Geohegan, " Digital Transfer Growth of Patterned 2D Metal Chalcogenides by Confined Nanoparticle Evaporation" *ACS Nano 8* (11), 11567-11575 (2014). DOI: 10.1021/nn5048124
8. Masoud Mahjouri-Samani, R. Gresback, M. Tian, K. Wang, Alexander Puretzky, Christopher Rouleau, Gyula Eres, Ilia Ivanov, Kai Xiao, Michael McGuire, Gerd Duscher, David Geohegan, "Pulsed Laser Deposition of Photoresponsive Two-Dimensional GaSe Nanosheet Networks," *Adv. Funct. Mat.* **40**, 6365 (2014). DOI: 10.1002/adfm.201401440
9. Alexander Puretzky, Igor Merkulov, Christopher Rouleau, Gyula Eres, and David Geohegan, "Revealing the surface and bulk regimes of isothermal graphene nucleation and growth on Ni with in situ kinetic measurements and modeling," *Carbon* **79**, 256 (2014). DOI: 10.1016/j.carbon.2014.07.066
10. A.A. Puretzky, D.B. Geohegan, S. Jesse, I.N. Ivanov, G. Eres, "In situ measurements and modeling of carbon nanotube array growth kinetics during chemical vapor deposition", *Appl. Phys. A* **81**, 223-240 (2005). DOI: 10.1007/s00339-005-3256-7
11. Alexander Puretzky, David Geohegan, Henrik Schittenhelm, Xudong Fan, Michael Guillorn, "Time-resolved diagnostics of single wall carbon nanotube synthesis by laser vaporization," *Appl. Surf. Sci.* **197**, 552 (2002). DOI: 10.1016/S0169-4332(02)00334-3
12. D.H. Lowndes, D.B. Geohegan, A.A. Puretzky, D.P. Norton, C.M. Rouleau, "Synthesis of Novel Thin-Film Materials by Pulsed Laser Deposition", *Science* **273**, 898-903 (1996). DOI:10.1126/science.273.5277.898
13. A.A. Puretzky, D.B. Geohegan, G.E. Jellison, and M.M. McGibbon, "Comparative diagnostics of ArF-and KrF-laser generated carbon plumes used for amorphous diamond-like carbon film deposition," *Appl. Surf. Sci.* **96**, 859 (1996). DOI: 10.1016/0169-4332(95)00567-6

Synergistic Activities, Honors, Awards:

ORNL Outstanding Scholarly Output Award (2020)
ORNL Distinguished Inventor Award (2018)
American Physical Society Fellow (2011)
Member of Materials Research Society, American Physical Society
Co-chair (2004–2021) of SPIE Photonics West 'Synthesis and Photonics of Nanoscale Materials' Symposium
International Conference on Laser Ablation (COLA) Advisory Committee, "Distinguished Service Award" (2009)
Guadalupe Workshop on SWCNT Growth Mechanisms Co-Chair (2011; 2013; 2015; 2019; 2021)
Spring Materials Research Society Symposium "Co-Chair" (2008; 2010)
Referee, Peer-Reviewed Journals: *Nature Communications, Nano Letters, ACS Nano, Small, Journal of Physical Chemistry C, Applied Physics Letters, Journal of Applied Physics, Applied Physics A, Applied Physics B, Carbon, Journal of Nanophotonics, EuroPhysics Letters*

Publications (as of 2020)

1 J. H. Ran, O. O. Dyck, X. Z. Wang, B. Yang, D. B. Geohegan, and K. Xiao, "Electron-Beam-Related Studies of Halide Perovskites: Challenges and Opportunities," *Adv Energy Mater* (2020).

2 A. A. Puretzky, Y. C. Lin, C. Z. Liu, A. M. Strasser, Y. L. Yu, S. Canulescu, C. M. Rouleau, K. Xiao, G. Duscher, and D. B. Geohegan, "In situ laser reflectivity to monitor and control the nucleation and growth of atomically thin 2D materials*," *2d Mater* **7** (2) (2020).

3 A. Maksov, O. Dyck, K. Wang, K. Xiao, D. B. Geohegan, B. G. Sumpter, R. K. Vasudevan, S. Jesse, S. V. Kalinin, and M. Ziatdinov, "Deep learning analysis of defect and phase evolution during electron beam-induced transformations in WS2 (vol 6, 15, 2019)," *Npj Comput Mater* **6** (1), 2020-2020 (2020).

