



**- WORKSHOP -**

# **Frontiers of Memristive Materials for Neuromorphic Processing Applications**

**Condensed Matter and Materials Research Committee**

**February 28, 2020**

**National Academies' Keck Center  
Room 100  
Washington, DC**

**Board on Physics and Astronomy**

# WELCOME

## To the Workshop on Frontiers of Memristive Materials for Neuromorphic Processing Applications

*The Board on Physics and Astronomy (BPA) of the National Academies of Sciences, Engineering, and Medicine seeks to advise the government and the public regarding important scientific opportunities and issues related to physics and astronomy. BPA's Condensed Matter and Materials Research Committee (CMMRC) hosts this workshop.*

*This workshop will focus on understanding the current state and future potential of memristive technologies, particularly polymer and ion dynamics based, and what will be needed to achieve energy efficient neuromorphic computing based on these technologies.*

*Your participation is greatly appreciated.*

### Workshop Planning Committee

#### **Leslie Momoda**

Vice President of Strategy  
HRL Laboratories, LLC

#### **Charles Ahn**

Professor of Applied Physics  
Yale University

#### **Giulia Galli**

Professor of Electronic Structure and Simulations, and Professor of Chemistry  
Argonne National Laboratory  
The University of Chicago

#### **Tom Lubensky**

Professor Emeritus  
University of Pennsylvania

#### **Ivan Schuller**

Distinguished Professor  
University of California, San Diego

#### **Dmitri Strukov**

Professor  
University of California, Santa Barbara

#### **R. Stanley Williams**

Chair and Professor  
Texas A&M University

#### **Tom Witten**

Professor in Physics  
The University of Chicago

### Staff

**James C. Lancaster**, Director

**Christopher J. Jones**, Program Officer

**Neeraj P. Gorkhaly**, Associate Program Officer

**Amisha Jinandra**, Research Associate

**Linda M. Walker**, Program Coordinator

**Beth Dolan**, Financial Associate

Friday, February 28, 2020		
Frontiers of Memristive Materials for Neuromorphic Processing Applications Workshop Keck Room 100		
10:00	Workshop introduction	Leslie Momoda, Chair <i>HRL Laboratories</i>
10:15	An Overview of Memristor Technologies	Stanley Williams <i>Texas A&amp;M University</i>
10:55	Q&A	
11:05	Advances in Memristor Materials Based on Ion Dynamics	Marek Skowronski <i>Carnegie Mellon University</i>
11:50	Q&A	
12:00 pm	Advances in Polymeric Memristive Elements	Alec Talin <i>Sandia National Laboratories</i>
12:40	Q&A	
12:50	Working Lunch	
1:50	Memristive Device Challenges for Contemporary Machine Learning and AI Applications	Dmitri Strukov <i>University of California</i>
2:30	Q&A	
2:40	Device Architectures to Meet Neuromorphic Computing Challenges	Catherine Schuman <i>Oak Ridge National Laboratories</i>
3:20	Q&A	
3:30	Break	
3:45	Introduction to Panel Discussion: Imperatives for Energy Efficient Computing	John Paul Strachan <i>Hewlett-Packard Laboratories</i>
3:55	Moderated discussion: The Future of Energy Efficient Computing Based on Memristive Elements  Moderator: John Paul Strachan	Panel members: Ivan Schuller Stanley Williams Marek Skowronski Alec Talin Dimtri Strukov Catherine Schuman
5:00	Concluding remarks	Leslie Momoda

## Guest Biographies



### **Catherine Schuman**

*Oak Ridge National Laboratories*

Katie Schuman is a Research Scientist in Computational Data Analytics at Oak Ridge National Laboratory. Katie received her doctorate in computer science from the University of Tennessee in 2015, where she completed her dissertation on the use of evolutionary algorithms to train spiking neural networks for neuromorphic systems. She is continuing her study of models and algorithms for neuromorphic computing, as well as other topics in artificial intelligence and machine learning, as part of her work at ORNL. Katie is also an adjunct assistant professor at the University of Tennessee, where she, along with four other professors at UT.

