



PROJECT FINAL REPORT

Grant Agreement number: 619456

Project acronym: SITOGA

Project title: Silicon CMOS compatible transition metal oxide technology for boosting highly integrated photonic devices with disruptive performance

Funding Scheme: Collaborative Project

Period covered: **from** 01/12/2013 **to** 31/03/2017

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Table of Contents:

| | | |
|----|---|----|
| 1. | Final publishable summary report. | 3 |
| | 1.1. Executive summary. | 3 |
| | 1.2. Project context and objectives. | 4 |
| | 1.3. Main S&T results/foreground. | 6 |
| | 1.4. Potential Impact | 14 |
| | 1.5. Contact. | 17 |
| 2. | Use and dissemination of foreground | 18 |
| | Section A (public) | 18 |
| | Section B | 24 |
| | Part B1 | 24 |
| | Part B2 | 24 |
| 3. | Report on societal implications | 26 |
| 4. | Final Report on the Distribution of the European Union Financial Contribution | 33 |

1. Final publishable summary report.

1.1. Executive summary.

The SITOGA project addresses the **integration of transition metal oxides (TMO) materials in silicon photonics technology** for the first time in a European-scale research initiative. TMO materials comprise a very diverse and fascinating class of compounds with properties that can be tailored for a wide variety of applications. SITOGA has focused on two disruptive TMO materials, **barium titanate (BaTiO₃) and vanadium dioxide (VO₂)**, for enabling breakthrough electro-optical functionalities due to their unique material properties not present in pure silicon. The figure below summarized the project concept.

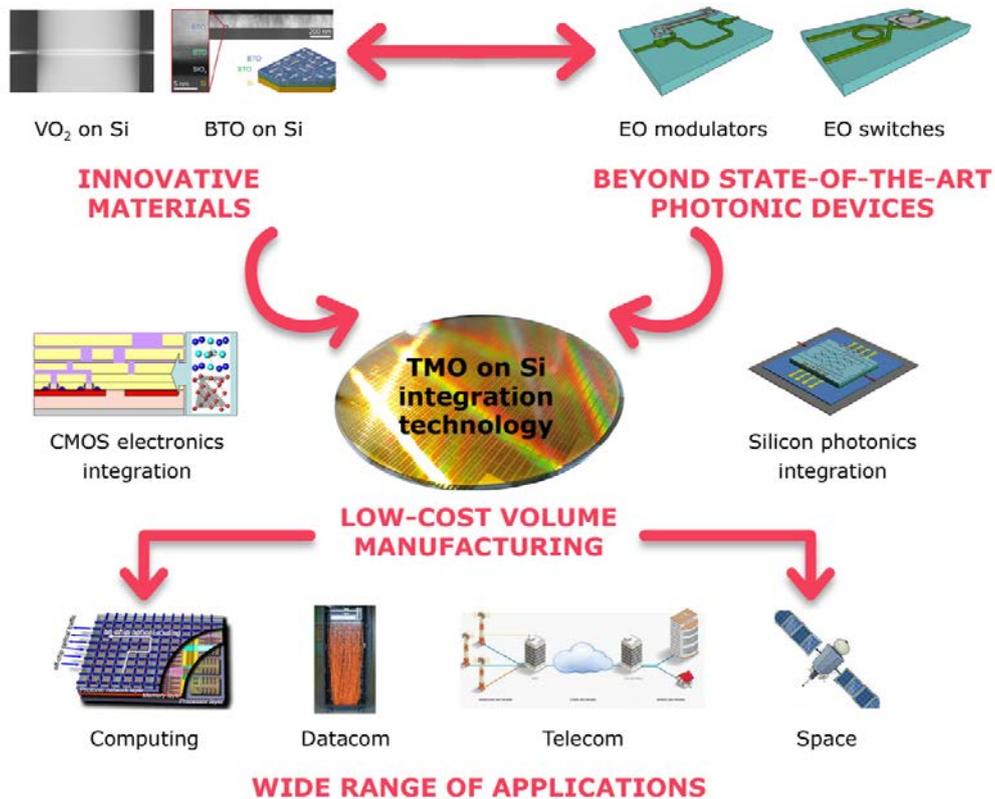


Figure 1.- SITOGA project conception.

Within the SITOGA project, we have successfully demonstrated the integration of BaTiO₃ and VO₂ technology on silicon devices with beyond state-of-the-art performance. **Electro-optical modulators** based on the developed BaTiO₃/Si technology have been for the first time demonstrated with modulation bandwidths up to 30GHz and digital data rates up to 40Gbps. **Electro-optical switching devices** with ultra-short active lengths based on the developed VO₂/Si technology have been successfully demonstrated with data transmission capabilities up to 40 Gbps. Strategies to minimize power consumption have been thoroughly analyzed and experimentally validated. The integration of the developed technology on the **IHP's silicon photonics platform (BiCMOS photonics)** has also been addressed and the roadmap beyond the project has been established. The materials technology integration into the silicon platform combined with the development of beyond state-of-the-art photonic devices is expected to pave the way towards a wide range of photonic applications. Therefore, the **exploitation of the technology** has been figured out in the context of evolving systems' requirements in telecom, datacom, spacecom and sensing markets.

1.2. Project context and objectives.

High performance information and communication (ICT) technologies, supported by strong progress in electronics, have proven as pervasive, driving forces in the world economy over the past two decades. They affect nearly every aspect of life: education, entertainment, transportation, workplace and personal communication to the basic infrastructures of our economy and society at large. One of the main driving forces behind these advances has been the big investment of the electronics industry on the silicon CMOS technology which has been translated in an impressive and continuous improvement in performance without penalizing the cost.

By contrast, until recent years, the photonic industry has been focused on different material technologies to optimize individual photonic devices: III-V compounds for lasers, lithium niobate for modulators, germanium for photodetectors or doped silica for passive optical devices. Nowadays, it is clear that a **common technological platform is a must to integrate all the above functionalities into a single photonic device**. Furthermore, a platform that uses most or all fabrication facilities used in CMOS electronics would facilitate the integration with the required electronics circuitry and reduce the cost for mass-manufacturing. At this point is where silicon photonics technology comes into play. Silicon photonics technology, also referred to as **CMOS photonics**, is currently one of the most promising platforms for enabling automated, low-cost volume manufacturing of highly integrated and complex photonic circuits mainly because the fabrication processing steps have been developed using standard CMOS fabrication infrastructure. The development of individual components has been the subject of intense research during the last decade. However, several challenges need still to be addressed for enabling the full development of commercial products.

One of the main challenges is still related to **improve the performance metrics of key photonic components, in particular active components**. The silicon material itself imposes barriers to the ultimate active performance that can be achieved and therefore the integration of new materials on silicon is emerging as an active field with the potential to generate technology breakthroughs leading to novel markets and applications. Clear examples of that are III-V compounds that have been widely investigated for solving the lack of an on-chip light source in silicon due to their well-proven lasing properties or Germanium that is the best approach for enabling photodetection in silicon at 1550 nm optical wavelengths due to its excellent properties for light absorption in the near infrared and CMOS compatibility.

The SITOGA project has addressed the integration of **transition metal oxides (TMO) materials** in the silicon photonics platform for offering **breakthrough electro-optical functionalities** due to their unique properties not present in pure silicon. Such integration combined with the development of **beyond state-of-the art photonic devices** is expected to pave the way towards a wide range of photonic applications.

TMOs comprise a very diverse and fascinating class of compounds with properties that can be tailored for a wide variety of applications. Many transition metal oxides have been prepared in bulk form or as thin films in the past several decades. However, obtaining single crystalline and high quality photonic waveguides has been a long-standing issue. The difficulty is largely related to the complex composition of TMOs, and most synthetic techniques developed in the past for nanophotonic waveguides cannot be simply applied. In fact, the benefit of using such materials is directly related to the structural quality of the crystal, so that a high quality fabrication process is a must for producing single crystal thin film.

