Phemtronics Newsletter

Issue 1 | December 2020

Special points of interest:

- Introducing PHEMTRONICS
- PHEMTRONICS Phase-Change Materials
- PHEMTRONICS Path to phase-change devices
- PHEMTRONICS Optical Approach to Phase-Transformation Dynamics

Inside this issue:

Phemtronics Started June 1st 2020!

As this unprecedented pandemic year wraps up, we see reasons for enthusiasm and hope, as in the face of the COVID-19 crisis, science has found new ways to work, connect and communicate. During this year we have successfully fulfilled the first steps to kick-off on June 1st, 2020 the FETOPEN project PHEMTRONICS.

PHEMTRONICS has received funding from the European Union's Horizon 2020 FETOPEN programme with GA No. 899598.

PHEMTRONICS has the ambitious vision of creating a unique path for translating forefront knowledge in phase-transformation dynamics in light controllable active matter with reconfigurable and interactively tunable dynamical properties into extreme broadband reconfigurable and adaptive devices by developing a radically novel transdimensional active matter platform that is intrinsically itself phase change, low-loss plasmonic and electronically topological. The photon-electron-phonon coupling will enable a new technology paradigm of adaptive optical signal processing with ultrafast network reconfiguration with key metrics of the femtosecond-scale switching time, ultralow power (femtojoule/bit) and broadband (microwave-to-optical frequencies) capability required for reliable multibit operations.

PHEMTRONICS exciting outcomes include demonstrators of:

- New generation of ultrafast and low-power switches
- Reconfigurable antennas
- Adaptive switching multiple band photodetectors for dynamic displays
- Reconfigurable Photonic Integrated Circuits design for 5G and LIDAR.

During these 6 months, we have clearly defined activity plans, missions, and ambitions of our core activities being: deposition of novel phase change materials, modelling of their phase change dynamics, understanding their optical behavior and their activation by light and plasmonics, to conceive and enable the adaptive and reconfigurable demonstrators mentioned above.

Our participatory process has successfully brought all Phemtronians to the same webpage: **www.phemtronics.eu.**

Further, during this year we have initiated the process to build up a strong competence in novel phase change materials active in the visible range beyond the telecom infrared range, establishing a transversal materials research group that involves CNR-NANOTEC, Tyndall, University of Cantabria, University of Linz and the SME NANOM.

Right now, we are establishing a strong transversal Device Engineering Team including University of Muenster, and the high-tech SMEs, NANOM, TEOX and VLCPhotonics that will be instrumental for reaching our ambition for the next decade in relation to the *Phemtronians* demonstrators.

Especially important was setting up our communication channels

As we look to the year ahead PHEMTRONICS will consolidate its commitment to contributing to and to interacting with the optics and photonics community.

In short, the year 2020 has, although being in the shade of the Sars-Cov-2, been a successful year for PHEMTRONICS. I am very grateful to all the *Phemtronians* for their commitment to research, their enthusiasm and hard work, making PHEMTRONICS contributing to developments and generating new knowledge to the benefit of society.

Wishing you all the happiest holidays and may 2021 be a great year!

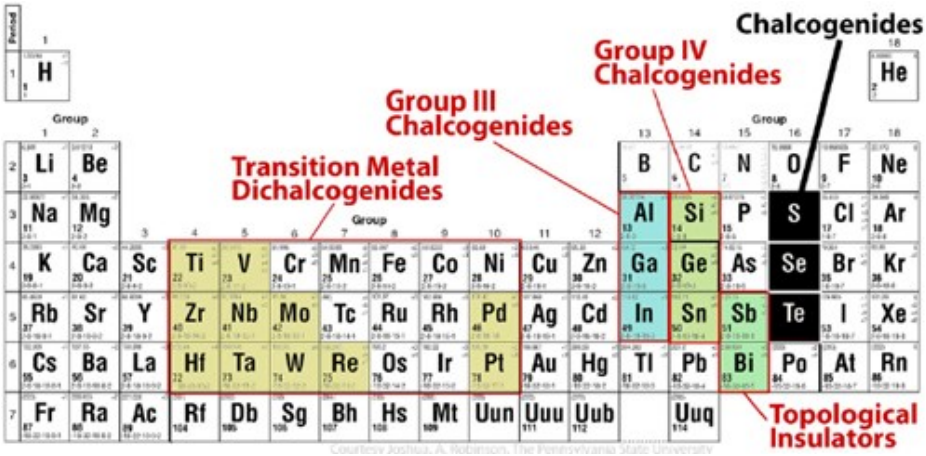
Thank you for being here throughout 2020.