### **Marek Skowronski**

*Carnegie Mellon University*

Professor Skowronski obtained his Ph.D. degree in Solid State Physics from Warsaw University (Warsaw, Poland). His post-doctoral appointment was at the Massachusetts Institute of Technology where he used junction spectroscopy to study compound semiconductors. This was followed by work at Cabot Corp. on growth of compound semiconductors. In 1988, he moved to Carnegie Mellon University where he focused on deposition of thin films for electronic applications, fabrication of devices for energy efficient electronics and neuromorphic computing, and electron microscopy.





### **Dmitri Strukov**

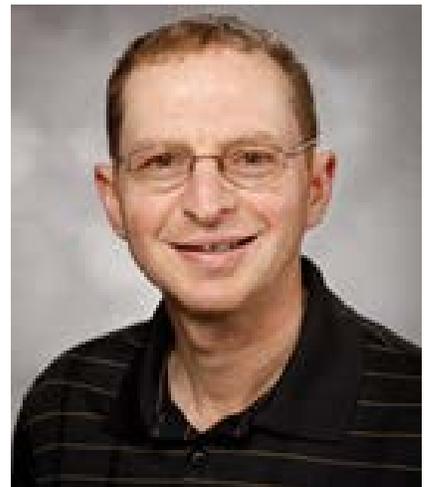
*University of California, Santa Barbara*

Dr. Dmitri Strukov is a professor of Electrical and Computer Engineering at the University of California, Santa Barbara. Dmitri's research broadly concerns different aspects of computation, in particular addressing questions on how to efficiently perform computation on various levels of abstraction. The research spans across different disciplines including: material science, device physics, circuit design, high-level computer architecture, and algorithms, with an emphasis on the emerging device technologies. He received a M.S. in applied physics and mathematics from the Moscow Institute of Physics and Technology in 1999 and a Ph.D. in electrical engineering from Stony Brook University in New York in 2006. He is a member of ACM and IEEE societies.

### **Alec Talin**

*Sandia National Laboratories*

Dr. Alec Talin is a Distinguished Member of Technical Staff at Sandia National Laboratories, in Livermore, CA, an Adjunct Associate Professor of Materials Science and Engineering at the University of Maryland, College Park, MD, and is a Fellow of the American Physical Society. Prior to joining Sandia in 2002, Alec spent six years as a research scientist and manager at the Motorola Corporate Labs in Phoenix, AZ, and was a Project Leader at the Center for Nanoscale Science and Technology at NIST from 2009 to 2012. Currently, Alec leads projects at Sandia in materials and devices for energy efficient computing, energy storage, and national security.



## **Stanley Williams**

*Texas A&M University*

Dr. R. Stanley Williams is an award winning researcher in nanotechnology, and is a professor at Texas A&M University. He is also a senior fellow and was the founding director of the Quantum Science Research Laboratory at Hewlett-Packard credited with developing and demonstrating the first solid state memristor. Dr. Williams earned a bachelor's degree in chemical physics in 1974 from Rice University and a Ph.D. in physical chemistry from the University of California, Berkeley in 1978. After graduating, he worked at Bell Labs before joining the faculty at UCLA, where he served as a professor from 1980 to 1995. He then joined HP Labs as director of its Information and Quantum Systems Lab. Dr. Williams has had many students and colleagues who are now leading researchers in this field, several of whom we would like to speak at the workshop.



## **Ivan Schuller**

*University of California, San Diego*

Dr. Ivan Schuller is a Distinguished Professor at the University of California in San Diego. He is a leading researcher in nanoscience and condensed matter physics and is the director of the DOE Energy Frontier Research Center on Quantum Materials for Energy Efficient Neuromorphic Computing (QMEENC). He earned his Ph.D. in physics from Northwestern University in 1976. From 1978-1987, he was a senior physicist and group leader at Argonne National Laboratory. Since 1987, he has been a professor of physics at the University of California, San Diego. He is also Layer Leader of Materials and Devices of CAL(IT)2 Institute, and Director of AFOSR/MURI at UCSD. Schuller is also a president of the Board of Trustees and Scientific Advisory Committee at the IMDEA Nanoscience Institute.