In the SITOGA project, we have focused on two disruptive TMO materials, **barium titanate (BaTiO₃)** and **vanadium oxide (VO₂)**, as the best approaches for enabling electro-optical modulation and switching functionalities with beyond state-of-the-art performance. While BaTiO₃ is interesting for its electro-optical activity, VO₂ is being actively investigated due to the ultra-large change in refractive index which follows the electrically-driven metal-insulator-transition (MIT). Table 1 summarizes the materials properties and key enhanced capabilities offered to the silicon platform.

| | Material unique properties at 1550nm optical wavelengths | Key enhanced capabilities offered to the silicon platform |
|--------------------------|--|--|
| BaTiO₃ | <ul style="list-style-type: none"> ▪ Ultra-high Pockels coefficient ▪ Low optical losses ▪ High refractive index ▪ Bistable performance via ferroelectric domain switching. | <ul style="list-style-type: none"> ▪ Ultra-fast and linear optical phase modulation ▪ CMOS compatible drive voltages with low insertion losses ▪ Electro-optical bistable performance for non-volatile photonic devices |
| VO₂ | <ul style="list-style-type: none"> ▪ Metal-insulator-transition induced thermally, electrically or optically ▪ Ultra large change of refractive index ▪ Bistable performance via phase transition triggering. | <ul style="list-style-type: none"> ▪ Ultra-small footprint ▪ Low power consumption ▪ Electro-optical bistable performance for non-volatile photonic devices |

Table 1.- Materials targeted in the SITOGA project.

SITOGA has addressed objectives that combine material technology, advanced development of complex photonic components and manufacturing of functional demonstrators for high-impact applications. In addition, exploratory research for enabling novel functionalities have also been investigated to exploit the unique material properties and developed technology. The main objections of the SITOGA project have been the following:

- Develop the **technology** (deposition pathways and processing) of two innovative transition metal oxides (TMO) materials, **BaTiO₃** and **VO₂**, with unique properties for boosting photonic integration in silicon CMOS.
- Demonstrate **beyond state-of-the-art electro-optical modulation and switching photonic components** and develop novel electro-optical functionalities.
- **Integrate the developed material technology on the silicon CMOS platform** for large-scale manufacturing of highly integrated and complex photonic devices.
- Validate the enhanced capabilities provided to the silicon platform by means of **two functional demonstrators** and define the **roadmap for the exploitation** of the developed technology.

The **SITOGA consortium** was selected to cover the whole technology development chain from material technology to manufacturing of demonstrators driven by industrial requirements. The consortium was composed by six partners: the Universitat Politècnica de València (UPVLC) in Spain, which is the coordinator, the Centre National de la Recherche Scientifique-Institut des Nanotechnologies de Lyon (CNRS-INL) in France, the Katholieke Universiteit Leuven (KUL) in Belgium, the Leibniz Institute for Innovative Microelectronics (IHP) in Germany, IBM Research GmbH in Switzerland and DAS Photonics in Spain.

IHP is one of the main players in Europe in the CMOS manufacturing of silicon photonics devices and reference microelectronics research institute with a strong industrial commitment. Therefore, one of the main goals of the project has been the **integration of the developed material technology in IHP's existing photonic SG25_H4 BiCMOS line** to establish a clear path towards exploitation of the developed technology. With this approach, affordable access to the developed technology would be available for prototyping purposes, especially in the case of fabless SMEs, and the route for industrialization in a commercial foundry would be possible.

1.3. Main S&T results/foreground.

The **work plan of the SITOGA project has been organized into six intercorrelated work packages (WPs)** which follows the logical phases to achieve the project goals by means of a bottom-up approach.

- **WP1:** Project management.
- **WP2:** Development of material technology.
- **WP3:** Development of BaTiO₃/Si components.
- **WP4:** Development of VO₂/Si components.
- **WP5:** Silicon photonics and CMOS integration.
- **WP6:** Roadmapping and exploitation.
- **WP7:** Dissemination.

Figure 2 describes the interdependencies between the different WPs as well as the leader, participants and main objective of each WP. The main S&T achievements in the technological WPs (WP2-WP5) are summarized below.

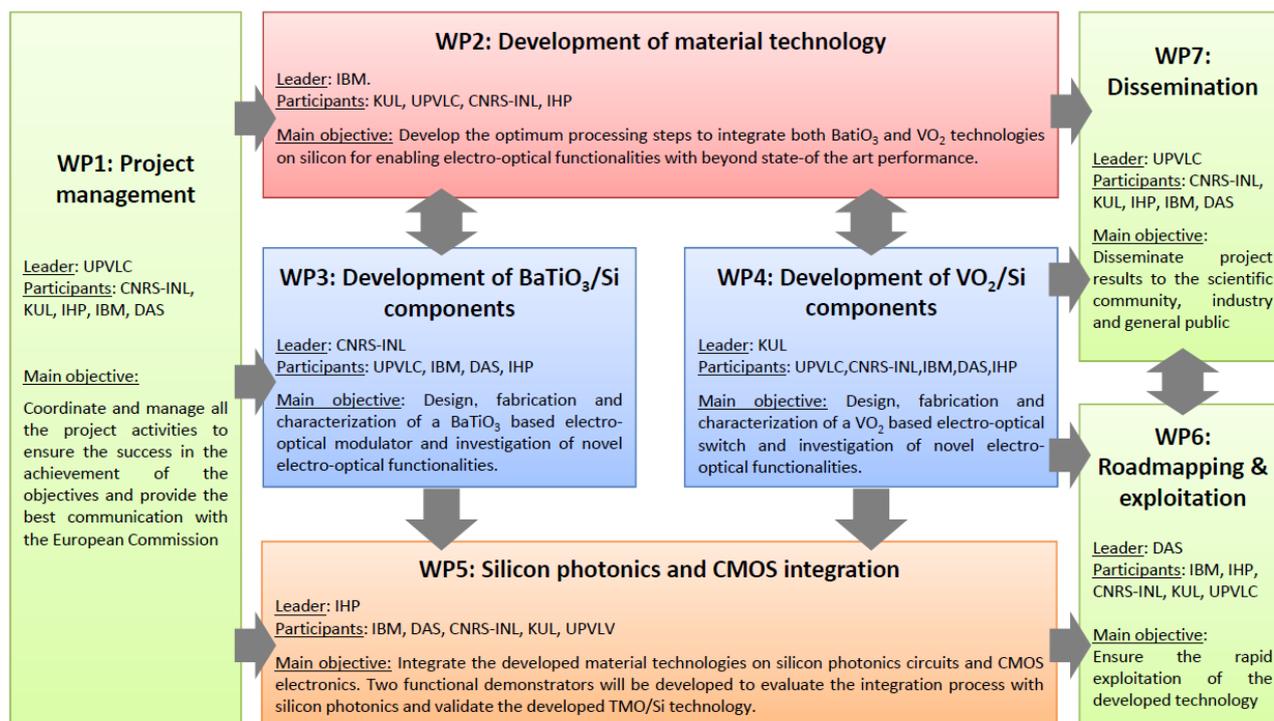


Figure 2.- Workpackage structure of SITOGA.

WP2. Development of material technology

The two material technologies, BaTiO₃ and VO₂, have been developed in this WP to fabricate the electro-optical modulator and switching device structures for WP3 and WP4 as well as the functional demonstrators for WP5.

Processes to grow BaTiO₃ (BTO) and VO₂ layers on top of SOI substrates have been successfully developed. BTO has been grown by using thin (3-4 nm thick) SrTiO₃ (STO) buffers in order to ensure good crystallinity and optimal structural quality. Molecular beam epitaxy (MBE) of STO and BTO was developed both at IBM (on 2" and 200 mm wafers) and INL (on max. 2" wafers). Furthermore, INL developed BTO growth by RF sputtering, and IBM compared BTO growth using four different deposition techniques (MBE, PVD, CVD and PLD).

Epitaxial growth of **high crystalline quality BTO thin films** has been demonstrated. The crystal quality measured via the FWHM of the rocking curve exceeds the goals set for the project (FWHM of the BTO (002) reflexion < 0.7°, see Figure 3(a)), and the surface roughness of the films (RMS ~0.3-0.5nm) is also significantly below the requirements (1nm). Furthermore, ferroelectricity has been demonstrated, and strategies, based on the control of the STO buffer thickness or on post-growth annealing, have been investigated to control the BTO ferroelectric orientation (a-axis or c-axis). Effective Pockels coefficients up to 120 pm/V have been demonstrated. The consortium has also faced up with high optical losses of more than 100dB/cm. The origin of such high optical losses has been thoroughly analyzed and several approaches have been successfully developed to reduce them to below 5dB/cm. Overall, minimization of the optical losses and control of the BTO ferroelectric domain structure remain as the main challenges to exploit the developed technology.

