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EDITORIAL

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Nanoscale Horizons Emerging Investigator Series: Dr Saptarshi Das, Pennsylvania State University, USA

Our Emerging Investigator Series features exceptional work by early-career nanoscience and nanotechnology researchers. Read Saptarshi Das's Emerging Investigator Series article 'Hardware Trojans based on two-dimensional memtransistors' (**https://doi.org/10.1039/D2NH00568A**) and read more about him in the interview below.

Dr Saptarshi Das is an Associate Professor at Pennsylvania State University, USA. He holds positions across various departments, including Engineering Science and Mechanics, Materials Science and Engineering, and Electrical Engineering and Computer Science. Dr Das served as an Assistant Professor at the same institution from 2016 to 2021 and held a role as an Assistant Scientist at the Center for Nanoscale Materials, Argonne National Laboratory, USA, from 2015 to 2016. Dr Das earned a PhD in Electrical and Computer Engineering from Purdue University in 2013 and a BE in Electronic and Telecommunication Engineering from Jadavpur University, India, in 2007.

Dr Das has been recognized with the prestigious CAREER Award from the National Science Foundation in 2021, the Young Investigator Award from the United States Air Force Office of Scientific Research in 2017, and the Rustum and Della Roy Innovation in Materials Research Award in 2020. Driven by a passion for both research and teaching, Dr Das has also been recognized with the Outstanding Research Award and Outstanding Teaching Award from the Penn State Engineering Alumni Society.

Dr Das's primary focus resides in pioneering materials research and innovation, with significant impact on neuromorphic computing, hardware security, and bio-inspired sensing devices. At the heart of the Das Research Group's mission is the development of groundbreaking technologies inspired by nature, aiming to enhance energy efficiency and ensure a sustainable future for society.

Read Saptarshi Das's Emerging Investigator Series article 'Hardware Trojans based on two-dimensional memtransistors' (https://doi.org/10.1039/D2NH00568A) and read more about him in the interview below:

NH: Your recent Nanoscale Horizons Communication explores the potential of 2D memtransistors to be used as hardware Trojans and exposes some of the vulnerabilities of in-memory computing. How has your research evolved from your first article to this most recent article and where do you see your research going in future?

SD: Reflecting upon my research journey, which spans from my days as a graduate student to my tenure track as an Assistant Professor and my subsequent position as a tenured Associate Professor, it becomes evident that my work has encompassed a wide and diverse range of topics within the realm of nanoelectronics and two-dimensional materials.

Among the many intriguing paths that my research has led me down, one of the most captivating is the exploration of neuromorphic computing and bio-inspired sensing. Driven by my fascination with emulating the intricate functionalities observed in biological systems, I have ventured into the realm of biomimetic neural networks, adaptive photo encoders, collision detectors inspired by insect vision, audiomorphic devices inspired by barn owls, and probabilistic computing inspired by dragonflies. More recently, my group has embraced the challenge of creating multisensory neuromorphic devices, drawing inspiration from the mating behaviors of butterflies, the escape actions of octopuses, and the foraging strategies of crayfish. These endeavors underscore my unwavering dedication to engineering electronics that replicate the remarkable capabilities found in the brains and sensory mechanisms of insects, avians, and aquatic creatures. Through these pursuits, my aim is to contribute meaningfully to the fields of artificial intelligence, sensor technology, and vision systems.

A significant portion of my research portfolio is also dedicated to advancing hardware security. My efforts have centered around the development of physically unclonable functions utilizing graphene and other two-dimensional materials. The overarching goal is to establish secure electronic systems that exhibit resilience against tampering and counterfeiting. My exploration into the realm of satisfiability attack-resistant devices and logic locking for integrated circuits stands as a testament to my unwavering commitment to fortifying hardware security measures. In these pursuits, I strive to play a role in safeguarding sensitive electronic systems from malicious attacks and unauthorized access.

Central to my research journey are the fundamental aspects of transistors and materials engineering. My investigations have taken me into the intricate nuances of transistors, with a particular focus on those constructed from two-dimensional materials like graphene, MoS_2, and WSe_2. I have contributed advancements in contact engineering, strain effects, and transport characteristics within these materials. My exploration of novel transistor architectures, steep-slope devices, and ambipolar characteristics exemplifies my drive to push the boundaries of transistor performance. Furthermore, my work in materials synthesis, defect engineering, and layer-transfer methods underscores my comprehensive grasp of materials properties and device fabrication techniques.

In summation, my trajectory of research has spanned a vast spectrum of topics, ranging from the realms of neuromorphic computing and bio-inspired sensing to the crucial arena of hardware security and the intricate fundamentals of transistors based on two-dimensional materials. These multifaceted contributions hold the potential to drive progress across a diverse array of fields, encompassing secure electronics, artificial intelligence, materials science, and emerging device technologies.

NH: How do you feel about Nanoscale Horizons as a place to publish research on this topic?

