Richiesta per borsa di studio da attivare ai sensi di quanto disposto dal D.M. n. 1061 del 10/08/2021

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CHIEDE

l'attivazione di una borsa di studio di dottorato ai sensi di quanto disposto dal D.M. n. 1061 del 10/08/2021. A tal fine comunica quanto segue:

La borsa sarà attivata sul seguente corso di dottorato accreditato per il XXXVII ciclo: Fisica

Area per la quale si presenta la richiesta (selezionare solo una delle due):

□ Innovazione

X □ Green

Tipologia di cofinanziamento (pari ad euro 8000 una tantum):

X□ Nome dell'Ente finanziatore pubblico o privato: Consiglio nazionale delle ricerche – CNR Istituto di Microelettronica e Microsistemi -IMM

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□ Fondi di ricerca dipartimentali

Progetto di Ricerca (massimo 10.000 battute complessive spazi inclusi) che comprenda

Descrizione del Progetto:

Obiettivi formativi:

Attività previste:

Attinenza del progetto all'area indicata:

Risultati attesi:

Azienda pubblica o privata coinvolta nazionale o straniera in cui si prevede di far svolgere il periodo obbligatorio da 6 a 12 mesi previsto dal Decreto Ministeriale:

STMicroelectronics srl - Agrate Brianza

Firma

RESEARCH PROPOSAL

PHASE CHANGE LAYERS FOR GREEN NEUROMORPHIC COMPUTING

STRATI A CAMBIAMENTO DI FASE PER COMPUTAZIONE NEUROMORFICA VERDE

Future society is faced with a major challenge: finding a sustainable equilibrium between limited natural resources and the growing need for energy, materials, connections between people and communities. A radically new scenario must be envisioned, based on a correct relationship between nature and human society, where benchmarks, such as that of "Moore's law", are replaced by the concept of sustainability. Scientists can largely contribute to this effort, developing novel technologies for an efficient management of resources. In the era of the internet of things, ideally any object will be equipped with some memory, computing and communication capability, so as to establish a degree of interconnection which emulates that of natural eco-systems. The efficient management of the huge amount of data produced requires the development of new technologies, typically involving problems of pattern recognition, which can be efficiently tackled using neuromorphic computing. The advent of such devices with ultra-low power consumption would be highly useful in many application fields. Materials that could enable information processes with state variables other than charge are very attractive, but often a fundamental issue in view of their exploitation is the poor compatibility with CMOS electronics. Instead, exploiting materials already used in the production lines of semiconductor industries is of great advantage.

Among various candidates, the resistive-switching phase-change memory (PCM) has been chosen, as it has gained considerable interest for its application in storage class memory, mainly due to scalability, fast writing, long data retention (more than 10 years) and very good endurance properties. PCMs store information in their amorphous and crystalline phases, which can be reversibly switched by the application of an external voltage or current. PCM technology still develops towards higher density, faster speed, and lower power consumption. In this scenario, we aim at investigating new PCM material combinations that have the potential to be implemented in neuromorphic computing platforms within parallel brain-inspired, neuro-computing architectures.

In fact, one drawback of conventional PCM is the large programming currents that are needed, because the phase change material necessitates to be melted. One promising strategy to reduce the programming currents is to improve the quality of active materials. Recently, superlattices (i.e. alternating thin layers of two different phase change materials) have been proposed for such a scope. As confirmed by many groups, superlattices not only showed reduced switching currents, but also enhanced endurance characteristics. This makes such an approach very attractive for future applications, especially for neuromorphic ones.

A thorough understanding and characterization of such devices is needed. Important characteristics are, among others, resistance drift in the RESET state, power consumption, endurance and the programming window. The drift of the resistance in the RESET state is a showstopper for multi-level data storage, because it results in the loss of information and therefore an important drawback of PCM devices. At the moment the drift in superlattice-based

PCM devices has not been investigated. It is thus unknown if it exists and how it will affect device performance. So, it is necessary to investigate the drift behavior in superlattice-based phase change memory cells.