The growth of **high quality VO₂ films** has also been demonstrated. The deposition of VO₂ thin films was optimized following a two-step process. An amorphous vanadium oxide (VO_x) film was first deposited by MBE at room temperature and then transformed into polycrystalline VO₂ by an ex-situ annealing at moderate temperatures. Significant efforts have been devoted to optimize the annealing process to maximize the resistance change across the metal-insulator transition (MIT) and reduce the transition temperature to improve the power consumption. The growth and annealing methods developed within the project have resulted in VO₂ films with optical constants similar to the values reported in literature. Finally, doping of VO₂ with Mg has been also investigated. In this case, a decrease of the transition temperature has been observed. Remarkably, even if the change in resistance between the insulating and the metallic state is reduced as compared with the undoped case, the change in refractive index between the two phases remains considerable large.

In parallel to the optimization of the deposition processes, the process flow to fabricate the target devices has been defined and optimized by combining the facilities of the different partners (INL, KUL, IBM, UPVLC and IHP) to achieve a fast delivery time and thus increase the number of design-fabrication-characterization cycles. Concerning **BTO/Si technology**, an etching process has been developed for efficiently patterning thin BTO films thus enabling the fabrication of fully etched optical waveguides (see Figure 3(c)). Furthermore, the integration of amorphous silicon (a-Si) layer on top of BTO thin films has also been developed. UPVLC and INL have optimized two PECVD processes (based on Ar and H₂) to grow a-Si with a refractive index value close to 3.47, optical losses below 10 dB/cm and reduced stress to avoid the delamination from the BTO layer. Different techniques have been investigated to ensure a good adhesion between the a-Si and BTO layers. Concerning **VO₂/Si technology**, VO₂ etching has been successfully demonstrated by reactive ion etching. However, for the waveguide devices, a lift-process has been finally chosen and developed, which simplifies the fabrication.

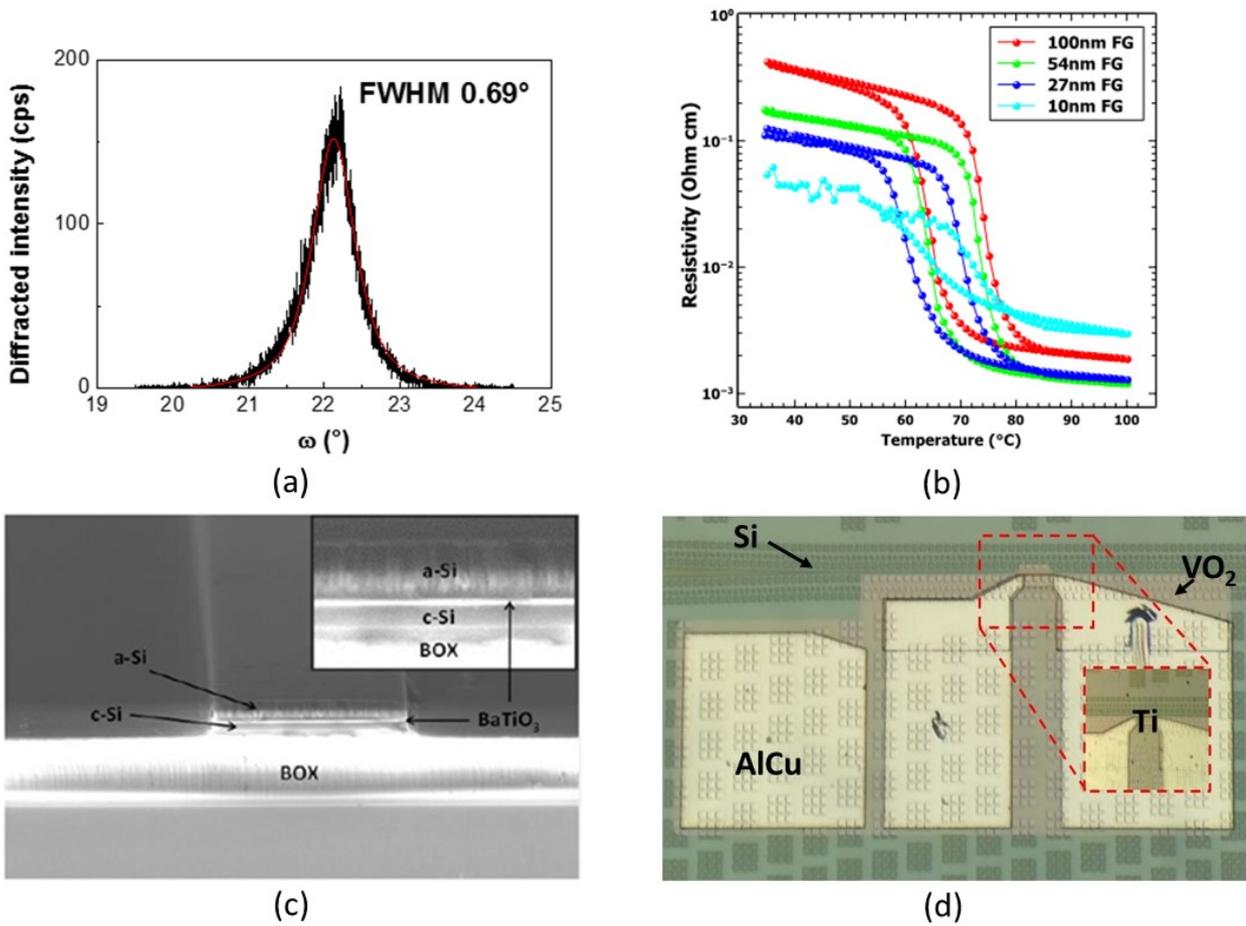


Figure 3.- (a) X-ray rocking around the [002] reflection recorded on a 50 nm thick BaTiO₃ layer grown by MBE on SrTiO₃/SOI. (b) Resistivity vs temperature characteristics recorded on VO₂ films with various thicknesses annealed in forming gas. (c) SEM cross-sectional view of a fully etched a-Si/BTO/SOI waveguide, where the developed recipe was used to etch the BTO layer. (d) Electrode with double metallization based on Ti and Al/Cu developed for thermo-optical switching the VO₂.

Finally, processes to fabricate electrodes have been developed for both BTO and VO₂ material technologies. Concerning **BTO/Si technology**, a method to estimate the relative permittivity of thin BTO films from experimental measurements has been developed. High values between 800 and 1600 have been estimated at 20 GHz. Furthermore, no substantial difference has been obtained by using BTO grown by molecular beam epitaxy and sputtering. The obtained permittivity has been used to properly design the RF electrodes for high speed modulation in hybrid BTO/Si devices. Coplanar strip-line electrodes have been fabricated and the possibility of achieving modulation bandwidths up to 40 GHz has been demonstrated. The bandwidth is limited by the microwave propagation losses and, in this case, lower losses have been obtained for BTO grown by MBE as compared to BTO grown by RF sputtering which suggest that process conditions could be optimized to minimize the dielectric losses of the BTO layer.

Concerning to the **VO₂ technology**, metallic electrodes have been deposited on top of the VO₂ film by using a lift-off process. Several electrodes configuration have been investigated to reduce the power consumption. Furthermore, an electrode with double metallization based on titanium and Al/Cu, shown in Figure 3(d), has been developed for thermo-optical switching the VO₂ in the fabricated devices.

In summary, the main results that have been achieved in WP2 are:

- Demonstration of epitaxial growth of high crystalline quality thin BaTiO₃ films on silicon and SOI substrates with very low surface roughness.
- Demonstration of the metal-to-insulator transition (MIT) response in VO₂ layers grown on silicon.
- Demonstration of an efficient BaTiO₃ etching process for thin films on silicon.
- Development of amorphous silicon technology with low optical losses, targeted refractive index and low stress.
- Development of a multi-line method to estimate the relative permittivity of thin BaTiO₃ films at RF frequencies.
- Demonstration of low loss RF travelling-wave electrodes in hybrid BaTiO₃/Si devices for high-speed modulation.