SD: *Nanoscale Horizons* garners widespread respect for its unwavering focus on cutting-edge advancements in nanoscience and nanotechnology. What sets this journal apart is its resolute commitment to showcasing high-impact, innovative research spanning across two-dimensional materials and nanoelectronics, areas of particular interest to me. The journal's dedication to interdisciplinary work and its esteemed reputation in the scientific community not only align with my research goals but also make it a profoundly desirable platform for disseminating my findings. The prospect of contributing to the advancement of nanoscale science and technology through this reputable outlet significantly bolsters my preference for considering *Nanoscale Horizons* as the journal of choice for publishing my research.

NH: What aspect of your work are you most excited about at the moment?

SD: I am thrilled to be engaged in pioneering and groundbreaking research focused on the development of high-performance 2D material-based sensing, computing, and storage devices. This cutting-edge exploration holds immense potential for transformative advancements in neuromorphic computing, hardware security, and bio-inspired sensing. The prospect of creating innovative technologies that draw inspiration from the complexities of biological systems while revolutionizing computing and security landscapes is truly exhilarating. My work in this dynamic field not only underscores my passion for pushing the boundaries of possibility but also extends far beyond the confines of the laboratory, holding the promise of profound societal impact, particularly in the realms of energy efficiency and sustainability.

NH: In your opinion, what are the most important questions to be asked/answered in this field of research?

SD: Working with two-dimensional (2D) materials offers both exciting possibilities and significant hurdles. The process involves intricate fabrication of high-quality, scalable materials and their integration into functional devices. Alongside this, ensuring the long-term stability and reliability of these materials is crucial.

In a similar vein, the pursuit of developing neuromorphic systems that mirror the complexity of the human brain while maintaining energy efficiency and robust learning algorithms presents substantial challenges. The task involves designing efficient hardware implementations, optimizing memory structures, and refining synaptic interfaces to push the boundaries of advancement.

Concurrently, the imperative to secure electronic systems against physical attacks, tampering, and counterfeiting cannot be overstated. Detecting hardware Trojans, guaranteeing supply chain integrity, and addressing emerging post-quantum threats remain ongoing concerns. Balancing the implementation of stringent security measures with maintaining optimal performance necessitates a creative and collaborative approach.

Amidst these intricate challenges, the significance of interdisciplinary collaboration becomes paramount. The spirit of collaboration stands as a pivotal force in surmounting hurdles and harnessing the complete capabilities of 2D materials. It paves the way to create versatile electronic devices that are instrumental in achieving high-performance neuromorphic computing, bio-inspired sensing, and hardware-based security primitives.

NH: What do you find most challenging about your research?

SD: Engaging in experimental research with novel materials and fundamental device concepts can be characterized by its demand for substantial time investments and the allocation of significant resources. The process encompasses not only securing financial support but also access to specialized equipment and skilled personnel, thus presenting a considerable challenge in itself. Similarly, designing and constructing nanodevices can present formidable challenges due to the involvement of intricate micro- and nanofabrication techniques, necessitating a high level of expertise. Attaining precise control over device dimensions and interfaces stands as a critical prerequisite for yielding insightful and meaningful outcomes. Simultaneously, delving into unexplored materials frequently reveals unforeseen phenomena or behaviors, underscoring the need for a thorough understanding of the subject. Finally, interpreting experimental outcomes and discerning between intrinsic material properties and extrinsic effects can prove to be a challenging endeavor, demanding meticulous data analysis and close collaboration with theoretical researchers to derive accurate and substantial conclusions. Despite these challenges, the pursuit of experimental research with novel materials and innovative device concepts offers the potential for transformative discoveries that can shape the future of science, technology, and society.

NH: In which upcoming conferences or events may our readers meet you?

SD: I participate in a wide range of conferences and workshops, and I have the privilege of delivering invited, plenary, and keynote lectures at various upcoming events. Some of the notable conferences include the International Conference of Solid State Devices and Materials in Nagoya, Japan; the Flatlands Beyond Graphene conference in Prague, Czech Republic; the Memristive Materials, Devices & Systems (MEMRISYS 2023) conference in Torino, Italy; the Recent Progress in Graphene and 2D Materials Research (RPGR) conference in Bengaluru, India; and the MRS Fall Meeting & Exhibit in Boston, USA.

NH: How do you spend your spare time?

SD: Beyond my research endeavors, I delight in using my spare time to embark on global adventures through travel, immersing myself in diverse cultures and landscapes. Exploring scenic trails through hiking is another passion of mine, offering a rejuvenating escape into nature's embrace. Additionally, I engage my curious mind by delving into an array of documentary videos that span captivating topics, including history, geopolitics, science, and the intricacies of the global economy. This multifaceted pursuit not only broadens my horizons but also provides a rewarding blend of leisure and intellectual enrichment.

NH: Can you share one piece of career-related advice or wisdom with other early career scientists?

SD: As you start your scientific journey, remember that exploring the basics of research can be tough. These challenges shouldn't discourage you, but remind you to stay focused. Just like you wanted help when you were learning, it's important to guide and support students now. They're the ones who bring your ideas to life. Dealing with tough feedback and grant rejections is normal, and you shouldn't stress too much. Keep learning and growing from these experiences. Try to connect your research with real-world problems and show how it can help. Don't give up on your ideas too quickly. Big achievements come from overcoming big challenges. And remember, the journey itself is a big part of the accomplishment. Being able to handle tough times and keep going is how real progress happens.