## **Moderator**



### **John Paul Strachan**

*Hewlett-Packard Laboratories*

Dr. John Paul Strachan is a Master Technologist and Research Manager at Hewlett Packard Labs, where he leads a team developing novel computational accelerators. He studied at MIT and Stanford University for his undergraduate and PhD, respectively, and has been a researcher at HP/HPE for the past eleven years. He has over 50 patents, has authored or co-authored over 60 peer-reviewed papers, and has been the PI of several US Government funded research programs. He has previously worked on nanomagnetic devices for memory for which he was awarded the Falicov Award from the American Vacuum Society, and has developed sensing systems for precision agriculture in a company, which he co-founded. He serves in many professional societies including IEEE IEDM ExComm, the Nanotechnology Council ExComm, past program chair and steering member of the International Conference on Rebooting Computing, and related communities.

**Any questions or comments can be asked in-person during Q&A or online at:**

**[www.Slido.com](http://www.Slido.com)**

**Event Code: #CMMRC2020**

## ABOUT THE CMMRC

The Condensed Matter and Materials Research Committee (CMMRC) is a standing BPA committee responsible for the fields of condensed matter science and materials research, including the physics, chemistry, and biological applications of these fields. The CMMRC develops programs and oversees activities on these topics by discussing current programs, policies, trends, and issues with researchers, managers, policy leaders, and federal agencies. The CMMRC also plans and develops prospectuses for studies and other activities (e.g., workshops), which are to be carried out by separately appointed ad hoc committees/panels and can result in longer-term consensus study reports. Such reports may contain assessments of research areas with recommendations aimed at facilitating scientific progress in the forefront areas of research in these fields.

**Susan Coppersmith**, *Chair*, University of Wisconsin at Madison  
**Tom Witten**, *Vice Chair*, University of Chicago  
**Pierre Wiltzius**, Past Chair, University of California-Santa Barbara  
**Raymundo Arroyave**, Texas A&M University  
**Charles Ahn**, Yale University  
**Karin Dahmen**, University of Illinois at Urbana-Champaign  
**Thomas Epps**, University of Delaware  
**Giulia Galli**, University of Chicago  
**Olivia A. Graeve**, University of California, San Diego  
**Aharon Kapitulnik**, Stanford University  
**Anthony Ku**, National Institute of Clean and Low-Carbon Energy  
**Tom Lubensky**, University of Pennsylvania  
**Leslie Momoda**, HRL Laboratories  
**Karen Winey**, University of Pennsylvania  
**Steven J. Zinkle**, University of Tennessee at Knoxville

## ABOUT THE BPA

The important questions in physics and astronomy change as we learn more about nature, and the rate of change has been increasing. The Board on Physics and Astronomy (BPA) seeks to inform the government and the public regarding important scientific opportunities and issues as well as the changing nature of science. The BPA builds bridges between the evolving subdisciplines of physics and astronomy and between these and other areas of science. The BPA is successful if it helps both the science community and society understand what is needed to continue the advance of physics and astronomy and why doing so is important