WP3. Development of BaTiO₃/Si components

The main goal of this WP has been the development of a hybrid BTO/Si electro-optical modulator device with a bandwidth above 40GHz, drive voltage below 2V, modulation length below 2 mm and insertion losses below 5dB.

The optimum **waveguide structure** to implement the proposed BTO/Si modulator was first designed and experimentally demonstrated. The half-etched waveguide structure shown in Figure 4 was chosen. A non-standard SOI substrate having 100 nm thick silicon layer was used as the optimum substrate. This geometry is more favourable since it allows achieving single mode operation and higher optical confinement than the standard 220nm thickness.

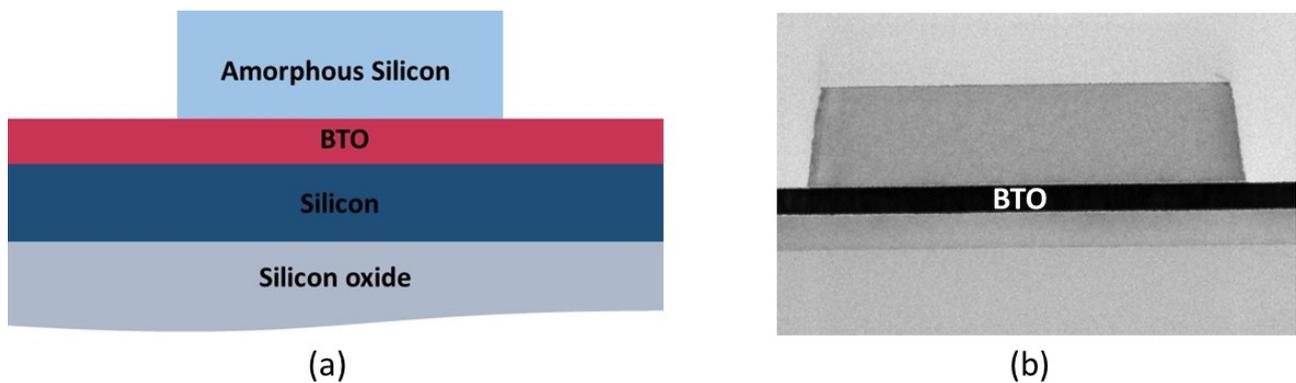


Figure 4. (a) Proposed BaTiO₃/Si waveguide structure and (b) TEM image of fabricated waveguide.

The BTO/Si electro-optical modulator based on a Mach-Zehnder (MZ) interferometer structure was then designed to meet the project specifications. The design has been focused on optimizing the V_{π} voltage but ensuring that propagation losses induced by the electrodes are negligible. Furthermore, the influence of BTO ferroelectric domain orientation on the electro-optical performance has also been extensively analyzed. Analytic expressions to calculate the V_{π} voltage have been derived for both BTO orientations and light polarizations and confirmed by simulations.

A $V\pi L$ as low as **0.27 V·cm** has been achieved in simulations for a-axis oriented BaTiO₃ and by conveniently rotating the waveguide in the horizontal plane at an optimum angle of 55° for which the electro-optical coefficient is maximized. Moreover, such study was later extended and the influence of multi-domain structure was analyzed. The control of the ferroelectric polarization orientation is therefore crucial and several fabrication approaches based on a post-deposition annealing process and the control of the SrTiO₃ buffer layer have been investigated in WP2 to achieve such control. Basic building blocks, such as multimode interference couplers (MMIs) and grating couplers, were also designed. Finally, coplanar strip-line electrodes were designed for high speed modulation beyond 40GHz and impedance matching to 50Ω based on the estimations of the relative permittivity of BTO.

The designed hybrid BTO/Si waveguide has been initially fabricated and characterized. However, unexpected high propagation losses were measured which significantly delayed the progress of the modulator fabrication. We were able to identify the sources of the losses and reduce them significantly to <5 dB/cm. Active devices were also fabricated and characterized. Several effects such as high BTO leakage and long-term drift responses were observed and investigated at DC and low modulation frequencies. Nevertheless, in the last phase of the project, we have been able to successfully demonstrate **electro-optical modulation at a very high-speed of 30GHz and data rate of 10Gbps**, and verify several key properties of the Pockels effect.

Lower efforts have been devoted to the exploratory research on **novel electro-optical functionalities**. Nevertheless, we have investigated the possibility of using the ferroelectric behaviour of BTO to fabricate non-volatile electro-optical devices. The idea is that if convenient built in electrical field is applied to the oxide layer, for instance by using asymmetric electrodes of doped substrates, the two polarization states that can be written remanently in the material by applying voltage pulses correspond to different refractive indices, so that the device can be switched in a non-volatile manner. We fully designed a non-volatile add-drop filter using this work principle, and we were able to demonstrate a hysteretic optical response of a ring resonator, unambiguously showing that the fabrication of a non-volatile electro-optical device is feasible. The last step towards its fabrication is the onset of a built-in electrical field in the oxide layer. In the end, we explored by simulation the contribution of piezoelectricity to modulation in MZM devices, which mainly contributes because it causes a change of the waveguide thickness and hence of the effective propagation index.

In summary, the main results that have been achieved in WP3 are:

- Identify the sources of high propagation losses in BaTiO₃/Si waveguides and reduce them significantly to <5 dB/cm.
- Design of a hybrid BaTiO₃/Si electro-optical MZ modulator with the target specifications.
- Demonstration of the designed BaTiO₃/Si waveguide with low optical losses.
- Demonstration of the designed BaTiO₃/Si MZ modulator with RF modulation up to 30GHz and digital data modulation up to 10 Gbps with a modulation length of only 1mm.
- Observation of the hysteretic optical response of BaTiO₃ based device, as a very last crucial stage before the fabrication of non-volatile electro-optical devices.

WP4. Development of VO₂/Si components

The main goal of this WP has been the development of a hybrid VO₂/Si electro-optical 2x2 switch device with a switching time below 1ns, power consumption below 1μW, footprint below 50 μm² and insertion losses below 1dB.

As in WP3, the optimum waveguide structure to implement the VO₂/Si switch was first chosen, designed and experimentally demonstrated. The structure, shown in Figure 5, is based on a fully etched silicon waveguide with a VO₂ film on top and it has been chosen to minimize propagation losses due to the high absorption in the VO₂ material while having enough optical confinement to achieve ultra-compact active lengths. The targeted **electro-optical 2x2 switch** has been based on an add drop microring resonator structure to achieve the target footprint. The device switches between the bar and cross states by exploiting the ultra large change of the VO₂ complex refractive index. Insertion losses is the most critical parameter as VO₂ has high absorption losses even in the insulating state. The design of the microring switch based on the VO₂/Si waveguide structure has been carried out by simultaneously optimizing the absorption loss and phase shift variation in the VO₂. In such way, insertion losses below 1.8 dB and crosstalk values above 12 dB has been achieved with a hybrid VO₂/Si waveguide of only 2.8 μm-length and TE polarization. Lower insertion losses are only possible if the imaginary part of the VO₂ refractive index in the insulating state is lowered. The optical bandwidth of the design switch is around 3.8nm that will allow a data throughput rate higher than 500Gbps. Furthermore, the throughput can be increased beyond Tbps operation by using a WDM optical signal with a wavelength spacing matched with the free spectral range of the ring resonances to simultaneously switch on and off a large number of wavelength channels.

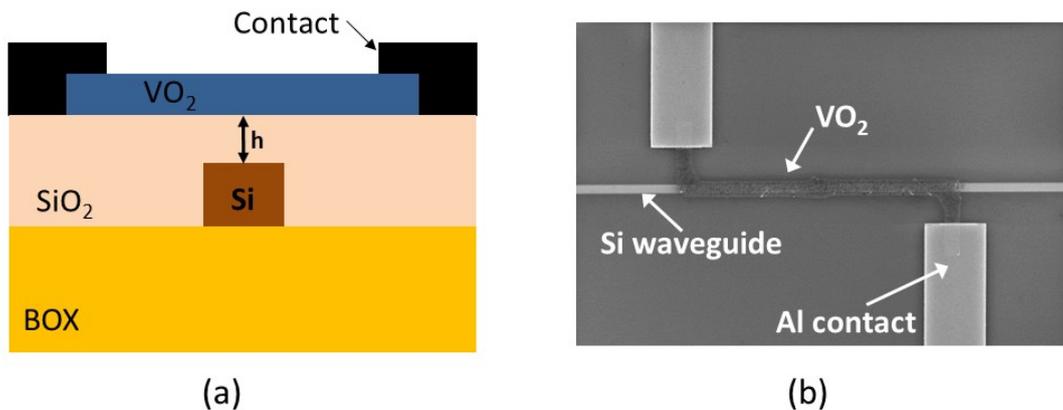


Figure 5. (a) Proposed VO₂/Si waveguide structure and (b) SEM image of one of the first fabricated devices.

