



**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

Green

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

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:

STMMicroelectronics Agrate Brianza

**Firma**



## RESEARCH PROPOSAL

### PHASE CHANGE LAYERS FOR NEUROMORPHIC APPLICATIONS

#### STRATI A CAMBIAMENTO DI FASE PER APPLICAZIONI NEUROMORFICHE

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. 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 high resistance (RESET) state, power consumption, endurance and the programming window. The drift of the resistance in the RESET state is a bottleneck 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 drawback 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<sub>2</sub>Te<sub>3</sub>, GeTe combined with GaTe, InTe, TiTe<sub>2</sub> and MoTe<sub>2</sub>. 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<sub>2</sub>Te<sub>3</sub>/TiTe<sub>2</sub>) was investigated. Furthermore, pure Sb<sub>2</sub>Te<sub>3</sub> displays poor stability of the amorphous phase, thus should be replaced by other PCMs that are more stable in terms of data retention.

## INNOVATION

This is an innovative, ambitious and challenging project which will draw the guidelines to approach open challenges spanning different fields of knowledge. In the following, the main foreseen contributions to research are listed.

- **Material science** – The development of analogue PCM devices requires an investigation at the material level. Indeed, the stack of the device must be optimised to facilitate gradual modifications of the microscopical configuration of the device, which macroscopically results in changes of the device conductance. Moreover, compatibility of different materials has to be studied in view of co-integration with CMOS systems.
- **Physics** – Understanding physical mechanisms underlying the device behaviour is fundamental to conceive (i) efficient programming algorithms to emulate synaptic behaviour, (ii) reliable models of the device, (iii) proper learning algorithms to exploit the device potential in neuromorphic networks, and (iv) adequate network architectures which take advantage of device features to maximise the system's accuracy.
- **Neuromorphic engineering** – The use of elements as PCM devices in neuromorphic paradigms is still dawning. This project is a pioneer in the field, aiming to build a system which exploits the physics of PCM devices to enable a biologically plausible computation.

This PhD project will pave the way for new generation systems which are strategic to enable the industrial transition and resilience of the new post-COVID-19 society. Its unique characteristics can fit in multiple scenarios, such as health monitoring, gesture recognition, robot navigation, ambient assisted living.



Scientific and technological contributions to new 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. 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 at the centre of the system development, will help in the future formulation of learning algorithms exploiting the intrinsic physical properties of PCM devices, to achieve better system accuracy.

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.

## 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.