4 Y. C. Lin, C. Z. Liu, Y. L. Yu, E. Zarkadoula, M. Yoon, A. A. Puretzky, L. B. Liang, X. R. Kong, Y. Y. Gu, A. Strasser, H. M. Meyer, M. Lorenz, M. F. Chisholm, I. N. Ivanov, C. M. Rouleau, G. Duscher, K. Xiao, and D. B. Geohegan, "Low Energy Implantation into Transition-Metal Dichalcogenide Monolayers to Form Janus Structures," *Acs Nano* **14** (4), 3896-3906 (2020).

5 Y. Y. Gu, H. Cai, J. C. Dong, Y. L. Yu, A. N. Hoffman, C. Z. Liu, A. D. Oyedele, Y. C. Lin, Z. Z. Ge, A. A. Puretzky, G. Duscher, M. F. Chisholm, P. D. Rack, C. M. Rouleau, Z. Gai, X. M. Meng, F. Ding, D. B. Geohegan, and K. Xiao, "Two-Dimensional Palladium Diselenide with Strong In-Plane Optical Anisotropy and High Mobility Grown by Chemical Vapor Deposition," *Adv Mater* **32** (19) (2020).

6 Y. L. Yu, A. W. Bataller, R. Younts, Y. F. Yu, G. Q. Li, A. A. Puretzky, D. B. Geohegan, K. Gundogdu, and L. Y. Cao, "Room-Temperature Electron-Hole Liquid in Monolayer MoS2," *Acs Nano* **13** (9), 10351-10358 (2019).

7 K. Xiao, A. Oyedele, S. Z. Yang, L. B. Liang, A. Puretzky, B. Sumpter, M. Chisholm, C. Rouleau, A. P. Li, and D. Geohegan, "Shape of things to come for 2D materials: Pentagonal layered PdSe2 for electronics," *Abstr Pap Am Chem S* **258** (2019).

8 K. Wang, A. A. Puretzky, Z. L. Hu, B. R. Srijanto, X. F. Li, N. Gupta, H. Yu, M. K. Tian, M. Mahjouri-Samani, X. Gao, A. Oyedele, C. M. Rouleau, G. Eres, B. I. Yakobson, M. Yoon, K. Xiao, and D. B. Geohegan, "Strain tolerance of two-dimensional crystal growth on curved surfaces," *Sci Adv* **5** (5) (2019).

9 M. K. Tian, C. Z. Liu, J. X. Ge, D. Geohegan, G. Duscher, and G. Eres, "Recent progress in characterization of the core-shell structure of black titania," *J Mater Res* **34** (7), 1138-1153 (2019).

10 X. H. Sang, X. F. Li, A. A. Puretzky, D. B. Geohegan, K. Xiao, and R. R. Unocic, "Atomic Insight into Thermolysis-Driven Growth of 2D MoS2," *Adv Funct Mater* **29** (52) (2019).

11 A. D. Oyedele, S. Z. Yang, T. L. Feng, A. V. Haglund, Y. Y. Gu, A. A. Puretzky, D. Briggs, C. M. Rouleau, M. F. Chisholm, R. R. Unocic, D. Mandrus, H. M. Meyer, S. T. Pantelides, D. B. Geohegan, and K. Xiao, "Defect-Mediated Phase Transformation in Anisotropic Two-Dimensional PdSe2 Crystals for Seamless Electrical Contacts," *J Am Chem Soc* **141** (22), 8928-8936 (2019).

12 A. Maksov, O. Dyck, K. Wang, K. Xiao, D. B. Geohegan, B. G. Sumpter, R. K. Vasudevan, S. Jesse, S. V. Kalinin, and M. Ziatdinov, "Deep learning analysis of defect and phase evolution during electron beam-induced transformations in WS2," *Npj Comput Mater* **5** (2019).

13 X. F. Li, J. J. Zhang, A. A. Puretzky, A. Yoshimura, X. H. Sang, Q. N. Cui, Y. Y. Li, L. B. Liang, A. W. Ghosh, H. Zhao, R. R. Unocic, V. Meunier, C. M. Rouleau, B. G. Sumpter, D. B. Geohegan, and K. Xiao, "Isotope-Engineering the Thermal Conductivity of Two-Dimensional MoS2," *Acs Nano* **13** (2), 2481-2489 (2019).

14 H. Cai, Y. Y. Gu, Y. C. Lin, Y. L. Yu, D. B. Geohegan, and K. Xiao, "Synthesis and emerging properties of 2D layered III-VI metal chalcogenides," *Appl Phys Rev* **6** (4) (2019).