The proposed hybrid VO₂/Si switching device has been successfully fabricated and characterized. We have been able to **demonstrate the metal-insulator (MIT) transition at room temperature**. The power consumption has been analyzed by using two approaches for changing the VO₂ state: electrical excitation and thermal heating. The minimum power consumption is in the mW range basically because the VO₂ becomes highly conductive in its metallic phase and an electrical current of the order of few mA is necessary to induce the phase transition. Therefore, the measured switching time is also in the μs range. Nevertheless, an **electrode based on a double metallization** has been developed and successfully demonstrated to minimize the power consumption by thermo-optical excitation. The hysteresis of the thermo-optical response has been characterized for both TE and TM polarization. A variation of optical losses above 30dB for applied electrical powers of 30mW has been demonstrated with a hybrid Si/VO₂ waveguide of only 20μm length and TM polarization.

The **influence of an external resistance** on the electro-optical switching performance has also been analyzed and experimentally characterized in devices based on switching the VO₂ by means of an electrical voltage applied between two electrodes (electrical excitation). Our results indicate that the external resistance plays a key role in the switching power consumption showing an optimum value, which depends on the dimensions of the VO₂ region between the electrodes. Therefore, **a power consumption reduction between 50% and 90%** has been demonstrated with the selection of the optimum value for the external resistance.

Finally, **novel electro-optical functionalities** have been investigated by exploiting the ultra large change of the VO₂ refractive index across the MIT. Tunable TE and TM pass polarizers based on a hybrid VO₂/Si waveguide structure have been achieved with insertion losses below 3dB. Ultra-compact electro-absorption modulators have also been proposed and designed. Furthermore, a novel modulation device with TM to TE polarization conversion has been achieved. The proposed device operates in a broadband wavelength range of 60nm with insertion losses below 0.5dB and modulation extinction ratios above 10dB. The possibility of implementing optical memories or multi-stable optical systems based on the VO₂ hysteretic performance has also been investigated.

In summary, the main results that have been achieved in WP4 are:

- Design of a 2x2 electro-optical switch based on an ultra-short VO₂/Si waveguide with insertion losses below 1.8dB, optical bandwidth of 3.8nm and footprint below 50 μm²
- Design of ultra-compact and tunable polarizers based on VO₂/Si waveguides.
- Design of a novel VO₂/Si modulation device with TM to TE polarization conversion.
- Demonstration of the metal-insulator (MIT) transition at room temperature in VO₂/Si devices by electrical excitation
- Demonstration of electro-optical switching in hybrid VO₂/Si waveguides and add-drop ring resonators by thermo-optical excitation
- Demonstration of novel approaches to minimize the power consumption

WP5. Silicon photonics and CMOS integration

The main goal of this WPs has been twofold. On one hand, the optimum integration route of the developed material technology on the silicon BiCMOS platform of IHP has been addressed. On the other hand, the target functional demonstrators have been developed.

Figure 6(a) shows a cross-section of the SG25_H4 BiCMOS technology of IHP with the possible **integration routes** of the transition metal oxides (TMO) technology. The main integration effort has been dedicated to the integration of the BTO technology. The integration of VO₂ devices has not specifically been studied due to the low temperature deposition process, which is compatible with the thermal budget in the BEOL of the BiCMOS process. The integration route of the BTO modulator has been defined and successfully proven. A more versatile integration route has also been identified that would enable the BTO integration in the lower backend. Several delays occurred during the fabrication of the silicon photonics/CMOS chips due to issues when bonding oxide layers at IBM on top of test wafers provided by IHP. Dealing with these difficulties required that partners IBM and IHP had to iteratively adjust their fabrication and bonding processes. However, the main origin of the low bonding yield was identified and the fabrication of the BTO demonstrator was finally achieved.

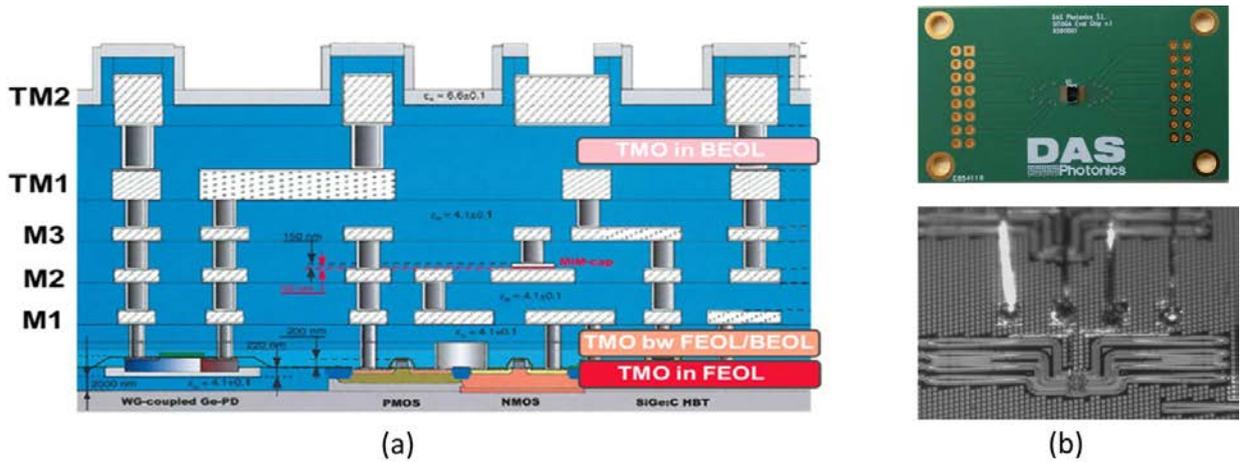


Figure 6. (a) Cross-section of the SG25_H4 BiCMOS technology of IHP with the possible integration routes. (b) Optical images of the 4x4 switching matrix interconnected to the control board by wire bonding.

The **two target demonstrators** have been (i) a 40Gbit/s DPSK transceiver with error-free performance and on-chip insertion losses below 5dB based on the BTO/Si technology and (ii) a 8x8 switching matrix with 100Gbit/s throughput and a total footprint below $3500\mu\text{m}^2$ based on the VO_2/Si technology. The two demonstrators have been designed, fabricated, and characterized. Although we could not achieve the specifications, we could show major achievements in the experimental realization of the devices.

For the **BTO/Si technology**, a working integration concept of functional BTO layers on wafers with CMOS circuitry has been developed. Electro-optical switching in BTO/Si waveguides based on the identical waveguide geometry as targeted for the demonstrator has been achieved. We successfully demonstrated modulation speeds up to 40Gbps in racetrack modulator which supposes a significant milestone for the SITOGA project. The demonstrator was also fabricated but the electro-optical characterization of the MZM transmitter was not possible due to issues in the circuit design.

For the **VO_2 technology**, we designed and fabricated 2x2, 4x4, and 8x8 switching matrices. An electronic board was also designed and fabricated to feed the switching matrix. Furthermore, the integration via wire bonding was developed. Electro-optical switching has been successfully demonstrated in the 2x2 and 4x4 matrices using the thermo-optic heater-based switching concept with a power consumption of 8mW. Furthermore, digital data transmission up to 40Gbps (limited by the available measurement set-up) has also been demonstrated in the 4x4 matrix.

In summary, the main results that have been achieved in WP5 are:

- Definition and demonstration of the optimum integration route of BTO and VO_2 materials in the SG25_H4 BiCMOS technology of IHP.
- Fabrication of the BTO/Si demonstrator and demonstration of digital modulation speeds up to 40Gbps in racetrack modulators.
- Demonstration of the routing capability of the 4x4 switching matrix based on the developed hybrid VO_2/Si optical switches with a data throughput up to 40Gbps and power consumption of 8mW.

