**Steven J. Randolph, Ph.D.**

*Staff Scientist*

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**Education**

*2005*; Ph.D. *Materials Science and Engineering*; University of Tennessee, Knoxville

Dissertation: “Experimental, Theoretical, and Device Application Development of Nanoscale Focused Electron-Beam-Induced Deposition”

*2004*; M.S. *Materials Science and Engineering;* University of Tennessee, Knoxville

Thesis: “Nanoscale Materials Processing: Electron-Beam-Induced Etching of Silicon and Silicon Dioxide”

*2002*; B.S. *Chemistry*; University of Tennessee, Knoxville; Focus: Physical and Biochemistry

Undergraduate Research: Electron spin resonance spectroscopy (ESR) for structural analysis of free radicals

**Professional Experience**

***2007-Present: Staff Scientist; ThermoFisher Scientific, Advanced Technology***

*Summary: Progressed from Scientist II, Senior Scientist, to Staff Scientist developing IP and publishing on business-relevant topics including femtosecond laser, electron, and ion induced beam chemistry for fabrication. Developed 3D light and electron correlative workflows for biological microscopy. Developed chemistries responsible for fabrication of high conductivity nanostructures as well as differential etch chemistries. Developed in-situ microfluidics platform for wet chemistry in environmental SEM. Developed expertise in a wide array of electron and ion microscopy and fabrication techniques targeted to semiconductor, life science, and materials science application space. Managed early adopter capital equipment development projects and supported all aspects from safety and regulatory compliance to end-user application and training. Ownership and responsibility for multiple prototype microscopes and a development laboratory. Member of environmental health and safety committee. Leading and mentoring numerous recent graduates of University of Oregon’s Semiconductor Processing and Optics Masters internship program.*

**Femtosecond Laser FIB/SEM Development**

* Developed novel workflow using serial cryogenic fs-laser tomography to study intact lithium metal coin cells.
* Managed project developing and integrating a femtosecond laser onto a plasma FIB / SEM system to allow high rate, low damage materials characterization.
* Extensive experience optimizing laser conditions and optics for improving cut quality for a given application
* Assisted marketing and sales to demonstrate the technology through customer facing demos and scientific publication / presentations.
* Transferred knowledge to production and service to all commercialization and support of the newly developed Helios 5 Laser PFIB.
* Continuing application support for our early adopter customers to ensure they get the most out of their investment.
* Gained valuable experience in safety and regulatory compliance to integrate and develop the first class-IV laser product in our division.
* Current work is focused on modification and characterization of cryogenically cooled samples to enable energy storage materials, such as lithium metal batteries, to be analyzed from the millimeter to the nanoscale domain.

**Biological Specimen Preparation for Correlative Microscopy**

* Super-resolution imaging of sub-diffraction limit biological structures.
* Correlative light & electron microscopy workflow development.
* Biological sample preparation for light, electron, and ion imaging.
* Developed imaging conditions for HER2 labeled SKBR3 cells for 3D analysis of filopodial protein organization
* Developed intellectual property on genetically expressible, EM contrast agents.
* Developed intellectual property on multiphoton- and electron-induced metal labeling of *C. elegans*
* Investigated cryosectioning of *C. elegans* with non-gallium focused ion beam including study of novel contrast mechanisms in cryosectioned and resin embedded samples.
* Designed, organized, and converted a physics lab space to accommodate wet chemistry, simple cell culture, fixation, labeling, embedding, ultramicrotomy, and fluorescence imaging.

**Light Optics for Imaging and Sample Modification**

* Developed expertise in super resolution imaging, specifically dSTORM to produce 3D reconstruction of immunolabeled structures.
* Investigated optimization of redox buffer chemistries for improved super resolution imaging.
* Developed synthetic biological system for rapid assessment of super resolution imaging conditions.
* Investigated use of super resolution microscopy with resin-embedded biological specimens.
* Femtosecond laser based serial sectioning tool and workflow development
* Multiphoton-induced surface chemistry using ultrashort pulsed laser induced deposition.
* Investigated multiphoton-driven biological ultrastructure heavy metal labeling for image contrast enhancement.

