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Using a synchrotron to understand nanoelectronics and design futuristic computers

Our research has been directed at understanding fundamental materials science and physics in a view to develop systems for next-generation information storage and computing. This is a challenging space due to the difficulties in not only understanding the nanoscale aspects of fundamental processes that are of interest in the field of computers (like phase transitions), but also in linking such understanding to overcoming the system-level computer issues such as the von Neumann architectural bottleneck and limitations of Boolean logic.

Using high-intensity synchrotron radiation, we have gained understanding of the principles of the physical origins of behaviors of metal oxides in memristors. We developed an *in-operando* time-multiplexed synchrotron mapping technique that improved signal resolution below 0.1% of the background and allowed us to directly observe very low-signal and localized processes, such as movement of oxygen atoms during information storage, which was not previously accessible due to limits in spatial and chemical resolutions. This led to the identification of Soret effect as a critical nanoscale force responsible for memristor operation and resulted in re-engineered memristors with a thousand-fold improvement operating lifetime. Further, using *in-operando* scanning transmission x-ray microscopy, we were able to resolve a decades-old controversy by revealing the decoupled nature of the electronic (Mott) and structural (Peierls) transitions in VO_2, through which we were also able to explain the physical origins of negative differential resistance in Mott insulators. These results have further enabled us to design computing systems that utilize several physical processes to perform computations, thereby breaking free of the limitations of the traditional computer architectures and Boolean logic.