1.4. Potential Impact

The increasing ubiquitous demand for high data rates is constantly pushing ICT technologies to their limit. Photonics has become the unique key enabler for the forecasted global data rate demand that will exceed 2.3 zettabytes/year in 2020, of which 20% correspond to mobile data, with an astounding CAGR of 22%¹. This has an enormous business impact in photonic devices, components and system vendors in the different application areas concerned, such as telecom (from long-haul to access) or datacom. In telecom, the trend is to increase the number of wavelengths employing DWDM schemes, but the more the wavelengths used, the higher the impact on consumption, footprint, complexity of the network and operating costs. This is also the case for datacom, where for large scale data centres and high-performance computing (HPC), power consumption is now one of the biggest concerns.

Advances in optical interconnects and active optical cables (AOC) through enhanced integration and parallelisation, as well as increasing the line rate to 100 Gb/s and above, as projected by various roadmaps such as the IEEE P802.3bs 400 GbE Task Force and the Infiniband Roadmap (IBTA), are required to cope with that massive data transmission rate demand. This global trend will have a direct impact in the global Silicon Photonics Market, which revenue is expected to grow up to \$1,078.9 million in 2022 at a CAGR of 22.1%, being APAC and Europe the fastest growing regions, with expected CAGRs of 27.4% and 26.1%², respectively. Therefore, it is clear that the technology developed in SITOGA may have a high potential impact on the silicon photonics market by offering access to electro-optical functionalities with improved performance.

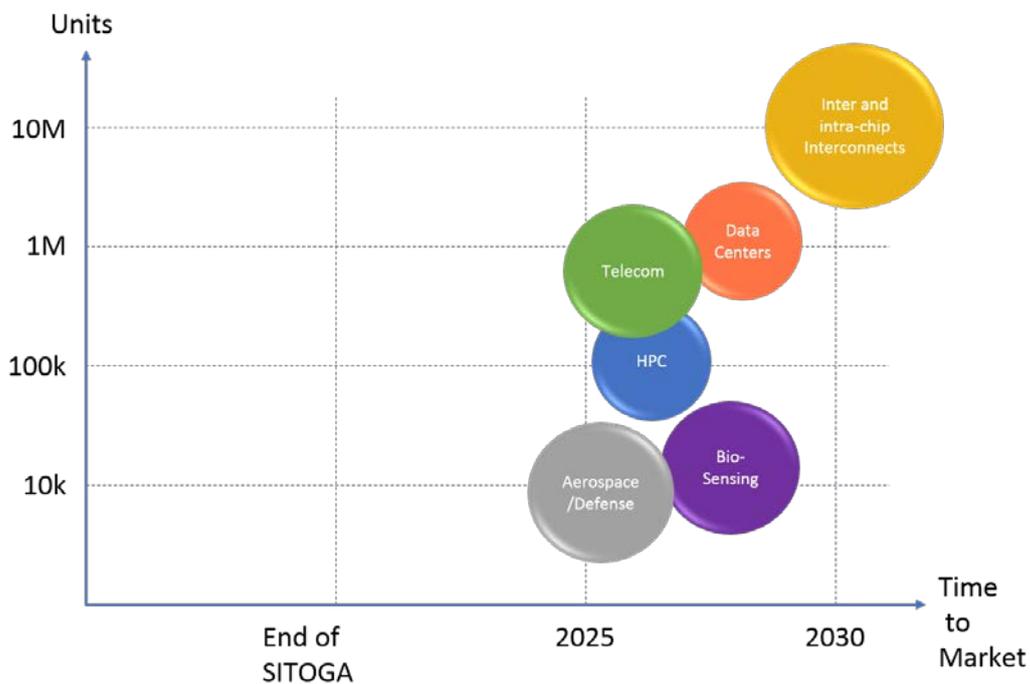


Figure 7. Markets' volume of silicon photonics for different applications that could be impacted by SITOGA technology.

¹ CISCO VNI Forecast and Methodology, 2015-2010, <http://www.cisco.com/c/en/us/solutions/collateral/service-provider/visual-networking-index-vni/complete-white-paper-c11-481360.html>

² Silicon Photonics Market by Component, Application and Geography – Global Forecast to 2022”, Markets and Markets

Besides telecom and datacom segments, significant economic impact can be generated in the satcom market, with a global revenue exceeding 100B\$/year and a CARG of 5-10% from 2010-2012. In the EU, the satcom manufacturing industry represents 50% of the space industry turnover with around 35.000 workforce. Overall, according to Euroconsult³, an average of 145 satellites with mass over 50 kg (over USD 250B market) will be launched in the period 2015-2025, and up to 900/year including planned small satellite mega-constellations. For this reason, the building blocks demonstrated could be used in the development of novel photonic based payloads. Partner DAS is pioneering the development of photonic payloads for SATCOM under ESA, EC4 and industrial contracts⁵.

In this framework, SITOGA is expected to reinforce EU's photonic industry competitiveness and leadership in photonic market sectors such as telecom, datacom and satcom, and to seize new opportunities by exploiting a novel and advantageous fabrication platform. The availability of the TMO/Si technology will strengthen and differentiate EU manufacturing base in photonics, contributing to foster innovation and creating value and jobs.

Other industrial sectors, such as health and well-being, energy efficiency or safety could also leverage on SITOGA technology to solve current technological hurdles present in the fabrication of devices and components. The global market for biosensors had a volume of 8,5 B \$ in 2012 and is expected to reach 16,8 B \$ in 2018, with an annual growth rate of 9,6. Medical applications of biosensors, including 'Point-of-Care' and 'Home Diagnostics' represent the largest share of the market, estimated 66,5% in 2012, equivalent to 5,6 B \$ in the year. These applications are expected to maintain their first position, reaching 10,8 B \$ in 2018.

The outcomes of SITOGA are fully in line with the current industry and EC diagnosis of what is required to strengthen the position of EU Photonics Industry, as described in ECSEL-JU “Multi-Annual Strategic Plan – Part B “Essential Capabilities - 1. Semiconductor Process, Equipment and Materials”⁶ and Photonics 21 “Multi-Annual Strategic Roadmap 2014-2020”, as SITOGA contributes to 1) Photonic integration, by developing a generic integration platform and foundry model, 2) Integration of photonics with microelectronics at the chip, board and system levels, 3) Technologies for cost-effective manufacturing of components and subsystems.

SITOGA has been driven by the exploitation plans of the participating members, and the intention of the partners is to transform the achievement of the project objectives in a commercial success beyond the project. However, given the early TRL of the project, commercialization is not an immediate outcome and further developments need to be carried out. High economic impact can be predicted after the demonstration of SITOGA fabrication processes and components in high added-value applications, keeping competitive costs. Considering the maturity level of the technology developed, each partner will exploit it in a different way. The exploitation activities have been focused on a realistic and application-oriented framework for SITOGA activities to ensure the shortest time to market.

³ http://www.euroconsult-ec.com/13_September_2016

⁴ The first photonic downconverter will be flying in HISPASAT H1F in 2017

⁵ H2020 project OPTIMA⁵ “Towards demonstration of photonic payload for Telecom Satellites”
http://cordis.europa.eu/project/rcn/206265_en.html

⁶ <http://www.ecsel-ju.eu/web/JU/ECSEL%20Work%20Plan.php>

During the project, the consortium has also made an extensive effort to disseminate the outcomes of the project. In the scientific scope, we have published 18 papers in scientific publications and 32 contributions to scientific conferences and workshops, some of them as invited talks. Additionally, 6 PhDs and 6 MSc have been carried out in the framework of the project. We have also organized two workshops and a session in a conference, and supported one international symposium.

We have also participated in an industry oriented post-ECOC workshop during 2016, with the participation of several members of the consortium. To maximize the dissemination impact of the developed technology, we have created a section in the website dedicated to Innovation & Technology where we have included several white papers that have been created and uploaded in the project website for free download.

Several activities have also been carried out to disseminate the project to the general public. Two press releases have been launched, one at the beginning of the project and one at the end. We have also created a LinkedIn group and IBM released a video for the Day of Photonics that had more than 550 visits⁷.