**Technical Program Management**

* Facilitated and fostered the collaborative efforts of Project 2 of the OHSU/FEI Living Lab joint work on 3D super resolution CLEM
* Technical lead for full workflow development enabling correlation between 3D super resolution image and TEM tomography of immunolabeled U2OS microtubule structures.
* Project manager and researcher on development of early adopter femtosecond laser equipped DualBeam for large scale tomography applications

**Beam-Induced Surface Chemistry**

* + - Beam chemistries for biofunctionalization of nanostructures with proteins, etc. via amine termination of surfaces and amide bond formation.
    - Self-assembly of nanostructures during ion bombardment of surfaces
    - Catalytic deposition through beam-induced surface functionalization.
* Identification of novel precursors and/or processes for electron- and ion-beam-induced CVD and gas-assisted etching.
* Discovery, development, and implementation on novel low resistivity ion-beam-induced metal CVD (multiple patents to be filed).
* Discovery, development, and implementation of gas-assisted electron-beam-induced etch chemistries using gas mixtures to optimize material selectivity.
* XeF2 as an oxidizing agent combined with a variety of fluorocarbon species results in differential etching of silicon/silicon dioxide/silicon nitride.
* Investigation of post-processing and *in-situ* purification techniques for improving electrical and compositional properties of ion and electron beam CVD materials
* Novel beam chemistry applications with non-standard ion sources (non-gallium ion, optical).
  + Sub-diffraction-limit pattern transfer using material-dependent laser ablation threshold.
    - *In-situ* fluid manipulation in environmental SEM (ESEM).
    - Deterministic and non-deterministic room-temperature, spontaneous metal CVD.
* Member of Environmental, Health, and Safety Committee.

***2005-2007: Post-doctoral researcher; Oak Ridge National Laboratory***

* + Responsible for maintenance and upkeep complex semiconductor equipment including stepper, contact aligner, RIE/ICP dry etch tool, PECVD, e-beam evaporator, profilometer, reflectometer, resist spinners, d.c. sputter coater, LPCVD, CMP.
  + Training users and facilitation of user projects involving the application of the above tools.
  + General cleanroom maintenance, organization, establishment of safety procedures.
  + Investigated conventional microfabrication processes as well as novel fabrication processes for creating field emission cathodes.
    - Electron-beam-induced tungsten nanopillar deposition in pre-fabricated diode and triode wells for testing field emission properties.
    - Continuation of earlier established, self-aligned carbon nanofiber field emission device fabrication.
  + Microfabrication process optimization for RIE/ICP dry etching, PECVD, PVD (sputter), optical stepper and contact lithography, wet etch, e-beam lithography.
  + Investigated stress-induced and/or thermally-induced preferred orientation of nickel films and subsequent effects on dewetting properties following catalytic nanoparticle formation.
    - Evaluated parameter space of pressure, power, d.c. substrate bias, temperature of r.f. nickel sputter deposition process.
    - Characterization of films as-deposited and post-dewetted by x-ray diffraction and electron microscopy.
    - Dewetted nanoparticles used as catalysts for carbon nanofiber growth by PECVD.

