Cornell NanoScale Facility
2020-2021
Research Accomplishments

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The 2020-2021 CNF Research Accomplishments are also available on the web: http://cnf.cornell.edu/publications/research_accomplishments

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Table of Contents

Technical Reports by Section ................................................................. ii-iv
Directors' Welcome .............................................................................. v-viii
CNF in the News .................................................................................. ix
2020 CNF Research-Related Patents, Presentations, and Publications .......... ix-xxii
Abbreviations and Their Meanings ....................................................... xxiii-xxvi
Photography Credits ........................................................................... xxvi
2020-2021 CNF Research Accomplishments ........................................ 2-147
Index ..................................................................................................... 148-150

Biological Applications, 2-35
Investigating Metabolic Regulation of Cancer Stem-Like Cells in the Perivascular Niche ........................................................................... 2
Generating Microfluidic Devices to Study Confined Migration of Cancer Cells ...................................................................................... 4
Body-on-a-Chip Systems for Drug Development and in vitro Interactions ......................................................................................... 6
Silicon Nitride Cantilevers for Muscle Myofibril Force Measurements ................................................................................................. 8
Nanophotonic Standing-Wave Array Trap for Single-Molecule Applications ......................................................................................... 10
Microfluidics Channels for Zinc Metal Homeostasis .............................. 12
Sample Cells for High Pressure Biological X-Ray Solution Scattering ......................................................................................... 14
Bacterial Mechanics and Mechanobiology ............................................. 16
Design and Application of Microfluidic Devices to Study Cell Migration in Confined Environments ......................................................... 18
Microfabrication of Fixed Length Sample Holders for Cryogenic Small Angle X-Ray Scattering ......................................................... 20
Metasurface-Enhanced Infrared Spectroscopy for the Measurement of Live Cells .................................................................................. 22
Retinal Implant Project ......................................................................... 24
Development of Heparin-Based Coacervate Loaded Liposomes as Non-Invasive Therapy for Myocardial Infarction ........................... 26
Test Chip for Impedance Spectroscopy of Neuro Excitability .................. 28
Fabrication of Microchip Devices for Organ-on-a-Chip and Lab-on-a-Chip ......................................................................................... 30
Human MSCs Release Multiple EV Populations Containing Mitochondria ......................................................................................... 32
Microfluidic Device to Study Breast Cancer Cell Migration .................... 34

Chemistry, 36-39
Peptoid Photoresists with Precisely Controllable Length and Composition ......................................................................................... 36
Controlling the Crystallite Size Distribution of Metal Organic Frameworks (MOFs) Using Base-Mediated Equilibrium Dynamics .............. 38

Electronics, 40-53
Graphene-on-Polymer Flexible Vaporizable Sensor .................................. 40
Towards Low-Coercive Field Operation of Sputtered Ferroelectric ScAlxN1-x ......................................................................................... 42
A High-Performance Epitaxial Transparent Oxide Thin-Film Transistor Fabricated at Back-End-Of-Line Temperature (< 450°C) by Suboxide Molecular-Beam Epitaxy ......................................................... 44
Fabrication and Manipulation of Microscale Opto-Electrically Transduced Electrodes (MOTEs) ........................................ 46
Millimeter-Wave Large Signal Performance of AlN/GaN/AlN HEMTs ................................................................. 48
Nitrogen Polar III-Nitride Resonant Tunneling Diodes ....... 50
CMOS Neural Probe with Multi-Turn Micro-Coil Magnetic Stimulation .......................................................... 52

Materials, 54-75
New Generation of DUV Photoresists with Precise Molecular Structure ............................ 54
A New Generation of Small Molecules for EUV Photolithography ........................................ 56
Mesoporous Thin Film Quantum Materials via Block Copolymer Self-Assembly Patterned by Photolithography ......................................................... 58
Nano-Scale Area-Selective Formation of Polymer Brushes ................................................................. 60
Raman Spectroscopy and Aging of the Low-Loss Ferrimagnet Vanadium Tetracyanoethylene. 62
Encapsulation of Photocathodes in Two-Dimensional Materials ......................................................... 64
Fabricating Planar Microwave Resonators for On-Chip Electron Spin Resonance Spectroscopy . 66