We can't wait to see What's Next in 2021!

Maria Losurdo,

Phemtronics Coordinator

Core Activity of PHEMTRONICS: Phase Change Materials in PHEMTRONICS Beyond Graphene and Transition Metal Dichalcogenides



There are now more than 600 different 2D materials recognized, most of which had 2D stability predicted only in the past decade, and some of which have not yet been synthesized, that go beyond the transition metal dichalcogenides (TMDs), including monochalcogenides (GaS, GaTe, GaSe, etc.).

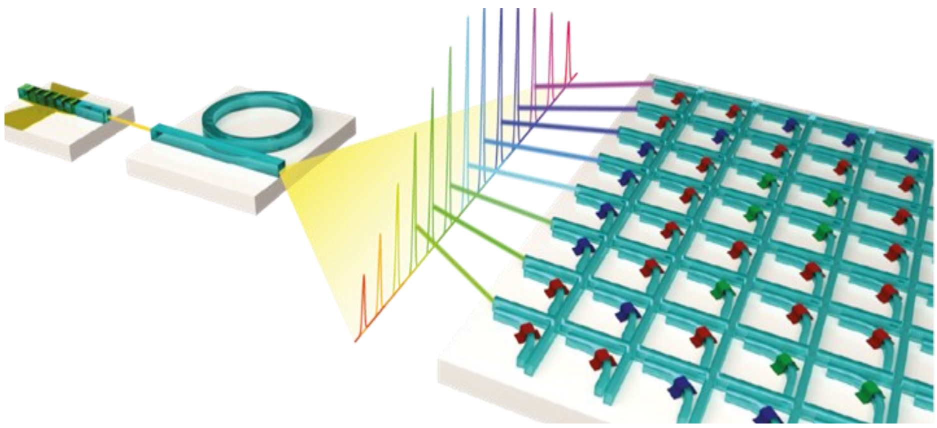
The great ability to tune the bandgap, band offset, carrier density, carrier polarity, and switching characteristics in those 2D TMDs provides unparalleled control over device properties and possibly new physical phenomena.

Phase-change memory arrays

"We are demonstrating a computational specific integrated photonic tensor core—the optical analog of an ASIC—capable of operating at Tera-Multiply-Accumulate per second (TMAC/s) speeds"

With the proliferation of ultra-high-speed mobile networks and internet-connected devices, along with the rise of artificial intelligence, the world is generating exponentially increasing amounts of data—data that needs to be processed in a fast, efficient and 'smart' way. These developments are pushing the limits of existing computing paradigms, and highly parallelized, fast and scalable hardware concepts are becoming progressively more important. To address these challenges, we have demonstrated a computational specific integrated photonic tensor core—the optical analog of an ASIC—capable of operating at Tera-Multiply-Accumulate per second (TMAC/s) speeds. The photonic tensor core achieved parallelized photonic in-memory computing using phase-change memory arrays and photonic chip-based optical frequency combs (soliton microcombs). The computation is reduced to measuring the optical transmission of reconfigurable and non-resonant passive components and can operate at a bandwidth exceeding 14 GHz, limited only by the speed of the modulators and photodetectors. While we focused on convolution processing, more generally our results indicate the major potential of integrated photonics for parallel, fast, and efficient computational hardware in demanding AI applications such as autonomous driving, live video processing, and next generation cloud computing services.