***2002-2005: Research Assistant, The University of Tennessee, Knoxville***

* Investigated various aspects of electron-beam-induced processing.
  + Studied effects of scan parameters and beam conditions on the effects of e-beam-induced etching of silicon and silicon dioxide. Proposed possible mechanism.
  + Studied and reported on material properties of tungsten as-deposited from e-beam-induced deposition from WF6 via AES, TEM, SEM, STEM, EDS.
  + Finite element thermal modeling of beam-induced heating effects during deposition of e-beam-induced dielectric nanopillars. Correlated to experiment.
  + Implemented Monte-Carlo electron-scattering model to determine energy distribution profiles during electron-beam-induced deposition.
  + Application of electron-beam-induced deposition for high-resolution single- and bi-layer e-beam lithographic patterning with hard masks.
  + Application of electron-beam-induced deposition for fabrication of nanoscale field emitters.
* Microfabrication process development for microscale vacuum encapsulation devices.
  + - Process development for device fabrication from CAD layout to final device testing.
    - Gained experience with wide array of standard microfabrication techniques such as optical lithography, PECVD, evaporation and sputtering (PVD), dry etching, wet etching, resist processing, thin film characterization and analysis.
    - Helped design and build in-house d.c. sputter tool to facilitated vacuum encapsulation project.
    - Completed vacuum encapsulation and successfully tested a vacuum-sealed microchamber (encapsulation).

**Research Interests**

* Fabrication, materials modification, and chemistry utilizing reactive ion beams.
* Cryogenic microscopy techniques in lithium metal battery research.
* Direct write beam chemistry and fabrication techniques in sample preparation for cryo TEM tomography and single particle analysis
* Nanofabrication and materials analysis utilizing ultrashort pulse laser technology.
* Super resolution fluorescence microscopy and correlative EM imaging of cellular ultrastructure.
* Novel imaging methods for determining receptor surface site chemical functionality.
* Ultrashort (femtosecond) pulsed laser materials processing and serial sectioning.
* Biological sample preparation for TEM/STEM and fluorescence microscopy and maintaining fluorescence.
* Biofunctionalization of surfaces and nanostructures via novel surface chemistry for molecular attachment and immobilization
* Atypical uses of electron microscopy, such as beam-induced chemistry for materials synthesis.
* Beam chemistry for biological contrast enhancement in electron microscopy
* Environmental SEM as a tool for imaging and manipulating samples that are non-equilibrium in high vacuum. Imaging of liquid stabilization and phase transformations phenomena *in-situ.*
* Beam-induced reactions: electron, ion, photon / gas, liquid, solid, adsorbed phases
* Structural characterization of materials via electron and x-ray diffraction.
* Mathematical modeling of complex physical systems
* Materials synthesis and structural, morphological, compositional characterization
* General nanofabrication of multilevel structures, such as MEMS and microfluidic devices

**Relevant Skill Set**

***Microscopy***

* Electron, Ion, and Scanning Probe Microscopies: SEM, FIB, TEM, STEM, ESEM, AFM
* Light Microscopies: Widefield fluorescence, Confocal fluorescence, Super-resolution PALM, dSTORM, 3D Super-resolution interferometric PALM (iPALM)

***Sample Preparation***

* Immunolabeling for fluorescence microscopies
* Plastic resin embedding of biological samples (U2OS, SKBR3 cancer cell lines; yeast) for correlative light and electron microscopies
* Preservation of fluorescence in resin embedded, immunolabeled biological systems.
* Ultramicrotomy for biological and materials TEM analysis
* DualBeam-based TEM lamellae preparation of biological, semiconductor, and materials samples.
* Micro-Computed-Tomography (µCT) sample preparation via ultrashort (femtosecond) pulsed laser ablation.

***Characterization and Analysis***

* EDS (Energy Dispersive X-ray Spectroscopy), X-ray Diffraction (XRD), Electron Backscatter Diffraction (EBSD), Mass Spectrometry (MS), Residual Gas Analysis (RGA), Electron diffraction, Profilometry, ESR and NMR resonance spectroscopy, electrical property determination via 2- and 4-point probing.