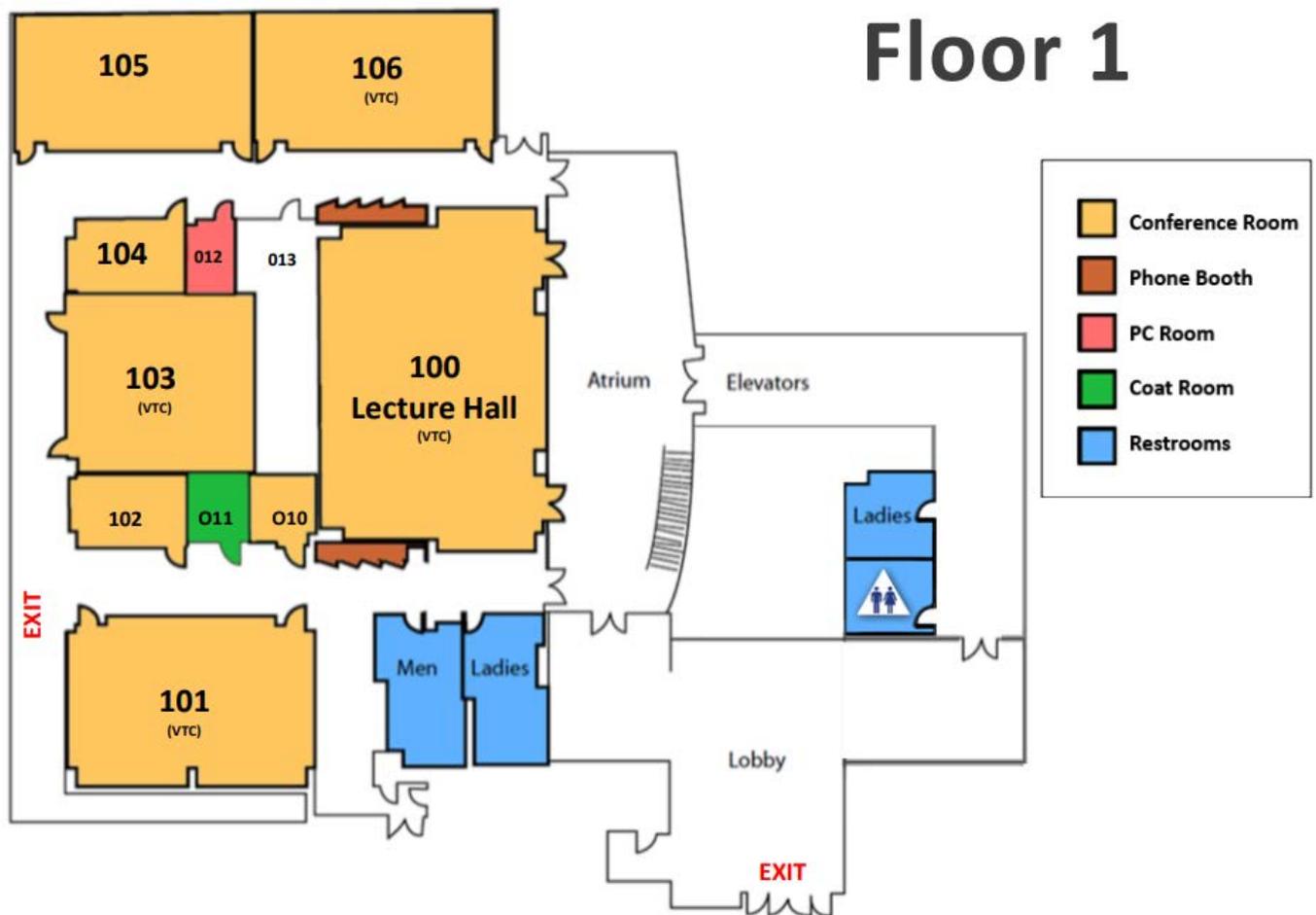
### Recent CMMRC-relevant reports

*Frontiers of Materials Research - A Decadal Survey*, **2019**  
*Harvesting the Fruits of Inquiry How Materials Discoveries Improve Our Lives*, **2014**  
*High Magnetic Field Science and its Application in the United States*, **2013**  
*Research at the Intersection of Physical and Life Sciences*, **2010**  
*Selling the Nation's Helium Reserve*, **2010**  
*Frontiers in Crystalline Matter: From Discovery to Technology*, **2009**  
*Biomolecular Materials and Processes*, **2008**  
*Condensed-Matter and Materials Physics: The Science of the World Around Us*, **2007**

More information can be found at <http://sites.nationalacademies.org/BPA>

## MAP

National Academies' Keck Center  
500 Fifth Street, NW  
Washington DC



**The Workshop** is in the Lecture Hall, Room 100

**Cafeteria** is located on the third floor, which is accessible from the main stairs or elevator

**Parking** is available. Entrance is located behind the building on 6<sup>th</sup> street.

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Thank you for attending.

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