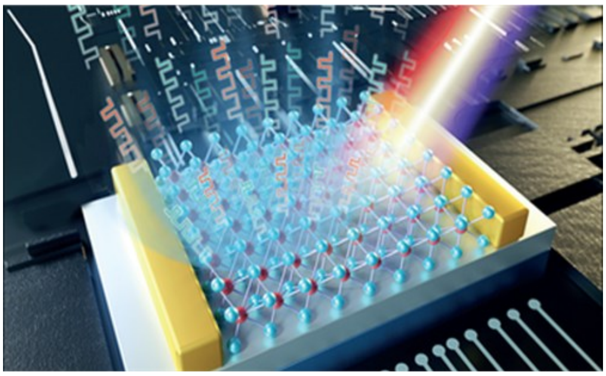
Prof. Wolfram Pernice,
Munster University



Phase Change Materials in Layered Forms: The Shape of Photonics to Come

Over the past decade, the fact that layered materials have shown a strong presence in photonics applications paved the way for phase change materials (PCMs) to come into focus of several research studies.[1,2]
Typically, with its metal to insulator transition, vanadium dioxide, VO_2 [3], and with its amorphous to crystalline transition $Ge_2Sb_2Te_5$, GST [4], are considered as the traditional PCMs due to the fact that they exhibit changes in electrical conductivity, optical reflectivity and thermal conductivity upon structural transformation. Recently, phase-change sulfides have been standing out as low-loss candidates for active reconfigurable photonics [5]. Aside from their phase change property sulfides such as GaS, Ga_2S_3, GeS, Sb_2S_3 are also attractive materials owing to the fact that they have an eco-friendly composition which allows sustainable design.

Producing and patterning PCMs in wafer scale thin film forms is essential in order to have them utilizable for required applications. For this reason, methods such as physical vapor deposition (PVD), chemical vapor deposition (CVD) and atomic layer deposition (ALD) and molecular beam epitaxy (MBE) are preferred for their synthesis. When it comes to characterization of these materials, techniques such as transmission ellipsometry and photothermal deflection spectroscopy are implemented as measuring the optical properties of these materials is the key point [6].
Strong optical phase modulation, fast and low-power switching, low material fatigue and long device lifetime, low insertion loss, and process compatibility are the improvements to be targeted in PCMs in the process of having them manufactured in layered forms. Providing further material specifications for PCMs in these fields hold the potential to open new gates in their integration to photonics applications [6].
As further tuning in the optoelectronic properties of PCMs are carried out, they can be claimed to become the leading candidate for refractive materials in photonic integrated circuits. For the near future, novel interdisciplinary research based on collaborations between photonics and materials science communities are promising to bring advantageous results.



Doğa Bilican
TEOX

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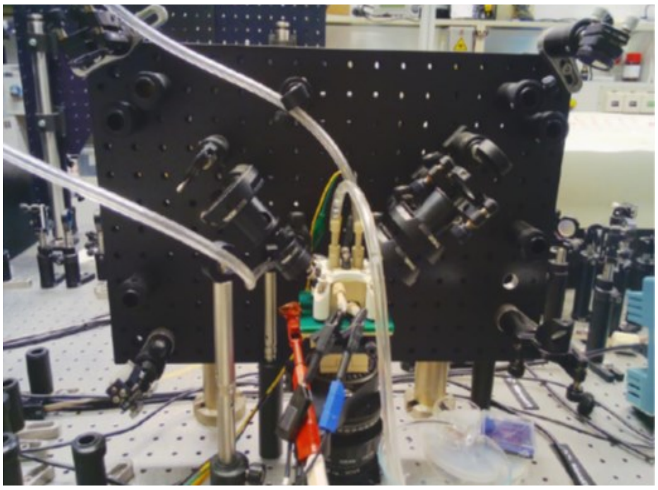
W. Dong et al. Advanced Functional Materials 29, 1806181 (2019).
A. Singh et al. ACS Photonics (2020). DOI: 10.1021/ acsphotonics.0c00915

The PHEMTRONICS approach of measuring and modelling Phase Change Dynamics

Since project start, we are investigating how to speed up phase transformations in order to achieve faster switching times by considering the approaches below.
Presently, GeSbTe, the currently used material is switching between the amorphous state and the crystalline one by a temperature cycle- first by heating and then by cooling slowly to enable the phase change or by melt quenching, such that the liquid state is "frozen in".
Both phase transitions are 1st order (in Ehrenfest nomenclature) and are driven by the rate of cooling. In order to reach the crystalline state (with lower Gibb´s energy) the cooling rate is less, whereas for melt quenching cooling is fast, a metastable state results, and the heat diffusion coefficient of the surrounding materials must be rather high (e.g. by a metallic surrounding). For both cases the driving force is the temperature gradient between the melt and the surrounding, the higher it is the faster the phase transition happens. The other important parameter is the volume of the material, mainly because the heat capacity scales with the volume, but also due to the fact that for nanoparticles surface and interface energies become more important. for a recent overview, please see the very clear paper by Martin Salinga et.al. , Nature Comm. DOI:10.1038/ncomms3371 (2013). It turns out that meld quenching will always limit the switching time above ~ 100ns, also for nanoparticles.