***Wet Laboratory Skills***

* Quantitative chemical analysis such as titrations, dilutions, solution preparation, neutralizations, electrochemistry, basic cell culture, labeling, fixation
* Lab and facility design and management; Environmental Health and Safety compliance
* Hazardous material/chemical handling and waste management

***Microfabrication and Sample Modification***

* Charged particle induced surface chemistry
* Ultrashort pulsed laser material processing (high rate material removal; deposition)
* PECVD, thermal CVD (LPCVD), PVD (evaporation, r.f. and d.c. sputter, reactive sputter)
* RIE and ICP dry etching, wet etching, CMP,
* Electrochemistry (electrodeposition, anodization, etc.)
* Lithography (optical, e-beam, novel techniques)
* Microfluidics device fabrication

***Computer simulation, programming, and CAD***

* LabView
* SIMION charged particle optics simulation
* Finite element methods for partial differential equation numerical solution
* Finite difference differential equation numerical solution
* MATLAB programming environment, Mathematica
* Monte-Carlo modeling methods
* L-Edit, Layout Editor, AutoCAD

**External Funding and Research Grants**

* Co-author/investigator: *Real-Time Electron Beam Studies of Dynamic Processes In Nano Scale Materials Physics.*  4 year Joint proposal between FEI and University of Technology at Sydney funded by the Australian Research Council, LP11020090.

**Patents and Inventions**

* Authored or co-authored approximately 50 novel invention disclosures in 13+ years
  + Multiple patents currently pending involving biofunctionalization, surface chemistry, and correlative light and electron microscopy techniques
  + Patents Awarded:
* Randolph, S., Miyasaki, J., Straw, M. *Fiducial-based correlative microscopy*, US Patent 9368321, (2016).
* Botman, A.P.J.M, Toth, M., Randolph, S., Narum, D., *Localized, in-vacuum modification of small structures*, US Patent 9255339 B2, (2016).
* Chandler, C.D., Randolph, S., Hartigan, G., *Gas delivery for beam processing systems,* US Patent 9,150,961, (2015).
* Botman, A.P.J.M., Randolph, S., Utlaut, M.W., *Microfluidics delivery systems*, US Patent 9,044,781, (2015).
* Randolph, S., Chandler, C.D., *High Selectivity, Low Damage Electron-Beam Delineation Etch*, U.S. Patent 8,778,804, (2014).
* Botman, A.P.J.M., Randolph, S., Toth, M., *Method of Depositing Material*, US Patent 8,853,078, (2014).
* Straw, M., Toth, M., Randolph, S., Lysaght, M., Utlaut, M., *Charged Particle Beam Masking for Laser Ablation Micromachining*, U.S. Patent 8,629,416, (2014).
* Toth, M., Lobo, C., Randolph, S., Chandler, C., *Method of Using Nitrogen Based Compounds to Reduce Contamination in Beam-Induced Thin Film Deposition*, US Patent 8,617,668, (2013).
* Randolph, S., Chandler, C.D., *Beam-Induced Deposition of Low-Resistivity Material*, US Patent 20,120,308,740, (2012).

**Invited Review Articles and Presentations**

1. Randolph, SJ, *Helios Laser PFIB: fs-Laser Enabling New Applications,* Focused Ion Beam User Group, EDFAS 2021 (Remote Conference).
2. Randolph SJ, Fowlkes JD, Rack PD. *Focused, nanoscale electron-beam-induced deposition and etching*. Critical Reviews in Solid State and Materials Sciences. 2006;31(3):55-89.
3. Botman, A., Randolph, S. J., Bahm, A., Straw, M. & Toth, M. Spontaneous nanostructure assembly with new focused charged particle beam-induced processes. in *Abstracts of Papers of The American Chemical Society* **247,** (2014).
4. Randolph SJ, Toth M, Chandler CD, *Present and future challenges in electron-beam-induced processing*, User Meeting of the Center for Nanophase Materials Sciences, Oak Ridge National Laboratory, Oak Ridge, TN, September 2008.