Scissionable Polymer Photoresist for Extreme Ultraviolet Lithography ........................................ 68
Control of Water Adsorption via Electrically Doped Graphene ......................................................... 70
Driving Structure Selection in Colloidal Particles Through Confinement ................................................................. 72
Elucidating the Chemical Crypsis Mechanism in South African Snakes by Determining Microscale and Nanoscale Structure-Function Relationships in Snake Skin Sheds and Replicas ................................................................. 74

Mechanical Devices, 76-91
Programmable Magnetic Microsystems ................................................................. 76
Smart Microscopic Robots ............................................................................................................. 78
Characterizing Disjoining Pressure of Water in SiO₂ Nanochannels by Wicking Experiments ................................................................. 80
Origami-Inspired Micro-Robotic Arm .......................................................................................... 82
Electrically Controllable Micro-Machines .................................................................................. 84
Nanoscale Hot-Wire Anemometer Probe with Contoured Silicon Probe Body ................................................................. 86
Hot-Wire Anemometer Probe with SU-8 Support Structure ................................................................. 88
Limit Cycle Oscillations in Silicon Structures Using Opto-Thermal Excitation ................................................................. 90

Optics & Opto-Electronics, 92-111
Ultra-Broadband Entangled Photons on a Nanophotonic Chip ................................................................. 92
Narrow Linewidth, Widely Tunable Integrated Lasers from Visible to Near-IR ................................................................. 94
Development of Single and Double Layer Anti-Reflective Coatings for Astronomical Instruments ................................................................................................. 96
Electrically Actuated Zoom-Lens Based on a Liquid-Crystal-Embedded Semiconductor Metasurface ................................................................. 98
Lithium Niobate Ring Resonator Device for Adiabatic Wavelength Conversion ................................................................. 100
Precise Phase Measurement with Weak Value Amplification on Integrated Photonic Chip ................................................................................................. 102
Engineered Second-Order Nonlinearity in SiN .................................................................................. 104
Description of the Thermal Control using Metamaterials Project ................................................................. 106
Metamaterial Spectrometer: A Low SWaP, Robust, High Performance Hyperspectral Sensor for Land and Atmospheric Remote Sensing ................................................................. 108
Stoichiometric Silicon Nitride Growth for Nonlinear Nanophotonics ................................................................. 110

2021 CNF Interns in the CNF Cleanroom
## Physics & Nano-Structure Physics, 112-139

- Controlling the Pre-Curvature of Surface Electrochemical Actuators for Microscopic Robots. ........................................... 112
- Current-Induced Magnetization Switching in a Ferrimagnetic Layer. ................................................................. 114
- Separation of Artifacts from Spin-Torque Ferromagnetic Resonance Measurements of Spin-Orbit Torque for the Low-Symmetry Semi-Metal ZrTe$_3$. ......................................................... 116
- Anisotropic Magnetoresistance in Graphene/Insulating Ferromagnet van der Waals Heterostructures. ...................... 118
- Small Devices for Photo-Induced Electrochemical Synthesis. .................................................................................... 120
- Nanofabricated Superconducting Devices for Vortex Dynamics and Qubits. ................................................................. 122
- Fabrication of Nanoscale Josephson Junctions for Quantum Coherent Superconducting Circuits. ................................ 124
- Nanoscale Magnetization and Current Imaging using Time-Resolved Scanning-Probe Magneto-Thermal Microscopy. .......... 126
- Strain Tuning of Quantum Emitters in Monolayer Transition Metal Dichalcogenides. .................................................. 128

