Ph.D. in Information Technology
Thesis Defenses

March 13, 2023
at 10:00
Room Beta

Matteo FARRONATO – XXXV Cycle

Neuromorphic devices based on 2D materials and their applications in computing

Supervisor: Prof. **Daniele Ielmini**

Abstract:

In the last six decades, the semiconductor technology has experienced a fast improvement thanks to the scaling in device dimensions and the increase in the number of components per unit area. These two phenomena, namely the Dennard scaling and the Moore's law, drove the developing of ever more powerful computing systems, often based on the von Neuman architecture. However, in more recent years, the transistor dimensional downscaling in the 2D plane has stopped, encountering physical limits imposed by silicon-based materials. In addition, with the ubiquitous diffusion of mobile computing and Internet of Things (IoT), the amount of data produced and processed explodes, bringing out the critical issues of modern computing architectures. Indeed, von Neumann architecture-based digital processors are hindered by the performance gap between the central processing unit (CPU) and memory, which makes them generally inefficient in terms of both energy and latency, particularly in datacentric applications. To face these challenges, new computing paradigms categorized under the concept of in-memory computing, are gaining interest, since they suppress the memory bottleneck and have an improved energy efficiency. Neuromorphic computing, inspired by the functionality of human brain, is one of the main examples of architectures implementing this paradigm. The realization of such systems passes through the development of innovative memory devices, called emerging memories, which, thanks to their area scalability, low current, fast operation, and CMOS compatibility, are more appealing than standard charge-based memories. A key aspect of emerging memories is their operation principle, that often relies on the physics of the active material. For that reason, large effort is devoted to the study of materials with peculiar properties exploitable for the realization of efficient memory devices. Among all, 2D layered materials offer a unique physical structure and excellent electronic properties. After the demonstration of Graphene in 2004, a large number of 2D semiconductors have been studied and used for the realization of several electronic devices. This doctoral dissertation focused on the development of innovative memory devices based on 2D materials and their use in neuromorphic computing. Devices have been fabricated in the clean room, following proper and reproducible nanofabrication steps. The work was made possible thanks to the availability of Polifab, the cleanroom facility of Politecnico di Milano. Two main devices, called memtransistors, have been developed. The first device, called ion-based memtransistor, has a reliable memory characteristic together with nanometric size. The realization of a memory array with several devices demonstrates the suitability of such device for memory operations. The second device, called electron-based memtransistor or charge trap memory (CTM), has a very similar structure with a channel length in the order of 100 nm. It exploits the trapping and de-trapping of charges at the oxide/semiconductor interface to obtain an analog memory effect. Its synaptic characteristics make the device perfect for the implementation of AI hardware accelerators and its use in neuromorphic computing applications. A pattern recognition system with a reservoir

computing approach was demonstrated using the device, obtaining state-of-the-art accuracy results with a very compact architecture. All the results presented in this dissertation have been published in international peer-reviewed scientific journals and conferences. They open the way for the realization of memory arrays suitable for the realization of in-memory computing architectures.

Saverio RICCI – XXXV Cycle

Development of crosspoint memory arrays for neuromorphic computing

Supervisor: Prof. **Daniele Ielmini**

Abstract:

The continuous improvement of fabrication techniques led the transistor scaling down to the ultimate physical limits, where the mechanisms which rule the world as we know are no more valid. Moore’s prediction about the doubling of transistors density every 1-2 years is slowing down and the computer performances are reaching a plateau. Moreover, nowadays computer architectures are affected by the latency caused by the continuous exchange of data between memory and processor, problem known as von Neumann bottleneck. In the era of the Internet-of-Things and Big Data analysis, emerging technology devices are appealing candidates to pave the way for new computing paradigms able to satisfy the increasing demand of computational power and energy saving. Emerging memristive technologies are a novel class of memory devices that have the peculiar behavior of changing their own electrical properties according to the external stimulation. This Ph.D. Dissertation revolves around the topic of RRAMs, starting from their fabrication, through characterization of single devices up to the development of proof-of-concept experiments in the fields of hardware accelerator, in-memory computing and brain-inspired architectures. In particular, the focus was on the interaction between the oxide layer and the metal electrodes, as a way to change the electrical properties according to the material combinations. An 8x8 crossbar array based on forming-free non volatile RRAMs was used to show the concept of the in-memory computing, proposing a simple circuit for the Power Iteration algorithm. The clustering of the Iris dataset was tackled thanks to the Principal Component Analysis, based on the eigenvector computed with the memristive-based accelerator. The tunability of both the retention time and the switching probability of volatile RRAMs based on silver electrode, was exploited to build a simple neuromorphic system able, with 5 only devices, to emulate the short-term memory mechanism that takes place in the human brain.

PhD Committee

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