**Peer-Reviewed Journal Articles**

1. Jungjohann, K., Gannon, R., Goriparti, S., Randolph, S.J., Johnson, D., Zavadil, K., Harris, S., Harrison, K. Cryogenic Laser Ablation Reveals Short Circuit Mechanism in Lithium Metal Batteries, *ACS Energy Lett.* 2021, **6**, 2138-2144.
2. J. Wang, S.J. Randolph, Q. Wu, A. Botman, J. Schardt, C. Bouchet-Marquis, X.L. Nan, C. Rue, M. Straw. Reactive oxygen FIB spin milling enables correlative workflow for 3D super-resolution light microscopy and serial FIB/SEM of cultured cells, *Nanoscale*, (**submitted 2021**)
3. Martin, A. A., et al. (2017). Radiation-Induced Damage and Recovery of Ultra-Nanocrystalline Diamond: Toward Applications in Harsh Environments, American Chemical Society. **9:** 39790-39794.
4. Kianinia, M. *et al.* Robust, directed assembly of fluorescent nanodiamonds. *Nanoscale* **8**, (2016).
5. Echlin, M. P., Straw, M., Randolph, S., Filevich, J. & Pollock, T. M. The TriBeam system: Femtosecond laser ablation in situ SEM. *Mater. Charact.* **100,** 1–12 (2015).
6. Martin, A. A., Randolph, S., Botman, A., Toth, M. & Aharonovich, I. Maskless milling of diamond by a focused oxygen ion beam. *Sci. Rep.* **5,** (2015).(Liang, Zhang et al. 2020)
7. Straw, M. & Randolph, S. Direct spatiotemporal analysis of femtosecond laser-induced plasma-mediated chemical reactions. *Laser Phys. Lett.* **11,** 035601 (2014).
8. Bresin, M., Botman, A., Randolph, S. J., Straw, M. & Hastings, J. T. Liquid Phase Electron-Beam-Induced Deposition on Bulk Substrates Using Environmental Scanning Electron Microscopy. *Microsc. Microanal.* **20,** 376–384 (2014).
9. Randolph, S. J., Botman, A. & Toth, M. Deposition of Highly Porous Nanocrystalline Platinum on Functionalized Substrates Through Fluorine-Induced Decomposition of Pt(PF3)4 Adsorbates. *Part. Part. Syst. Charact.* **30,** 201300036 (2013).
10. Botman, A., Bahm, A., Randolph, S., Straw, M. & Toth, M. Spontaneous Growth of Gallium-Filled Microcapillaries on Ion-Bombarded GaN. *Phys. Rev. Lett.* **111,** 135503 (2013).
11. Randolph, S. J. S., Botman, A. & Toth, M. Capsule-free fluid delivery and beam-induced electrodeposition in a scanning electron microscope. *RSC Adv.* **3,** 20016–20023 (2013).
12. Randolph, S., Toth, M., Cullen, J., Chandler, C. & Lobo, C. Kinetics of gas mediated electron beam induced etching. *Appl. Phys. Lett.* **99,** 213103 (2011).
13. Young, R. *et al.* A comparison of xenon plasma FIB technology with conventional gallium LMIS FIB: imaging, milling, and gas-assisted applications. *Microsc. Microanal.* **17,** 652–653 (2011).
14. Botman, A. *et al.* Electron postgrowth irradiation of platinum-containing nanostructures grown by electron-beam-induced deposition from Pt (PF3) 4. *J. Vac. Sci. Technol. B* **27,** 2759–2763 (2009).
15. Li, J. *et al.* Electron postgrowth irradiation of platinum-containing nanostructures grown by electron-beam-induced deposition from Pt (PF3) 4. *J. Vac. Sci. Technol. B Microelectron. Nanom. Struct.* **27,** 2759–2763 (2009).
16. Klein, K. L. *et al.* Single crystal nanowires grown via electron-beam-induced deposition. *Nanotechnology* **19,** 345705 (2008).
17. Rahman, T. *et al.* Integration of a dose control circuit with a vertically aligned nanofiber field emission device. *J. Vac. Sci. Technol. B* **25,** (2007).
18. Rack, P. D., Fowlkes, J. D. & Randolph, S. J. In situ probing of the growth and morphology in electron-beam-induced deposited nanostructures. *Nanotechnology* **18,** 465602 (2007).
19. Randolph, S. J. *et al.* Controlling thin film structure for the dewetting of catalyst nanoparticle arrays for subsequent carbon nanofiber growth. *Nanotechnology* **18,** 465304 (2007).
20. Randolph, S. J., Fowlkes, J. D. & Rack, P. D. Focused, nanoscale electron-bearn-induced deposition and etching. *Crit. Rev. Solid State Mater. Sci.* **31,** 55–89 (2006).
21. Choi, Y. R., Rack, P. D., Randolph, S. J., Smith, D. A. & Joy, D. C. Pressure effect of growing with electron beam-induced deposition with tungsten hexafluoride and tetraethylorthosilicate precursor. *Scanning* **28,** 311–318 (2006).
22. Yang, X. *et al.* Integrated tungsten nanofiber field emission cathodes selectively grown by nanoscale electron beam-induced deposition. *Appl. Phys. Lett.* **86,** 183106 (2005).
23. Randolph, S. J., Fowlkes, J. D. & Rack, P. D. Effects of heat generation during electron-beam-induced deposition of nanostructures. *J. Appl. Phys.* **97,** 124312 (2005).
24. Randolph, S. J., Fowlkes, J. D. & Rack, P. D. Focused electron-beam-induced etching of silicon dioxide. *J. Appl. Phys.* **98,** 34902 (2005).
25. Fowlkes, J. D., Randolph, S. J. & Rack, P. D. Growth and Simulation of High – Aspect Ratio Nanopillars by Primary and Secondary Electron – Induced Deposition. *J. Vac. Sci. Technol. B* **23,** 2825–2832 (2005).
26. Randolph, S. J., Hale, M. D., Guillorn, M. A., Rack, P. D. & Simpson, M. L. A microfabrication process for a vacuum-encapsulated microchamber. *Microelectron. Eng.* **77,** 412–419 (2005).
27. Rack, P. D. *et al.* Nanoscale electron-beam-stimulated processing. *Appl. Phys. Lett.* **82,** 2326–2328 (2003).