- Mechanically Driven Electron Spins with a Diamond Thin-Film Bulk Acoustic Resonator. ........................................... 130
- Fabrication of Nanophotonic Optical Cavity Device from Inverse Design. ................................................................. 132
- Charge-Order-Enhanced Capacitance in Semiconductor Moiré Superlattices. ................................................................. 134
- Thermal and Electrical Properties of Quasi-1D van der Waals Nanowires. ................................................................. 136
- Superconducting Thin Film Growth, Process Development, Defects Investigation, and Device Fabrication for Radio-Frequency Accelerating Cavities. ................................................................. 138

## Process & Characterization, 140-147

- Characterization of Extracellular Vesicles Produced from Glycocalyx-Engineered Cells *in vitro*. ................................ 140
- NanoScale Hole Patterns Etched into Glass for Spectral Sensing. ............................................................................ 142
- 300 mm E-Beam Lithography. ........................................................................................................................................ 144
- Characterization of Additively Manufactured High Aspect Ratio Microchannels via Two-Photon Polymerization. ........ 146

## INDEX, 148-150

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**CNF Youth Outreach; At-Home Science Experiments**

- CNF’s Youth Outreach Program Coordinator, Tom Pennell has developed several at home science experiments for youth to explore the growing field of nanotechnology.
- These experiments will be accompanied by a three part virtual presentation at Cornell University’s upcoming 4H Career Explorations event (June 2021).
- Students will have a live tour of the CNF cleanroom, live demonstrations and an introduction into interesting areas of nanoscale research.
- Researchers from the facility will also be available to discuss how they got into the field of nanoscale research with attendees.
- CNF will also be distributing these at home experiments to other schools and youth groups in the surrounding area.
Directors' Welcome

The Cornell NanoScale Science & Technology Facility presents the 2020-2021 CNF Research Accomplishments!

We are honored to showcase excellence in research demonstrated by users and research groups utilizing the plethora of resources offered at the CNF. We thank the users for their contributions to this publication. This collection of work demonstrates the wide range of emerging science and technology fields that utilize nanotechnology tools to achieve diverse state-of-the-art results. In addition to the 73 featured research reports, a section on CNF-research-related patents, presentations, and publications (close to 360 in 2020) is included.

Technical Staff. Phil and Mike will receive a plaque and acknowledgement at the NNCI Annual Conference as well as travel support to attend the conference. The 2021 NNCI Annual Conference, hosted by Northwestern University (SHyNE), will be held Monday, November 1st through Wednesday, November 3rd. The exceptional staff at the CNF have been consistently recognized with NNCI Outstanding Staff Member Awards. Past award recipients include Chris Alpha-Technical Staff (2018), and Tom Pennell-Education and Outreach (2020).

New User Fees Waived for the Remainder of 2021

In June the CNF fully reopened, allowing out of state users back into the facility. With this announcement we introduced an incentive benefiting new grad students and new external users looking to utilize the CNF — new user orientation fees have been eliminated for the remainder of the year.

If you or someone in your research group would like to become a new CNF user, please visit the Getting Started section of the CNF website to initiate the process. Additionally, if you know of someone who may be interested in becoming a new CNF user, please feel free to share this announcement. (https://cnf.cornell.edu/howto)

NNCI and NNCI Awards

The CNF is delighted to continue its membership in the National Nanotechnology Coordinated Infrastructure (NNCI) with support provided by the National Science Foundation (NSF) and the NYSTAR/ESD Matching Grant Program from New York State. This support is essential to CNF and its position at the forefront of nanofabrication. Earlier this year the CNF submitted the year 6 annual report and participated in a successful, virtual, reverse site visit as part of the cooperative agreement with the NNCI.