Generally, besides "melt-quenching" to reach a metastable state, we are investigating the following processes:



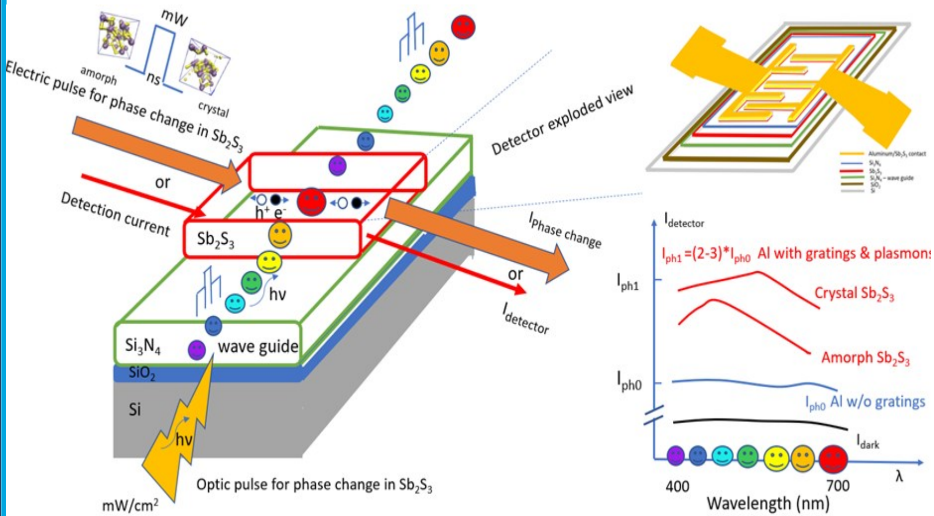
1. diffusionless (non-equilibrium) transitions, as e.g. in martensitic steels and shape memory alloys.
2. ferroelectric (equilibrium) phase transitions as e.g. in SrTiO4, where the limiting kinetic time scale is the movement of an ion due to a soft phonon and an electric impulse. Here we expect that switching times of 1- a few picoseconds, i.e. values of the inverse of the phonon frequencies. Such transitions could even be initiated with fs laser pulses, where the envelope of the laser pulse is no longer than approximately one half-wave.
3. second order (equilibrium) phase transitions, where instead of structural material changes (i.e. atom / ion movement) the electronic states and electronic correlations build up. This happens due to entanglement and is formally "instantaneous" respectively propagating with the speed of light. Furthermore, the participating particles are a factor of 10000 less heavy than ions and can - in principle react much faster than ions or atoms. However, it is unclear, if the refractive index contrast resulting from a 2nd order phase transition is sufficient to realize optical switching. For this goal we currently investigate theoretically nonlinear nonlinear plasmonic effects and their response functions.

From the experimental point of view we are following two paths: Firstly, we modify the existing SHG- SFG 35 ps pulse duration system such that pump probe measurements on the model system of the solid liquid interface (our drosophila, because electric fields can be applied) become possible. Secondly, we started a cooperation with ELI Beamlines – Dolní Břežany, close to Prague, CZ, where pump probe ellipsometry measurements can be done with ~ 100fs resolution. We plan to make common in situ measurements on the liquid solid interface as soon as the pandemic COVID-19 situation will allow, .