⁷ www.youtube.com/watch?v=zC3knz_WY2c

1.5. Contact.

Project's website: <http://sitoga.eu/>

Logo:



Consortium's Contact Details

| Beneficiary | Name of main contact | e-mail |
|-------------|--------------------------------|--|
| UPV | Pablo Sanchis Kilders (coord.) | pabsanki@dcom.upv.es |
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| DAS | Domenico Tulli | dtulli@dasphotonics.com |

2. Use and dissemination of foreground

Section A (public)

| TEMPLATE A1: LIST OF SCIENTIFIC (PEER REVIEWED) PUBLICATIONS, STARTING WITH THE MOST IMPORTANT ONES | | | | | | | | | |
|---|---|--------------------|--|---------------------------------|--------------------------------|------|-----------|---|--------------|
| | Title | Main author | Title of the periodical or the series | Number, date or frequency | Publisher | Year | Pages | Permanent identifier | Open Access? |
| 1 | <i>Barium Titanate (BaTiO₃) RF Characterization for Application in Electro-Optic Modulators</i> | Álvaro Rosa | - | Submitted | - | 2017 | - | - | - |
| 2 | <i>Impact of the external resistance on the switching power consumption in VO₂ nano gap junctions</i> | Luis Sánchez | - | Submitted | - | 2017 | - | - | - |
| 3 | <i>Microstructure and ferroelectricity of BaTiO₃ thin films on Si for integrated Photonics</i> | Kristy J. Kormondy | <i>Nanotechnology</i> | vol. 28, n° 7 | IOP Publishing | 2017 | 75706 | https://doi.org/10.1088/1361-6528/aa53c2 | Yes |
| 4 | <i>Low Temperature Epitaxial Barium Titanate Thin Film Growth in High Vacuum CVD</i> | M. Reinke | <i>Adv. Mater. Interfaces</i> | 1700116 | John Wiley&Sons | 2017 | | 10.1002/admi.201700116 | Yes |
| 5 | <i>Ultra-compact electro-absorption VO₂-Si modulator with TM to TE conversion</i> | Luis Sánchez | <i>Journal of Optics</i> | Volume 19, n° 3 | IOP Publishing | 2017 | | https://doi.org/10.1088/2040-8986/aa5c06 | Yes |
| 6 | <i>Electro-Optical Modulation based on Pockels effect in BaTiO₃ with a Multi-Domain Structure</i> | Pau Castera | <i>IEEE Photonics Technology Letters</i> | Vol. 28, Issue. 9, 1 May 2016 | IEEE | 2016 | 990-993 | 10.1109/LPT.2016.2522509 | Yes |
| 7 | <i>A hybrid barium titanate – silicon photonics platform for ultra-efficient electro-optic tuning</i> | Stefan Abel | <i>Journal of Lightwave Technology</i> | Vol. 34, No. 8, 15 April 2016 | The Optical Society of America | 2016 | 1688-1693 | 10.1109/JLT.2015.2510282 | Yes |
| 8 | <i>An electric-field driven Mott metal-insulator transition in correlated thin films: an inhomogeneous dynamical mean-field theory approach</i> | P. Bakalov | <i>Physical Review B</i> | Vol. 93, Issue 16, 8 April 2016 | American Physical Society | 2016 | 165112 | http://dx.doi.org/10.1103/PhysRevB.93.165112 | Yes |
| 9 | <i>Low-loss and compact silicon rib</i> | Antoine | <i>IEEE Photonics</i> | Vol. 28, No. 3, 1 | IEEE | 2016 | 299-302 | 10.1109/LPT.2015.2495230 | Yes |

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|----|---|---------------------------|------------------------------------|--|---------------------------------------|------|-------------|---|-----|
| | <i>waveguide bends</i> | <i>Brimont</i> | <i>Technology Letters</i> | <i>February 2016</i> | | | | | |
| 10 | <i>Low-Loss BaTiO₃-Si Waveguides for Nonlinear Integrated Photonics</i> | <i>Felix Eltes</i> | <i>ACS Photonics</i> | <i>Vol 3, (9)</i> | <i>ACS Publishing</i> | 2016 | 1698-1703 | 10.1021/acsp Photonics.6b00350 | Yes |
| 11 | <i>High ferroelectric polarization in c-oriented BaTiO₃ epitaxial thin films on SrTiO₃/Si(001)</i> | <i>M. Scigaj</i> | <i>Applied Physics Letters</i> | <i>Vol. 109, issue 12</i> | <i>AIP Publishing</i> | 2016 | - | http://dx.doi.org/10.1063/1.4962836 | Yes |
| 12 | <i>Analysis and design optimization of a hybrid VO₂/Silicon 2x2 microring switch</i> | <i>Luis Sánchez</i> | <i>IEEE Photonics Journal</i> | <i>Vol. 8, n° 2</i> | <i>IEEE Photonics Society</i> | 2016 | - | 10.1109/JPHOT.2016.2551463 | Yes |
| 13 | <i>Analysis of the Pockels effect in ferroelectric barium titanate thin films on Si(001)</i> | <i>Kristy J. Kormondy</i> | <i>Microelectronic Engineering</i> | <i>Volume 147, 1 November 2015</i> | <i>Elsevier</i> | 2015 | 215-218 | http://dx.doi.org/10.1016/j.mee.2015.04.041 | Yes |
| 14 | <i>Production of VO₂ thin films through post deposition annealing of V₂O₃ and VO_x films</i> | <i>Bart van Bilzen</i> | <i>Thin Solid Films</i> | <i>Volume 591, Part A, 30 September 2015</i> | <i>Elsevier</i> | 2015 | 143-148 | http://dx.doi.org/10.1016/j.tsf.2015.08.036 | Yes |
| 15 | <i>Collapse of the low temperature insulating state in Cr-doped V₂O₃ thin films</i> | <i>P. Homm</i> | <i>Appl. Phys. Lett.</i> | <i>Vol. 107, 18 September 2015</i> | <i>AIP Publishing</i> | 2015 | 111904 | http://dx.doi.org/10.1063/1.4931372 | Yes |
| 16 | <i>Influence of BaTiO₃ ferroelectric orientation for electro-optic modulation on silicon</i> | <i>Pau Castera</i> | <i>Optics Express</i> | <i>Vol. 23, Issue 12, 2 June 2015</i> | <i>The Optical Society of America</i> | 2015 | 15332-15342 | 10.1364/OE.23.015332 | Yes |
| 17 | <i>Ultra-compact TE and TM pass polarizers based on vanadium dioxide on silicon</i> | <i>Luis Sánchez</i> | <i>Optics Letters</i> | <i>Vol. 40, No. 7, April 1, 2015</i> | <i>The Optical Society of America</i> | 2015 | 1452- 1455 | http://dx.doi.org/10.1364/OL.40.001452 | Yes |
| 18 | <i>Modeling the anisotropic electro-optic interaction in hybrid silicon-ferroelectric optical modulator</i> | <i>Xuan Hu</i> | <i>Optics Express</i> | <i>Vol. 23, Issue 2, 23 January 2015</i> | <i>The Optical Society of America</i> | 2015 | 1699-1714 | 10.1364/OE.23.001699 | Yes |