15 D. B. Brown, W. Q. Shen, X. F. Li, K. Xiao, D. B. Geohegan, and S. Kumar, "Spatial Mapping of Thermal Boundary Conductance at Metal-Molybdenum Diselenide Interfaces," *Acs Appl Mater Inter* **11** (15), 14418-14426 (2019).

16 N. Briggs, S. Subramanian, Z. Lin, X. F. Li, X. T. Zhang, K. H. Zhang, K. Xiao, D. Geohegan, R. Wallace, L. Q. Chen, M. Terrones, A. Ebrahimi, S. Das, J. Redwing, C. Hinkle, K. Momeni, A. van Duin, V. Crespi, S. Kar, and J. A. Robinson, "A roadmap for electronic grade 2D materials," *2d Mater* **6** (2) (2019).

17 B. Yang, W. M. Ming, M. H. Du, J. K. Keum, A. A. Puretzky, C. M. Rouleau, J. S. Huang, D. B. Geohegan, X. P. Wang, and K. Xiao, "Real-Time Observation of Order-Disorder Transformation of Organic Cations Induced Phase Transition and Anomalous Photoluminescence in Hybrid Perovskites," *Adv Mater* **30** (22) (2018).

18 R. K. Vasudevan, N. Laanait, E. M. Ferragut, K. Wang, D. B. Geohegan, K. Xiao, M. Ziatdinov, S. Jesse, O. Dyck, and S. V. Kalinin, "Mapping mesoscopic phase evolution during E-beam induced transformations via deep learning of atomically resolved images," *Npj Comput Mater* **4** (2018).
19 R. K. Vasudevan, N. Laanait, E. M. Ferragut, K. Wang, D. B. Geohegan, K. Xiao, M. Ziatdinov, S. Jesse, O. Dyck, and S. V. Kalinin, "Mapping mesoscopic phase evolution during E-beam induced transformations via deep learning of atomically resolved images (vol 4, 30, 2018)," *Npj Comput Mater* **4** (2018).
20 N. Soetan, A. Puretzky, K. Reid, A. Boulesbaa, H. F. Zarick, A. Hunt, O. Rose, S. Rosenthal, D. B. Geohegan, and R. Bardhan, "Ultrafast Spectral Dynamics of CsPb(BrxCl1-x)(3) Mixed-Halide Nanocrystals," *Acs Photonics* **5** (9), 3575-3583 (2018).
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22 R. Rao, C. L. Pint, A. E. Islam, R. S. Weatherup, S. Hofmann, E. R. Meshot, F. Q. Wu, C. W. Zhou, N. Dee, P. B. Amama, J. Carpena-Nunez, W. B. Shi, D. L. Plata, E. S. Penev, B. I. Yakobson, P. B. Balbuena, C. Bichara, D. N. Futaba, S. Noda, H. M. Shin, K. S. Kim, B. Simard, F. Mirri, M. Pasquali, F. Fornasiero, E. I. Kauppinen, M. Arnold, B. A. Cola, P. Nikolaev, S. Arepalli, H. M. Cheng, D. N. Zakharov, E. A. Stach, J. Zhang, F. Wei, M. Terrones, D. B. Geohegan, B. Maruyama, S. Maruyama, Y. Li, W. W. Adams, and A. J. Hart, "Carbon Nanotubes and Related Nanomaterials: Critical Advances and Challenges for Synthesis toward Mainstream Commercial Applications," *Acs Nano* **12** (12), 11756-11784 (2018).
23 A. A. Puretzky, A. D. Oyedele, K. Xiao, A. V. Haglund, B. G. Sumpter, D. Mandrus, D. B. Geohegan, and L. B. Liang, "Anomalous interlayer vibrations in strongly coupled layered PdSe2," *2d Mater* **5** (3) (2018).
24 A. D. Oyedele, C. M. Rouleau, D. B. Geohegan, and K. Xiao, "The growth and assembly of organic molecules and inorganic 2D materials on graphene for van der Waals heterostructures," *Carbon* **131**, 246-257 (2018).
25 E. Inclan, D. Geohegan, and M. Yoon, "A hybrid optimization algorithm to explore atomic configurations of TiO2 nanoparticles," *Comp Mater Sci* **141**, 1-9 (2018).
26 G. Eres, C. M. Rouleau, A. A. Puretzky, D. B. Geohegan, and H. Wang, "Cooperative Behavior in the Evolution of Alignment and Structure in Vertically Aligned Carbon-Nanotube Arrays Grown using Chemical Vapor Deposition," *Phys Rev Appl* **10** (2) (2018).
27 D. B. Brown, X. F. Li, K. Xiao, D. B. Geohegan, and S. Kumar, "Thermal Boundary Conductance Mapping at Metal-MoSe2 Interface," *Intsoc Conf Thermal*, 67-72 (2018).
28 M. Z. Bellus, M. Mahjouri-Samani, S. D. Lane, A. D. Oyedele, X. F. Li, A. A. Puretzky, D. Geohegan, K. Xiao, and H. Zhao, "Photocarrier Transfer across Monolayer MoS2-MoSe2 Lateral Heterojunctions," *Acs Nano* **12** (7), 7086-7092 (2018).
29 J. Bauer, L. S. Quintanar, K. Wang, A. A. Puretzky, K. Xiao, D. B. Geohegan, and A. Boulesbaa, "Ultrafast Exciton Dissociation at the 2D-WS2 Monolayer/Perovskite Interface," *J Phys Chem C* **122** (50), 28910-28917 (2018).
30 H. F. Zarick, A. Boulesbaa, E. M. Talbert, A. Puretzky, D. Geohegan, and R. Bardhan, "Ultrafast Excited-State Dynamics in Shape- and Composition-Controlled Gold-Silver Bimetallic Nanostructures," *J Phys Chem C* **121** (8), 4540-4547 (2017).
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32 H. Yu, N. Gupta, Z. L. Hu, K. Wang, B. R. Srijanto, K. Xiao, D. B. Geohegan, and B. I. Yakobson, "Tilt Grain Boundary Topology Induced by Substrate Topography," *Acs Nano* **11** (9), 8612-8618 (2017).
33 B. Yang, C. C. Brown, J. S. Huang, L. Collins, X. H. Sang, R. R. Unocic, S. Jesse, S. V. Kalinin, A. Belianinov, J. Jakowski, D. B. Geohegan, B. G. Sumpter, K. Xiao, and O. S. Ovchinnikova, "Enhancing Ion Migration in Grain Boundaries of Hybrid Organic-Inorganic Perovskites by Chlorine," *Adv Funct Mater* **27** (26) (2017).
34 K. Wang, N. Cross, A. Boulesbaa, P. R. Pudasaini, M. K. Tian, M. Mahjouri-Samani, M. P. Oxley, C. M. Rouleau, A. A. Puretzky, P. D. Rack, K. Xiao, M. Yoon, G. Eres, G. Duscher, and D. B. Geohegan, "Correlating the optical properties of WS2 monolayers grown by CVD with isoelectronic Mo doping level," *Proc Spie* **10093** (2017).
35 M. Tian, M. Mahjouri-Samani, K. Wang, A. A. Puretzky, D. B. Geohegan, W. D. Tennyson, N. Cross, C. M. Rouleau, T. A. Zawodzinski, G. Duscher, and G. Eres, "Black Anatase Formation by Annealing of