Prof. Kurt Hingerl, Johannes Kepler University

NANOM Phase Change Materials in PHEMTRONICS: Sb_2S_3 as Next Generation Low Loss Phase Change Materials for Photonic Applications

Sb_2S_3 is a phase change materials with extremely low losses in both states. They provide an attractive alternative to GST in reconfigurable photonic circuits and open new avenues for both phase and amplitude modulation. NANOM is active in:



I) **Materials synthesis:**

Antimony trisulfide (Sb_2S_3, a chalcogenide material that exhibits large refractive index changes of about 1 between crystalline and amorphous states) was synthesized by a cheap and versatile method (chemical bath deposition/electroless plating):

$2Sb^{3+} + 3S^{2-} \longrightarrow Sb_2S_3$

SiO_2, glass, Al_2O_3, optical fiber, PET (polyethylene terephthalate) were used as substrate materials.

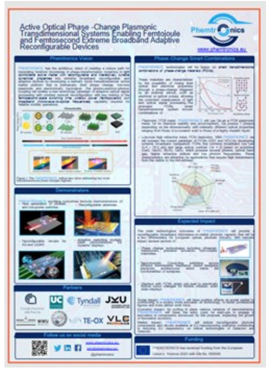
II) Device

A SOI-CMOS compatible plasmonic wideband waveguided Al-Sb_2S_3-Al photodetector electro -optically tunable in the visible spectrum via phase change material was designed. It is presented in the schematic view:

Marin Gheorghe, NANOM

PHEMTRONICS Profile

Downlod our Leaflets and Posters



PHEMTRONICS Members Stories

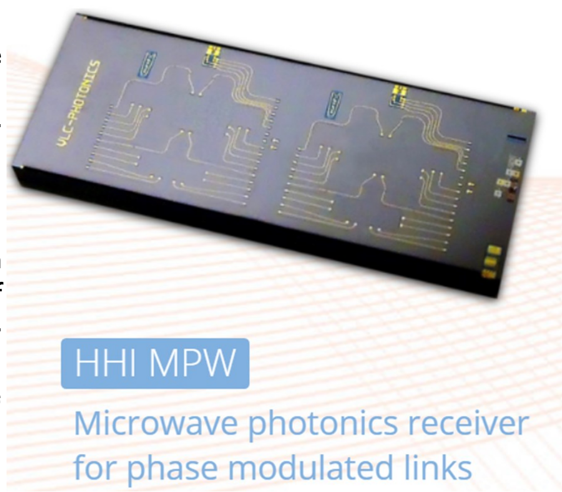
Announcing Advisory Board members

Recognizing the full worth of the Advisory Board, we are welcoming the Members of the PHEMTRONICS Advisory Board, distinguished professionals from the reconfigurable microelectronic and photonic industry

Member	Position, Organization	Expertise
Dr. **Esther Lopez**	Senior Expert Product Development at ACORDE Technologies, S.A Spain	Swicthes, modulators, antennas technology design, production and characterization
Dr. **Karl Gedda**	Executive Officer of the OPTICS VALLEY Cluster SYSTEMATIC Cluster France	Start-up Europe Ambassador Connecting Innovation Ecosystems & Accelerating Deep Tech start-ups
Prof. **Harish Bhaskaran**	Professor of Applied Nanomaterials, University of Oxford, CEO of Dualmatter Computing, UK	Phase Change Materials Nanoengineering

We are celebrating VLCPhotonics that announced a partnership with Hitachi High Tech as:

Tokyo, November 12, 2020 – Hitachi High-Tech Corporation today announced that VLC Photonics S.L. has become Hitachi High-Tech's subsidiary company and will continue to provide Photonic Integrated Circuit (PIC) engineering services as part of the Company's broader offering.
A long-term provider of components and services to the optical communications industry, Hitachi High-Tech is aware of the increasing need of customers for greater integration and innovation. As the foremost independent provider of PIC design, test and engineering services, VLC is in an excellent position to help Hitachi High-Tech serve the new requirements of its existing customers as well as providing a base for the development of new service provisions.



Meet the YOUNG RESEARCHERS TEAM

PHEMTRONICS, in the spirit of the FETOPEN gatekeepers to build leading research and innovation capacity across Europe, is involving as key actors excellent young researchers. Their collaboration generates

Yael Gutiérrez
Grant Researcher at CNR NANOTEC

PhD in Physics with background in DFT calculations and characterization of material's optical properties, electromagnetic theory and simulation of plasmonic systems. Yael's main research interest is reconfigurable plasmonics and the development of new phase change materials with controllable optical response.