**Conferences: Contributed Talks and Posters**

\* Indicates SJR as presenter

1. *Electrolyte Comparison for Li-Metal Anodes with Cryo-Laser PFIB.* Microscopy and Microanalysis (2021).
2. *DualBeam Platform Applications in Lithium Battery Research,* 239th Electrochemical Society (2021).
3. *Identifying Intact Electrode Interfaces with Cryogenic Electron Microscopy*, MRS (2021)
4. T*riBeam Tomography for 3D Data Acquisition*, Microscopy and Microanalysis (2020)
5. *Cryo-EM of Li Metal Battery Aging and Failure Mechanisms*, Microscopy and Microanalysis (2020).
6. *Cross-platform Holder Kit for a Real 3D Correlative Tomography and Microscopy*, Microscopy and Microanalysis (2020)
7. *Femtosecond Laser-Enabled TriBeam as a Platform for Analysis of Thermally- and Charge-Sensitive Materials*, Microscopy and Microanalysis (2019)\*
8. *Advances in Multi-beam and Multi-ion FIB-SEM for 3D Correlative Microscopy*, Microscopy and Microanalysis (2019)
9. *Site-specific in-situ laser ablation of charge sensitive materials*, Microscopy and Microanalysis (2019)
10. *Combined femtosecond laser and plasma DualBeam for in-situ failure and materials analysis*, Failure Analysis and Material Diagnostics of Electronic Components (2018)
11. *Evidence for surface-plasmon-mediated precursor dissociation in ultrashort-pulse-laser-induced surface chemistry*, American Chemical Society (2017)\*
12. *Hydrogen-beam induced deposition of platinum and tungsten microstructures*. The 59th International Conference on Electron, Ion, and Photon Beam Technology and Nanofabrication (2015).
13. *Spontaneous nanostructure assembly with new focused charged particle beam-induced processes.* 247th ACS National Meeting (March), Dallas, TX, USA, 2014.
14. *In-situ Microfluidics using a Liquid Injector for the Study of Beam-Induced and Dynamic Processes.*Electron, Ion and Photon Beam Technology and Nanofabrication (EIPBN) International Conference, Nashville, TN, USA, 2013*.*
15. *XeF2-Mediated Bottom-Up Growth of Pillars on GaN by Energetic Ga+ Ion Beam Irradiation,* 4th FEBIP Workshop, Zaragoza, Spain, 2012.
16. *Kinetics of Gas-Mediated Electron Beam Induced Etching*, 4th FEBIP Workshop, Zaragoza, Spain, 2012.
17. *Rapid Localized Deposition of High Purity Platinum by Spontaneous Reaction of Pt(PF3)4 with XeF2 in a Scanning Electron Microscope,* 4th FEBIP Workshop, Zaragoza, Spain, 2012.\*
18. *Liquid Precursors for in-situ Beam-Induced Electrochemistry*, 4th FEBIP Workshop, Zaragoza, Spain, 2012.
19. *Pure, rapid and localized deposition of platinum by spontaneous reaction of Pt(PF3)4 with XeF2 in a scanning electron microscope*; 37th International Conference on Micro and Nano Engineering, Berlin, Germany, 2011.
20. *Material Removal Over Several Orders of Magnitude*, Microscopy and Microanalysis 2011, Nashville, Tennessee, 2011.\*
21. *Electron-beam-induced etch chemistries: Improved contrast in high-resolution electron microscopy*; The 3rd International Conference on Focused-Electron-Beam-Induced Processing; Albany, New York, 2010.\*
22. *Gas-Mediated Electron and Ion Beam Induced Deposition using Ammonia as a Purification Medium*,The 54th International Conference on Electron, Ion, and Photon Beam Technology and Nanofabrication, Anchorage, Alaska, 2010.
23. *Electron-beam-induced delineation etching*; The 2nd FEI Internal Technical Conference, Eindhoven, The Netherlands, 2009.\*