Amorphous Nanoparticles and the Role of the Ti2O3 Shell in Self-Organized Crystallization by Particle Attachment," *Acs Appl Mater Inter* **9** (26), 22018-22025 (2017).

36 W. D. Tennyson, M. K. Tian, A. B. Papandrew, C. M. Rouleau, A. A. Puretzky, B. T. Sneed, K. L. More, G. M. Veith, G. Duscher, T. A. Zawodzinski, and D. B. Geohegan, "Bottom up synthesis of boron-doped graphene for stable intermediate temperature fuel cell electrodes," *Carbon* **123**, 605-615 (2017).

37 W. D. Tennyson, M. K. Tian, K. L. More, D. B. Geohegan, A. A. Puretzky, A. B. Papandrew, C. M. Rouleau, and M. Yoon, "Pulsed laser vaporization synthesis of boron loaded few layered graphene," *Proc Spie* **10093** (2017).

38 E. M. Talbert, H. F. Zarick, A. Boulesbaa, N. Soetan, A. A. Puretzky, D. B. Geohegan, and R. Bardhan, "Bromine substitution improves excited-state dynamics in mesoporous mixed halide perovskite films," *Nanoscale* **9** (33), 12005-12013 (2017).

39 M. G. Stanford, P. R. Pudasaini, E. T. Gallmeier, N. Cross, L. Liang, A. Oyedele, G. Duscher, M. Mahjouri-Samani, K. Wang, K. Xiao, D. B. Geohegan, A. Belianinov, B. G. Sumpter, and P. D. Rack, "High Conduction Hopping Behavior Induced in Transition Metal Dichalcogenides by Percolating Defect Networks: Toward Atomically Thin Circuits," *Adv Funct Mater* **27** (36) (2017).

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