In the Phemtronics project she will be involved in the synthesis and characterization of new gallium based PCM dichalcogenides as well as in their optical and structural characterization through spectroscopic ellipsometry and Raman spectroscopy. She will also contribute to the design and simulation of new plasmonic systems with reconfigurable response based on this materials.

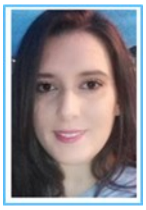
Contact: yael.gutierrezvela@nanotec.cnr.it

Gonzalo Santos
PhD student at UC

PhD student in Science and Technology. His main research interest is the DFT simulation of the optical properties of phase-change materials (PCMs) and the study of their electromagnetic response.

In the Phemtronics Project, Gonzalo will be involved in the simulation of the optical behavior of this type of materials in order to predict and guide experimental team in the interaction produced between light and PCMs.

Contact: gonzalo.santos@unican.es



Rihem Noumi
R&D engineer at TE-OX

PhD in Electrical Engineering. Her main research interests are in the field of LWA antenna design and SIW technology. She has an expertise in conception, design, and test of RF components, especially antennas.

Rihem will be involved in the project in modelling, simulation of ultra-fast reconfigurable microwave switches and devices using electromagnetics software (CST, HFSS) and the electrical characterisation using wafer probe station and RF network analyser.

Contact: rihem.noumi@te-ox.com

Olga Ishchenko
R&D engineer at TE-OX

Dr. Eng. in Chemistry with background in material science, thin-films coatings and nanostructures fabrication and characterisation.

Olga has experience in thin films deposition techniques such as CVD methods, mainly ALD and MOCVD; in electronic device fabrication in clean room environment (photolithography, etching techniques, metals deposition). She has also an experience in nanostructures fabrication and characterisation methods. She works on VO2 nanowires synthesis via the hydrothermal method, metallic and oxides nanoparticles self-organisation approach via block-copolymer assembly and other chemical ways of nanostructures synthesis.

In the Phemtronics project, Olga will be involved in ultra-fast optically controlled switches design and fabrication. Olga is also responsible of the website development

Contact: olga.ishchenko@te-ox.com

Doğa Bilican
R&D engineer at TE-OX

Ph.D. in Materials Science. Doğa's main research interests include electrochemical deposition, sputter deposition, arc melting and suction casting. She has also experience in sustainable materials selection and process design and materials characterization by methods such as scanning electron microscopy, confocal microscopy, X-ray diffraction.

Within the framework of PHEMTRONICS project, she will be responsible for the synthesis of phase change materials in thin film forms by sputter deposition and characterization of the synthesized films in structural, morphological, chemical and electrical aspects.

Contact: doga.bilican@te-ox.com

Stefano Dicorato
PhD student at CNR NANOTEC

Master's degree in Materials Science and Technology. Stefano's main research interest concerns the processing and characterization of nanostructures. He has expertise in plasma treatment, thin film deposition by ALD and screen printing. He has also experience in the optical characterization by ellipsometry and compositional/structural analysis by Raman.

In the project, he will manage the deposition, processing and characterization of phase change materials.

Contact: stefano.dicorato@nanotec.cnr.it

Why Iron-man and why not Fe-male?

This joke is not for everyone

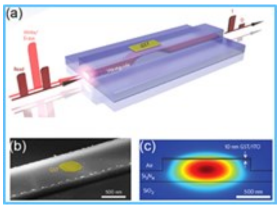
Meet the PHEMTRONICS CONSORTIUM

PHEMTRONICS consortium integrates 8 partners from 7 countries.
It fosters interaction between 3 universities, 2 research centres and 3 innovative SMEs, bringing together all the relevant expertise in materials, phase-change dynamics, nanofabrication, optical modelling and photonics building blocks design and fabrication. Innovation will result from the synergy between fundamental knowledge advancements and phase-change technology.