Congratulations are extended to Michael Skvarla and Phil Infante who were honored with national awards from the NNCI. Annually, the NNCI acknowledges the efforts of NNCI staff who provide exceptional service and support to network users in the categories of Technical Staff, Education and Outreach, and User Support. This year Mike was awarded the NNCI Staff Award in the User Support category and Phil was granted the NNCI Staff Award for
New Partnerships

Cornell Visualization and Imaging Partnership (CVIP)

CNF and the Cornell Institute of Biotechnology (Biotech) partnered to further advance Cornell’s excellence in life science characterization and imaging capabilities. CNF users now have access to a broad range of 3-D characterization tools including a variety of confocal microscopes, super-resolution microscopes, and micro/nano-x-ray-CT scanning. The mission of this partnership is to foster and enhance the convergence of research fields while unifying new approaches and ideas to inspire innovation and discovery. CNF cleanroom and Biotech users are now able to mutually access resources in both centers.

Cornell Multiscale 3D Fabrication Partnership (CM3FP)

CNF has also partnered with the Rapid Prototyping Lab in the Mechanical Engineering department to provide access to additional multiscale, 3D printing resources. The objective is to provide a broader range of technologies to users. These expanded resources will leverage existing expertise, instrumentation/tools, and administrative support to impact research involving life sciences, heterointegration, and nano/micro-scale technology. CNF and RPL staff will serve as a gateway to new 3D printers, provide consultation, software services, design help, billing, and user support.

Please contact the user program managers (userprogram@cnf.cornell.edu) and/or visit the CNF websites below for additional information on utilizing these resources.

https://www.cnf.cornell.edu/howto/cvip
https://www.cnf.cornell.edu/howto/cm3fp

New Equipment

The CNF continues to upgrade its capabilities in order to remain at the forefront of nanotechnology. We thank you for your patience and continued support as it has been a major effort by the CNF staff to catch up on installation of these tools while dealing with supply chain issues, and other COVID-imposed obstacles. The following equipment has been acquired over the past year and either is installed or being installed.

Plasma-Therm ALE
(installed, developing the technology)

CNF was able to obtain an advanced ALE instrument from Plasma-Therm. CNF and Plasma-Therm have partnered to develop processes and instrumentation for Atomic Layer Etching (ALE). ALE is an etching technology analogous to Atomic Layer Deposition (ALD) whereby atomically thin layers are added (in the case of ALD) or subtracted (in the case of ALE), by alternating self-limiting chemical reactions, allowing ultra-precise processing, one atomic layer at a time. The system is equipped with a Woollam M2000 in-situ spectroscopic ellipsometer and Langmuir probe. We look forward to developing and sharing new processes on this tool with the CNF and NNCI user communities.

AJA Sputtering Deposition System #3
(Installed, ready for use)

CNF installed an AJA Orion 5 system that supplements CNF’s other two AJA Orion 8 RF and DC sputtering systems. The tool will have a host of standard materials available and will allow sputtering of materials like Gold that would not otherwise be permitted in the sputter tools. The Orion 5 tool currently has three 2-inch guns installed but has room for five guns total and has two DC power supplies to allow for co-sputtering. Please reach out to staff for information on criteria for new target additions to the sputter tools.
Veeco Savannah Atomic Layer Deposition System (ALD) *(installed, ready for qualification)*

This system joins CNF’s other two ALD systems, the Oxford FlexAL and the Arradiance GemStar; The Savannah will be dedicated to the deposition of metal films, in particular Aluminum, Platinum, Palladium, and Ruthenium. It is equipped with an ozone generator to assist in lower temperature deposition and to broaden the spectrum of available precursors.

**Plasma-Therm HDPCVD** *(installed, SiO₂ and Si₃N₄ process qualified)*

CNF has obtained a high-density plasma chemical vapor deposition system (HPCVD or ICP-PECVD). This system is capable of depositing high density SiO₂, Si₃N₄, a-SiC, and doped a-Si films at low temperatures, ranging from 80°C to 175°C. These materials will be exceptionally smooth, dense, and conformal; perfect for applications where ALD or PECVD may not be ideal due to rate or temperature limitations. This new system has replaced the GSI PECVD system and further supports efforts in 2D materials and heterointegration, as well as photonics, biotech, MEMS, and CMOS projects.