24. *Sub-10-nm electron-beam-induced etching*; The 2nd International Conference on Focused-Electron-Beam-Induced Processing; Thun, Switzerland, 2008.\*
25. *Beam Chemistry Considerations for Next-Generation High Current FIB Columns;* The 1st FEI Internal Technical Conference, Portland, OR, 2007.\*
26. *Operation of the Digital Electrostatic e-beam Array Lithography (DEAL) prototype with dose control* (2007) Technical Digest of the 20th International Vacuum Nanoelectronics Conference, IVNC 07, art. No. 4480993, pp. 197-199.
27. *Digitally addressable vertically aligned carbon nanofibers for implementation of massively parallel maskless lithography* (2007) 2007 International Semiconductor Device Research Symposium, ISDRS, art. No. 4422425.
28. *Integration of a dose control circuit with a vertically aligned nanofiber field emission device* (2006) IVNC and IFES 2006 - Technical Digest - l9th International Vacuum Nanoelectronics Conference and 50th International Field Emission Symposium, art. No. 4134510, pp. 161-162.
29. *New strategies for improvement and implementation of the digital electrostatic e-beam array lithography (DEAL) concept*; IVNC and IFES 2006 - Technical Digest - 19th International Vacuum Nanoelectronics Conference and 50th International Field Emission Symposium; Guilin, China.\*
30. *Development of a bilayer nanolithography scheme utilizing electron-beam-induced deposition of an ultrathin resist*, 50th International Conference on Electron, Ion, and Photon Beam Technology and Nanofabrication, Baltimore, MD (May30-June 2, 2006).\*
31. *Compositional and Structural Characterization of Tungsten Nanostructures Produced by Electron Beam-Induced Deposition*, 52nd International AVS Conference, Boston, MA (Oct. 30-Nov. 4 2005).
32. *Electron Beam Induced Processing of Nanoscale Features: Process Parameters, Simulated Growth, and Nanoscale Applications*, 52nd International AVS Conference, Boston, MA (Oct. 30-Nov. 4 2005).
33. *Maskless, Direct-Write Nanolithography using Electron Beam-Induced Deposition*, 52nd International AVS Conference, Boston, MA (Oct. 30-Nov. 4 2005).\*
34. *Unraveling the complex variable space of electron beam induced deposition by a Monte – Carlo based, 3D growth simulation*, 49th International Conference on Electron, Ion, and Photon Beam Technology and Nanofabrication, Orlando, FL (June 1-4, 2005).
35. *Progress toward realization of the digital electrostatic e-beam array lithography (DEAL) concept* (2005) Technical Digest of the 18th International Vacuum Nanoelectronics Conference, IVNC 2005, 2005, art. No. 1619491, pp. 74-75.
36. *Localized Heating Effects during Electron Beam-Induced Deposition of Nanostructures*, 51st International American Vacuum Society Conference, Anaheim CA (November 14-19, 2004).\*
37. *A Three - Dimensional Computer Simulation of Electron - Beam Induced Deposition (EBID,)* 51st International American Vacuum Society Conference, Anaheim CA (November 14-19, 2004).
38. *Electron Interactions in Nanoscale Focused Electron Beam Processing*, 50th International American Vacuum Society Conference, Baltimore MD (November 3-7, 2003).
39. *Vacuum Encapsulation of Micron-Sized Vacuum Field Effect Transistors*, 50th International American Vacuum Society Conference, Baltimore MD (November 3-7, 2003).\*
40. *Soft electron beam etching for precision TEM sample preparation* (2003) Proceedings of SPIE - The International Society for Optical Engineering, 5038 II, pp. 943-949.