CNR-NANOTEC, *Coordinator* www.nanotec.cnr.it

The National Research Council (CNR) is a public non-profit governmental research organization promoting and transferring research activities in the main sectors of knowledge growth and of its applications for the scientific, technological, economic and social development of the Country. The primary objective of the Institute of Nanotechnology is the fundamental study and the manipulation of systems on nanometric scale to enable applications in various technologies (ICT, photonics, micronanoelectronic, sensing, energy, life science). NANOTEC will develop and apply advanced methods for depositing and characterizing new 2D phase-change materials a and novel plasmonic nanosystems with surface plasmon resonance tuneable from the NIR to VIS and UV and for identifying and controlling their light- and electron-activated phase change chemistry dynamics

The WWU Münster www.uni-muenster.de/Physik.PI/Pernice/



The WWU Münster is part of the German U15 universities and ranked consistently one of the top research institutions in Germany. A particular focus area at WWU are the nanosciences and nanotechnology. The group of W. Pernice focus is the investigation of responsive nanosystems, photonic circuits, tunable and hybrid photonic devices, including waveguide integrated phase change material components.
WWU within PHEMTRONICS provides key expertise in phase change photonics, nanofabrication, numerical design of reconfigurable photonic devices, as well as the design and fabrication of waveguide integrated photodetectors

Tyndall National Institute www.tyndall.ie

In 2020, UCC celebrated 10 years since becoming the first University in the world to be awarded a Green Flag from the Foundation for Environmental Education. Green Campus involves a seven-step programme and a cycle of continual improvement. An international ranking which examines sustainability practices in universities across the world, has ranked University College Cork (UCC) today at ninth, the only Irish university to make the top 10 of the 'greenest universities' in the world for sustainability.

The Johannes Kepler University Linz www.jku.at/zona

The Johannes Kepler University Linz (JKU) offers bachelor's, master's, diploma and doctoral degrees in business, engineering, law, social sciences and natural sciences.
In Phemtronics, the JKU main missions are: to develop an atomistic understanding of phase transformation in materials by analytical models and computational physics (mainly DFT) and to apply stochastic approaches and predictive modelling for the design of materials and of devices. Equilibrium thermodynamic experiments on first and second order phase transitions will be used to derive thermodynamics of 2D phase transformations

Universidad de Cantabria www.unican.es

UC is one of the three universities that has been in the Top 10 list of the main Spanish rankings both in education as well as in research quality. It is a modern public institution whose main purpose is to contribute to social progress through a firm commitment to teaching and scientific excellence. Since its creation in 1972, it has provided university education for more than 40,000 students.
UC role in Phemtronics is focused on the design and simulation of reconfigurable plasmonic structures based on the materials developed during the project. Through DFT calculations, the team at UC will also help to establish the electronic structure and optical properties of the materials studied within the consortium

NANOM MEMS SRL www.nanomems.com

NANOM MEMS SRL is a private company focused on research and production of a large class of materials and technologies.
NANOM will contribute to the ink printing of materials and fabrication of the hybrids plasmonic system/sulphides using their fabrication facilities, in testing electrically them and their stability. It will enable a demonstrator by upscaling broadband detectors and arrays of detectors

TE-OX www.te-ox.com

TE-OX is a French start-up developing ultra-fast electronic components and devices based on materials exhibiting Metal-Insulator Phase Transition (like VO2 and Nickelates). TE-OX provides modelling, simulation and manufacturing of new RF-switches based on VO2 and their integration on semiconducting platforms (Si, SiGe and GaN).
TE-OX's role in Phemtronics is focused on the development of processes and materials, e.g. oxides and space layers needed for device fabrication. TE-OX will take in charge the fabrication of ultra-fast optically controlled switches, optical routers and multiplexers. TE-OX will also participate in the device reconfigurability characterisation as well as RF measurements under electro-optical activation

VLC Photonics www.vlcphotonics.com

VLC Photonics is a photonic design house based in Valencia, Spain, which provides services and turn-key photonic integration solutions towards multiple application fields. It has a wide experience with various material platforms (silicon photonics, indium phosphide, silicon nitride, PLC, polymer) and offers fabless development services for photonic integrated circuits in Telecom/Datacom, microwave photonics, quantum optics, lidar, bio-photonics and optical sensing markets. The company is a spin-off from the Universitat Politècnica de València. The role of VLC in PHEMTRONICS is to design and fabricate the building blocks, providing the required waveguides and contribute to a demonstrator of reconfigurable photonic circuit