**Angstrom UHV Load-locked Evaporator** *(just arrived at the end of August)*

This custom tool from Angstrom Engineering includes in situ ion beam cleaning, GLAD (Glancing Angle Deposition) with rotation, and sample heating. With a load lock and an ultrahigh vacuum system this tool can deposit high purity metal films required for many CNF applications.

**Bruker Dektak XT** *(installed, being qualified)*

In order to increase the reliability and capability of our profilometry suite, the CNF has added a Bruker Dektak XT stylus profilometer with 4Å repeatability. We have sample stages to accommodate wafer pieces, as well as full size wafers up to 200 mm. The software gives us motorized stage translation and rotation in addition to sequencing for up to 200 sites. The tool is loaded with a 2 μm radius of curvature diamond-tipped stylus. The Vision64 software can also use the tool measurements to create a 3D map of the scanned surface.

CNF REU Interns

Since 1991, we have hosted the Cornell NanoScale Science & Technology Facility Research Experiences for Undergraduates (CNF REU) Program.

After canceling the hands-on event last year due to COVID restrictions, we were pleased to welcome six interns from the Cornell College of Engineering undergraduate community this year. Four students participated as CNF REU interns — Kareena Dash (see page 56), Niaa Jenkins-Johnston (page 2), Elisabeth Wang (page 4), and Zhangqi Zheng (page 112). In addition, Micah Chen from the Cornell Center for Transportation, Environment, and Community Health’s (CTECH) REU Program and Francesca Bard (page 54), a summer undergraduate student and CNF user, were “adopted” in order for them to benefit from our logistical support over the summer.

These six students worked diligently for ten weeks on their specific research projects focusing on topics that included biological applications, materials characterization, nanophysics, and evaluation of transportation sustainability. There were multiple opportunities to garner presentation skills by offering progress updates and concluding the program with the submission of a final report. Many of the participants will continue with their respective research groups into the fall semester.

The 2021 CNF REU Program reports, photo album, and final presentation videos will soon be available online at https://cnf.cornell.edu/education/reu/2021
We plan to conduct a nation-wide search for our 2022 CNF REU interns in November. Keep an eye on https://cnf.cornell.edu/education/reu for information regarding next year's application process.

TCN and Outreach

The CNF’s Technology and Characterization at the Nanoscale (TCN) short course is offered twice each year. It continues to provide an excellent opportunity for the scientific community to learn about the field of nanofabrication from in-house experts. The TCN is open to participants from academia, industry and government, and includes lectures, demonstrations and activities in the cleanroom. Due to COVID we were pleased to offer this course virtually, which resulted in us reaching a broader audience with increased attendance. With this in mind, going forward, the CNF will be offering the January TCN course virtually and the June TCN course in person. The technical staff are also working to develop new educational modules based on developing technologies. Please reach out to Tom Pennell, our Youth Outreach Program Coordinator, if you are interested in having a specific device type featured in the instruction.

CNF’s youth outreach program continues to partner with 4H and recently hosted students from across NY State for Cornell’s annual Career Explorations event. Tom Pennell, created five new at home nanoscience experiments based on photolithography, materials science, and nanorobotics. He has packaged nearly 300 of them with the required materials to be distributed to any youth groups interested in learning more about our field. (See page iv for more....)

The youth outreach program will also be taking part in a national 4H summit in September, teaching students about nanotechnology and how it relates to space exploration.

In Person Again

With the lifting of restrictions in June, almost all the CNF staff came back to work in the office full time, in person. We celebrated in the most typical CNF staff kind of way — we gathered with a BBQ party. A good time was had by all!

While we are back in the office for the most part, it’s a good idea to call ahead if you want to meet with someone in particular, to make sure they are in fact “in person” that day.

THANK YOU to the CNF COMMUNITY!