**References**

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* Kate Klein, Assistant Professor of Mechanical Engineering, University of the District of Columbia. Email: [nanokate@gmail.com](mailto:nanokate@gmail.com)
* Jason Fowlkes, Oak Ridge National Laboratory, Research Staff. Email: [fowlkesjd@ornl.gov](mailto:fowlkesjd@ornl.gov)
* © 2017 American Chemical Society. Ultra-nanocrystalline diamond (UNCD) is increasingly being used in the fabrication of devices and coatings due to its excellent tribological properties, corrosion resistance, and biocompatibility. Here, we study its response to irradiation with kiloelectronvolt electrons as a controlled model for extreme ionizing environments. Real time Raman spectroscopy reveals that the radiation-damage mechanism entails dehydrogenation of UNCD grain boundaries, and we show that the damage can be recovered by annealing at 883 K. Our results have significant practical implications for the implementation of UNCD in extreme environment applications, and indicate that the films can be used as radiation sensors.

1. Liang, Q., et al. (2020). "Performance Improvement by Ozone Treatment of 2D PdSe2." ACS Nano **14**(5): 5668-5677.
2. Atomic-scale defects in two-dimensional transition metal dichalcogenides (TMDs) often dominate their physical and chemical properties. Introducing defects in a controllable manner can tailor properties of TMDs. For example, chalcogen atom defects in TMDs were reported to trigger phase transition, induce ferromagnetism, and drive superconductivity. However, reported strategies to induce chalcogen atom defects including postgrowth annealing, laser irradiation, or plasma usually require high temperature (such as 500 degrees C) or cause unwanted structural damage. Here, we demonstrate low-temperature (60 degrees C) partial surface oxidation in 2D PdSe2 with low disorder and good stability. The combination of scanning tunneling microscopy, X-ray photoelectron spectroscopy, and density functional theory calculations provide evidence of atomic-scale partial oxidation with both atomic resolution and chemical sensitivity. We also experimentally demonstrate that this controllable oxygen incorporation effectively tailors the electronic, optoelectronic, and catalytic activity of PdSe2. This work provides a pathway toward fine-tuning the physical and chemical properties of 2D TMDs and their applications in nanoelectronics, optoelectronics, and electrocatalysis.