At the same time, a thorough understanding and characterization of new layered structures are needed, especially for what concerns the structural quality of the active layers. The intermixing of the materials, for instance, is a showstopper for multi-level data storage, because it results in the formation of an additional layer, which might cost the loss of performance, or even of information, thus resulting an important drawback of PCM neuromorphic devices. At the moment the intermixing in superlattice-based PCM devices has been investigated only for a couple of cases. So, it is necessary to perform a screening of the most suited combinations. Afterward, the best candidates will be fabricated and investigated in terms of intermixing. This research will make a great contribution to the development of PCM technology. The materials of first choice for the realization of novel heterostructures are GeSbTe, Sb_2Te_3, GeTe combined with GaTe, InTe, $TiTe_2$ and $MoTe_2$. In fact, recently the idea of alternating active PCM and other chalcogenide based layers (serving as thermal barriers) showed impressive results. However, only one configuration ($Sb_2Te_3/TiTe_2$) was investigated. Furthermore, pure Sb_2Te_3 displays poor stability of the amorphous phase, thus should be replaced by other PCMs that are more stable in terms of data retention.

GREEN IMPACT

This is an innovative, ambitious and challenging project which will draw the guidelines to approach open challenges spanning different fields of knowledge to achieve an highly competitive green new technology. In the following, the main foreseen contributions to energy savings are listed.

- Portable devices, such as mobile and smart phones, tablet PCs and notebooks, will highly profit of power-efficient neuromorphic computing. Portable devices are distinguished by their small sizes and light weight; they should operate while on the move, regardless of proximity to a power source. High energy consumption and hence reduced battery life makes the devices much less attractive. Furthermore, user preferences, towards carrying less, motivated to integrating several different applications in a single multi-purpose portable device. This often leads to even much higher energy consumption and consequently novel neuromorphic computing concepts might be helpful in terms of energy savings.
- Even an energy-efficient server farm still consumes about half of its full power when doing virtually no work. Neuromorphic computing has extremely low static power consumption; that is why its employment would provide huge energy savings. The benefits are not only related to the electricity for the server but also the energy necessary for cooling the data center and its infrastructure. These savings in energy consumption would significantly lower the environmental burden.

Scientific and technological contributions to new green technology – this project stems from the concept of creating a system which can be integrated in smart devices without the necessity to transmit data to a remote host and which decreases the computational costs of processing, thus providing energy savings. The realisation of the project requires the generation of new basic knowledge across several fields. New insights will be gained with respect to material science and device physics. Moreover, in the project a radical change of perspective, which places the device with its low programming power at the centre of the system development, will help in the future formulation of learning algorithms exploiting the intrinsic physical properties of PCM devices.

Social, economic impact and market creation – Thanks to the possibility of continuous adaptation to the external environment, the system will bring a disruptive advancement across disciplines. As an example, medical devices, such as pacemakers, will be able to monitor biological signals from the patient and adapt their behaviour to changes due to ageing or different ongoing activities. In robotics, it can be used for drone navigation in catastrophic scenarios or autonomous systems assisting people able to communicate only with gestures. In neuroprosthesis, the system will improve the communication between the patient and the artificial prosthesis which will be able to naturally adapt to the unique neural characteristics of the patient. The versatility of the system will bring major returns to industries and society by contributing to improve life quality, or even to save lives. All those improvements will be accomplished always with considerable energy savings and green technology adoption.

EDUCATIONAL OBJECTIVES

Research in device improvement always strives to make PCM devices matching standard machine learning requirements, e.g. linearity and deterministic behaviour of synapses. Within this thesis PCM devices' natural behaviour will be studied in a sort of device-centric approach. Such an approach will significantly enhance the performance of the proposed system, enabling its use in several applications, from medicine to robotics. At the same time, this approach will accordingly shape in the round the PhD candidate.

He/She will learn ***fabrication and characterization of high-quality PCM layered thin films*** on conductive and insulating layers, using facilities operating at the Department of Physics of the University of Rome Tor Vergata and at the Consiglio nazionale delle ricerche (CNR) Istituto per la Microelettronica e i Microsistemi (IMM) located in the area of Tor Vergata will be thoroughly used. ***Test vehicle structures*** will be fabricated at CNR-IMM for functional testing of the neuromorphic cells performed using a dedicated electrical setup.

The industrial partner STMicroelectronics is strongly engaged in this field and has a long standing cooperation with Dr. R. Calarco and Prof. F. Arciprete. STM has the need to maintain leadership in integrating computing, and enabling Artificial Intelligence, with a low power solution, like with PCMs, which will become a differentiator in such field. Therefore, STM will be hosting the PhD candidate for the foreseen industrial stage in its center in Agrate Brianza.