Thank you to all CNF users for their continued patience and understanding during these unprecedented times. It is imperative we remain diligent in our efforts as a community to support ongoing safety protocols in order to help safeguard the progress we have made. We will continue to monitor the course of the pandemic and provide updates when warranted and directed by the University and Tompkins County Health Department.

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The CNF's Nano-Sized McGraw Tower

Once again the Cornell NanoScale Facility (CNF) makes a molehill out of a mountain — or in this case, the smallest rendition of Cornell's iconic McGraw Clock tower.

Twenty-four years ago, physics professor Harold Craighead and then-doctoral student Dustin Carr, Ph.D. '00, created the world’s smallest guitar using cutting-edge technology in what was then the Cornell Nanofabrication Facility. They’re at it again at the center – now known as the Cornell NanoScale Science and Technology Facility (CNF), in Duffield Hall. A team led by staff photolithographer Ed Camacho has created the world’s smallest rendition of Cornell’s iconic McGraw Tower – complete with its 161 interior steps, two sets of stairs and 21 bells.

“This is possibly the world’s smallest bell tower,” said Camacho, whose achievement of epic proportions was accomplished using one of CNF’s newest tools: the NanoScribe GT2 Laser Lithography System, a two-photon polymerization volumetric 3D printer.

https://www.14850.com/051119827-mcgraw-tower-model/

More than 27,000 Civil Air Patrol Names Headed to the Moon

The US Air Force Auxiliary Civil Air Patrol (CAP) partnered with the CNF to etch more than 27,000 CAP member names, 270 Air Force Association (AFA) StellarXplorers names, an 80th anniversary CAP logo, and messages from CAP and AFA leadership onto a microchip the size of a postage stamp. This microchip, carrying 27,285 names, messages, and images, is set to be carried to the Moon later this year aboard Astrobotic’s Peregrine lunar lander.

“Among these names are more than 4,000 CAP high school cadets,” says Lt. Paul Douglas, Burke Composite Squadron’s Aerospace Education officer. “My personal hope is that our young cadets will stand in their back yards, look up at the Moon, and dream big. They’ll know if they can make it to the Moon, they can do anything.”

The CNF technical staff worked with CAP to design the chip, starting with a computer-aided design (CAD) through using their photolithography, etching, and dicing tools to lay down an 80-nanometer thin film of silicon nitride on a standard silicon wafer. Details of the process — from start to finished chip, 0.5” across the hexagon, flat edge to flat edge — can be found in the Image Gallery online. https://cnf.cornell.edu/node/325

Which Crops Can Survive Drought? Nanosensors May Offer Clues.

Abraham Stroock's technique can be used to track how water flows through plants, which could be key to breeding more resilient crops in an increasingly hot, dry climate. (This work was performed in part at the CNF)

https://www.wired.com/story/which-crops-can-survive-drought-nanosensors-may-offer-clues/


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### Common Abbreviations & Meanings

