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Designing Artificial Synapses for Application-Specific Neuromorphic Computing Using Magnetic and 2D Materials

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Abstract: As we look to the future of computing in immersive environments for edge applications, new materials, devices, and circuits provide new ways to efficiently compute. In particular, hardware-aware neuromorphic computing takes inspiration from the brain to encode information in bio-mimetic artificial synapses and neurons assembled into neural networks. Most simply, an artificial synapse should have controllable resistance levels to set the connectivity between neurons. Features of linearity in the weight change and symmetric response to positive and negative weight updates are also desirable for efficient neural network training. But, if we can add additional features to the synapses themselves, inspired by the features of the brain, these can lead to system-level benefits depending on the application. I will present my group's work on designing, building, and measuring artificial synapses using both magnetic materials and atomically thin (2D) materials. By electrically controlling a magnetic domain wall (DW) underneath a magnetic tunnel junction (MTJ) memory element, we show 3-5 controllable weight states that are highly stable at room temperature [1]. Tuning the device geometry in turn tunes the metaplastic behavior of the synapse, allowing application-specific design for either inference or online learning. We will show how this DW-MTJ artificial synapse can satisfy the necessary requirements for artificial neural networks integrated with CMOS. I will then show our results on designing bilayer graphene transistors as artificial synapses that are constructed from fully bio-compatible materials, respond in biologically-relevant timescales, and have ultra-low switching energy [2]. The graphene artificial synapses also show unique metaplasticity that can be used to outperform ideal linear synapses in classification tasks. Such devices are strong candidates for bio-interfaced neuromorphic computing. These results show the impact new materials can have as we encounter new computing needs.

References:

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[2] D. Kireev, S. Liu, H. Jin, T. P. Xiao, C. H. Bennett, D. Akinwande, and J. A. C. Incorvia. "Metaplastic and Energy-Efficient Biocompatible Graphene Artificial Synaptic Transistors for Enhanced Accuracy Neuromorphic Computing." *Nature Communications* 13, 4386 (2022). <DOI 10.1038/s41467-022-32078-6>.

Bio: Dr. Jean Anne C. Incorvia is an Assistant Professor and holds the Fellow of Advanced Micro Devices (AMD) Chair in Computer Engineering in the Department of Electrical and Computer Engineering at The University of Texas at Austin, where she directs the Integrated Nano Computing (INC) Lab. Dr. Incorvia develops practical nanodevices for the future of computing using emerging physics and materials. Dr. Incorvia received her bachelor's in physics from UC Berkeley in 2008 and her Ph.D. in physics from Harvard University in 2015, cross-registered at MIT. From 2015-2017, she completed a postdoc at Stanford University. She has over 60 articles published in peer-reviewed journals and conference proceedings and has given over 60 invited talks. She received a 2020 US National Science Foundation CAREER award, the 2020 IEEE Magnetics Society Early Career Award, and a 2021 Intel Rising Stars award. She was an invited contributor to the 2020 and 2022 IEEE International Roadmap for Devices and Systems (IDRS). She is serving on the administrative committee of the IEEE Magnetics Society, and she has served on and taken leadership roles in the International Electron Devices Meeting (IEDM), the Device Research Conference (DRC), the Magnetism and Magnetic Materials Conference (MMM), and Intermag.