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 899598

NEWS

The Phemtronics Consortium is editing the following Special Issues

- NANOMATERIALS Special Issue "**Plasmonics and Nano-Optics from UV to THz: Materials and Applications**"
For Manuscript Submission Information, please visit: https://www.mdpi.com/journal/nanomaterials/special_issues/Plasmonics_Nano_optics

- JOURNAL of APPLIED PHYSICS **"Plasmonics: Enabling Functionalities with Novel Materials"**
For Manuscript Submission Information, please visit: https://publishing.aip.org/publications/journals/special-topics/jap/plasmonics-enabling-functionalities-with-novel-materials/

The Phemtronics Consortium has published the following papers

- Plasmonics beyond noble metals: Exploiting phase and compositional changes for manipulating plasmonic performance. Journal of Applied Physics 128, 080901 (2020) https://doi.org/10.1063/5.0020752 [open acess]
- Polymorphic gallium for active resonance tuning in photonic nanostructures: from bulk gallium to two-dimensional (2D) gallenene, Nanophotonics 2020; 9(14): 4233–4252. https://doi.org/10.1515/nanoph-2020-0314 [open access]
- Non-Absorbing Dielectric Materials for Surface-Enhanced Spectroscopies and Chiral Sensing in the UV Nanomaterials 10, 2078 https://doi.org/10.3390/nano10102078 [open access]

Upcoming Events Where to Meet Phemtronics

- E-MRS SPRIMG MEETING—**Current trends in optical and X-ray metrology of advanced materials for nanoscale devices V,**
[Abstract and Summary Submission Deadline January 19, 2021]
- CLEO/Europe - EQEC 2021, 20–24 June 2021, Munich, Germany.
[Call for Papers Deadline 29 January 2021]

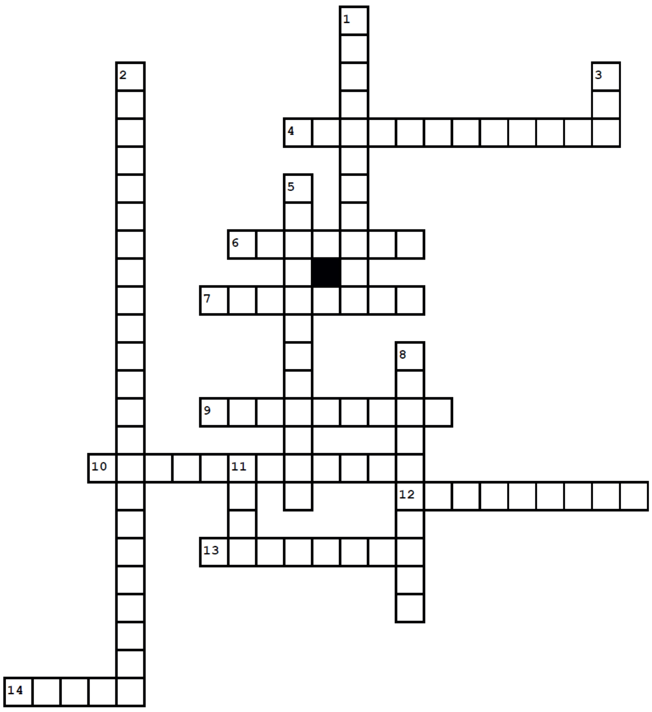
PLAY WITH US ….AND STAY CONNECTED

Across

4. Electric current through a photosensitive device.
6. Liquid metal near room temperature with plasmonic response from the UV to the NIR.
7. The 2D and G are the main Raman bands of _____.
9. High-performance photonic simulation software that enables prediction of light's behaviour within complex structures and systems.
10. ___ computing emulates the neural structure of the human brain.
12. Stanford R. ____ is considered the father of PCMs.
13. Sb2S3.
14. ____ spectroscopy is the main technique used to characterize two-dimensional materials.

Down

1. GST is used for the fabriation integrated photonic phase change ____ memories.
2. CVD.
3. Well-know phase materials used in the fabrication of the DVD technology.
5. Surface sensitive and non-destructive optical technique widely used to determine thin film thickness and optical constants.
8. _____are the chemical elements in group 16 of the periodic table.
11. Vanadium Dioxide is know for being a ____-insulator with a metal-to-insulator transition.



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