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Meaning</th>
</tr>
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<tbody>
<tr>
<td>CH</td>
<td>Cornell High Energy Synchrotron Source</td>
</tr>
<tr>
<td>CHF</td>
<td>trifluoromethane</td>
</tr>
<tr>
<td>Cl</td>
<td>chlorine</td>
</tr>
<tr>
<td>Cl₂</td>
<td>chlorine gas</td>
</tr>
<tr>
<td>Cl₂/SF₆</td>
<td>chlorine sulfur hexafluoride</td>
</tr>
<tr>
<td>cm</td>
<td>centimeter</td>
</tr>
<tr>
<td>CMOS</td>
<td>complementary metal oxide semiconductor</td>
</tr>
<tr>
<td>CMP</td>
<td>chemical mechanical polishing</td>
</tr>
<tr>
<td>CNF</td>
<td>Cornell NanoScale Science &amp; Technology Facility</td>
</tr>
<tr>
<td>Co</td>
<td>cobalt</td>
</tr>
<tr>
<td>CO₂</td>
<td>carbon dioxide</td>
</tr>
<tr>
<td>Co₂O₃</td>
<td>cobalt oxide</td>
</tr>
<tr>
<td>CoFeAl</td>
<td>cobalt iron aluminum</td>
</tr>
<tr>
<td>CoFeB</td>
<td>cobalt iron boron</td>
</tr>
<tr>
<td>CoP</td>
<td>cobalt porphyrin</td>
</tr>
<tr>
<td>CPC</td>
<td>colloidal photonic crystal</td>
</tr>
<tr>
<td>CPD</td>
<td>contact potential difference</td>
</tr>
<tr>
<td>CgP</td>
<td>cytosine-phosphate-guanine</td>
</tr>
<tr>
<td>Cr</td>
<td>chromium</td>
</tr>
<tr>
<td>CRDS</td>
<td>cavity ring-down spectrometer</td>
</tr>
<tr>
<td>cryoSAXS</td>
<td>cryogenic small angle x-ray scattering</td>
</tr>
<tr>
<td>CTE</td>
<td>coefficients of thermal expansion</td>
</tr>
<tr>
<td>CTL</td>
<td>confinement tuning layer</td>
</tr>
<tr>
<td>Cu</td>
<td>copper</td>
</tr>
<tr>
<td>CVD</td>
<td>cardiovascular disease</td>
</tr>
<tr>
<td>CVD</td>
<td>chemical vapor deposition</td>
</tr>
<tr>
<td>CW</td>
<td>continuous wave</td>
</tr>
<tr>
<td>CXRF</td>
<td>confocal x-ray fluorescence microscopy</td>
</tr>
<tr>
<td>DARPA</td>
<td>Defense Advanced Research Projects Agency</td>
</tr>
<tr>
<td>DC</td>
<td>direct current</td>
</tr>
<tr>
<td>DCE</td>
<td>1,2-dichloroethane</td>
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<tr>
<td>DCM</td>
<td>dichloromethane</td>
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<tr>
<td>DEP</td>
<td>dielectrophoresis</td>
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<td>DFT</td>
<td>density functional theory</td>
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<tr>
<td>DFT</td>
<td>discrete Fourier transform</td>
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<tr>
<td>DI</td>
<td>de-ionized</td>
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<tr>
<td>DMF</td>
<td>dimethyl formamide</td>
</tr>
<tr>
<td>DNA</td>
<td>deoxyribonucleic acid</td>
</tr>
<tr>
<td>DNP</td>
<td>dynamic nuclear polarization</td>
</tr>
<tr>
<td>DOE</td>
<td>United States Department of Energy</td>
</tr>
<tr>
<td>DPPC</td>
<td>1,2-dipalmitoyl-sn-glycero-3-phosphocholine</td>
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<tr>
<td>DRAM</td>
<td>dynamic random access memory</td>
</tr>
<tr>
<td>DRIE</td>
<td>deep reactive ion etch</td>
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<tr>
<td>DSA</td>
<td>directed self assembly</td>
</tr>
<tr>
<td>dsDNA</td>
<td>double-stranded DNA</td>
</tr>
<tr>
<td>DUV</td>
<td>deep ultraviolet</td>
</tr>
<tr>
<td>e-beam</td>
<td>electron beam lithography</td>
</tr>
<tr>
<td>E. coli</td>
<td>Escherichia coli</td>
</tr>
<tr>
<td>EBL</td>
<td>electron-beam lithography</td>
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<tr>
<td>EDS</td>
<td>energy dispersive spectroscopy</td>
</tr>
<tr>
<td>EELS</td>
<td>electron energy loss spectroscopy</td>
</tr>
<tr>
<td>EG</td>
<td>ethylene glycol</td>
</tr>
<tr>
<td>μl</td>
<td>microliter</td>
</tr>
<tr>
<td>μm</td>
<td>micron, micrometer</td>
</tr>
<tr>
<td>μN</td>
<td>micro-Newton</td>
</tr>
<tr>
<td>μs</td>
<td>microsecond</td>
</tr>
<tr>
<td>Ω</td>
<td>Ohm</td>
</tr>
<tr>
<td>&lt;</td>
<td>is less than</td>
</tr>
<tr>
<td>&gt;</td>
<td>is greater than</td>
</tr>
<tr>
<td>±</td>
<td>approximately</td>
</tr>
<tr>
<td>1D</td>
<td>one-dimensional</td>
</tr>
<tr>
<td>2D</td>
<td>two-dimensional</td>
</tr>
<tr>
<td>2DEG</td>
<td>two-dimensional electron gas</td>
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<tr>
<td>3D</td>
<td>three-dimensional</td>
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<tr>
<td>³He</td>
<td>helium-3</td>
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<tr>
<td>α-Al₂O₃</td>
<td>sapphire</td>
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<tr>
<td>a-Si</td>
<td>amorphous silicon</td>
</tr>
<tr>
<td>AC</td>
<td>alternating current</td>
</tr>
<tr>
<td>AFM</td>
<td>atomic force microscopy/microscope</td>
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<tr>
<td>AFOSR</td>
<td>Air Force Office of Scientific Research</td>
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<tr>
<td>Ag</td>
<td>silver</td>
</tr>
<tr>
<td>Al</td>
<td>aluminum</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>aluminum oxide</td>
</tr>
<tr>
<td>ALD</td>
<td>atomic layer deposition</td>
</tr>
<tr>
<td>AlGaAs</td>
<td>aluminum gallium arsenide</td>
</tr>
<tr>
<td>AlGaN</td>
<td>aluminum gallium nitride</td>
</tr>
<tr>
<td>Ar</td>
<td>argon</td>
</tr>
<tr>
<td>ARC</td>
<td>anti-reflective coating</td>
</tr>
<tr>
<td>ArF</td>
<td>argon fluoride</td>
</tr>
<tr>
<td>As</td>
<td>arsenic</td>
</tr>
<tr>
<td>atm</td>
<td>standard atmosphere (as a unit of pressure)</td>
</tr>
<tr>
<td>Au</td>
<td>gold</td>
</tr>
<tr>
<td>AuNPs</td>
<td>gold nanoparticles</td>
</tr>
<tr>
<td>B</td>
<td>boron</td>
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<tr>
<td>B. subtilis</td>
<td>Bacillus subtilis</td>
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<td>Bi</td>
<td>bismuth</td>
</tr>
<tr>
<td>BOE</td>
<td>buffered oxide etch</td>
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<td>Br</td>
<td>bromine</td>
</tr>
<tr>
<td>C</td>
<td>carbon</td>
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<tr>
<td>C</td>
<td>centigrade</td>
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<tr>
<td>C₃V</td>
<td>capacitance-voltage</td>
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<td>C₄H₄N₂</td>
<td>carbon nitride</td>
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<td>CaCl₂</td>
<td>calcium chloride</td>
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<tr>
<td>CAD</td>
<td>computer-aided design</td>
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<tr>
<td>CaF₂</td>
<td>calcium fluoride</td>
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<td>CCMR</td>
<td>Cornell Center for Materials Research</td>
</tr>
<tr>
<td>Cd</td>
<td>cadmium</td>
</tr>
<tr>
<td>Cd₂S</td>
<td>cadmium sulfide</td>
</tr>
<tr>
<td>CdSe</td>
<td>cadmium selenide</td>
</tr>
<tr>
<td>CDW</td>
<td>charge-density-wave</td>
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<tr>
<td>Ce</td>
<td>cerium</td>
</tr>
<tr>
<td>CF₄</td>
<td>carbon tetrafluoride or tetrafluoromethane</td>
</tr>
<tr>
<td>CFD</td>
<td>computational fluid dynamics</td>
</tr>
<tr>
<td>CH₄</td>
<td>methane</td>
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