TEMPLATE A2: LIST OF DISSEMINATION ACTIVITIES

| NO. | Type of activity | Main leader | Title | Date/Period | Place | Type of audience | Countries addressed |
|-----|---|-------------------------------|---|------------------------------|--------------------------|-----------------------------|----------------------|
| 1 | <i>Press release</i> | <i>Pablo Sanchis Kilders</i> | <i>Presentation of SITOGA project to the press</i> | <i>March 2014</i> | <i>Spain</i> | <i>General Public</i> | <i>Spain</i> |
| 2 | <i>Press video</i> | <i>Pablo Sanchis Kilders</i> | <i>Presentation of SITOGA. Video distributed in the metropolitan bus net (300.000 travellers per day)</i> | <i>March 2014</i> | <i>Valencia (Spain)</i> | <i>General Public</i> | <i>Spain</i> |
| 3 | <i>Social media</i> | <i>Pablo Sanchis Kilders</i> | <i>Creation of LinkedIn site: http://www.linkedin.com/groups/SITOGA-Silicon-CMOS-compatible-transition-7453878</i> | <i>March 2014</i> | <i>-</i> | <i>All</i> | <i>International</i> |
| 4 | <i>Workshop: The XXII International Workshop on Optical Wave & Waveguide Theory and Numerical Modelling</i> | <i>Xuan Hu</i> | <i>Full-vectorial finite-difference analysis of ferroelectric BaTiO₃ device</i> | <i>June 2014</i> | <i>Nice (France)</i> | <i>Scientific Community</i> | <i>International</i> |
| 5 | <i>Summer School: Silicon Photonics Summer School organized by PLAT4M project</i> | <i>Sébastien Cueff</i> | <i>Electro-optic modulation with functional oxides monolithically integrated on silicon</i> | <i>29 June – 4 July 2014</i> | <i>Ghent (Belgium)</i> | <i>Scientific Community</i> | <i>International</i> |
| 6 | <i>Conference: 16th International Conference on Transparent Optical Networks (ICTON)</i> | <i>Pablo Sanchis Kilders</i> | <i>Silicon CMOS compatible transition metal oxide technology for boosting highly integrated photonic devices with disruptive performance (invited paper)</i> | <i>7-10 July 2014</i> | <i>Graz (Austria)</i> | <i>Scientific Community</i> | <i>International</i> |
| 7 | <i>Conference: 11th International Conference on Group IV Photonics</i> | <i>Xuan Hu</i> | <i>Slot waveguide electro-optic modulator with ferroelectric oxide BaTiO₃ on Silicon</i> | <i>27-29 August 2014</i> | <i>Paris (France)</i> | <i>Scientific Community</i> | <i>International</i> |
| 8 | <i>Video: Day of photonics</i> | <i>IBM</i> | <i>www.youtube.com/watch?v=zC3knz_WY2c</i> | <i>October 2014</i> | <i>-</i> | <i>All</i> | <i>International</i> |
| 9 | <i>Workshop: Oxides for optics and photonics (co-organization)</i> | <i>CNRS, IBM</i> | <i>French network CNRS "Functional oxides: from material to device"</i> | <i>December 2014</i> | <i>Paris (France)</i> | <i>Scientific Community</i> | <i>International</i> |
| 10 | <i>Workshop: OXYFUN Workshop</i> | <i>Sébastien Cueff</i> | <i>Electro-optic modulation using hybrid silicon-ferroelectric oxide slot waveguide</i> | <i>December 2014</i> | <i>Lyon (France)</i> | <i>Scientific Community</i> | <i>International</i> |
| 11 | <i>Workshop: OXYFUN Workshop</i> | <i>Guillaume Saint-Girons</i> | <i>Heterostructures combining functional oxides and semiconductors for integrated photonics (invited)</i> | <i>December 2014</i> | <i>Lyon (France)</i> | <i>Scientific Community</i> | <i>International</i> |
| 12 | <i>Workshop: The XXII International Workshop on Optical Wave & Waveguide Theory and Numerical Modelling</i> | <i>X. Hu</i> | <i>Full-vectorial finite-difference analysis of ferroelectric BaTiO₃ device</i> | <i>2014</i> | <i>Nice (France)</i> | <i>Scientific Community</i> | <i>International</i> |
| 13 | <i>Conference: EuroMBE 2015</i> | <i>Kristy J. Kormondy</i> | <i>Barium titanate epitaxial films on silicon: structure and electro-optic properties</i> | <i>March 2015</i> | <i>Canazei (Italy)</i> | <i>Scientific Community</i> | <i>International</i> |
| 14 | <i>Conference: APS March Meeting</i> | <i>Kristy J. Kormondy</i> | <i>Integrated silicon nanophotonics: structure and electro-optic properties of BaTiO₃ on Si(001)</i> | <i>March 2015</i> | <i>San Antonio (USA)</i> | <i>Scientific Community</i> | <i>International</i> |

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|----|--|---------------------------------------|---|---------------------|--------------------|----------------------|---------------|
| 15 | Workshop: COST TO-BE Workshop | Jean Fompeyrine | Oxides for photonics (invited) | March 2015 | Aveiro (Portugal) | Scientific Community | International |
| 16 | Conference: Spring EMRS 2015 | Kristy J. Kormondy | Ferroelectric BaTiO ₃ thin films on silicon: crystalline structure and electro-optic response | May 2015 | Lille (France) | Scientific Community | International |
| 17 | Symposium: E-MRS Spring Meeting | CNRS, IBM | Multifunctional binary and complex oxides films and nanostructures for nanoelectronics and energy applications - II | May 2015 | Lille (France) | Scientific Community | International |
| 18 | Conference: 19th Conference on "Insulating Films on Semiconductors" | Kristy J. Kormondy | Analysis of the Pockels effect in ferroelectric barium titanate thin films on Si(001) | July 2015 | Udine, Italy | Scientific Community | International |
| 19 | Conference: 17th International Conference on Transparent Optical Networks (ICTON) | Pablo Sanchis Kilders | Ultra-Low Power Hybrid VO ₂ /Si Photonic Microring Switch (invited paper) | 5-9 July 2015 | Budapest (Hungary) | Scientific Community | International |
| 20 | Conference: 17th International Conference on Transparent Optical Networks (ICTON) | Pedro Rojo Romeo | Integration of functional oxides on SOI for agile silicon photonics (invited paper) | 5-9 July 2015 | Budapest (Hungary) | Scientific Community | International |
| 21 | Conference: 12th International Conference on Group IV Photonics | Pau Castera | Highly efficient BaTiO ₃ on Silicon Electro-Optic Mach-Zehnder Modulator | August 26-28, 2015 | Vancouver (Canada) | Scientific Community | International |
| 22 | Conference: 12th International Conference on Group IV Photonics | Luis Sánchez | Design of an ultra-compact hybrid VO ₂ /silicon switch | August 26-28, 2015 | Vancouver (Canada) | Scientific Community | International |
| 23 | Conference: European Conference on Optical Communication (ECOC) | Stefan Abel | Barium-titanate integrated with silicon photonics for ultraefficient electro-optical performance | 27 Sep-1Oct, 2015 | Valencia (Spain) | Scientific Community | International |
| 24 | Symposium: Symposium L, Fall EMRS 2015 | Jean Fompeyrine | Functional oxides for integrated photonics (invited) | September 2015 | Warsaw (Poland) | Scientific Community | International |
| 25 | Symposium: Symposium O, Fall EMRS 2015 | F. Eltes | Propagation losses in hybrid BaTiO ₃ /silicon photonic waveguides | September 2015 | Warsaw (Poland) | Scientific Community | International |
| 26 | Conference: TRENDOXIDES 2015 | Mariela Menghini | Exploring the metal-insulator transition in pure and doped V ₂ O ₃ (ultra)thin films | 18 Nov. 2015 | Brescia (Italy) | Scientific Community | International |
| 27 | Symposium: Symposium FF, Fall MRS 2015 | Stefan Abel | Oxides for photonics (invited) | 29 Nov- 4 Dec, 2015 | Boston (USA) | Scientific Community | International |
| 28 | Symposium: Symposium FF, Fall MRS 2015 | Jean-Pierre Locquet | The Metal-Insulator Transition in Vanadium Oxide Based Films and Heterostructures (invited) | 29 Nov- 4 Dec, 2015 | Boston (USA) | Scientific Community | International |
| 29 | Symposium: Symposium FF, Fall MRS 2015 | Kristy J. Kormondy | Ferroelectric nanophotonics : structure and electro-optic response in BaTiO ₃ /Si (001) | 29 Nov- 4 Dec, 2015 | Boston (USA) | Scientific Community | International |
| 30 | Symposium: Symposium FF, Fall MRS 2015 | Kristy J. Kormondy | Influence of tetragonal structure on the electro-optic response of BaTiO ₃ /silicon photonic structures | 29 Nov- 4 Dec, 2015 | Boston (USA) | Scientific Community | International |
| 31 | Symposium: Symposium FF, Fall MRS 2015 | Chiara Marchiori, Catherine Dubordieu | Integration of Functional Oxides with Semiconductors | 29 Nov- 4 Dec, 2015 | Boston (USA) | Scientific Community | International |
| 32 | Conference: MRS Fall Meeting | Sébastien Cuffe | Hybrid silicon-ferroelectric oxide slot waveguide for on-chip optoelectronics | 29 Nov- 4 Dec, 2015 | Boston (USA) | Scientific Community | International |

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|----|---|------------------------|---|-------------------------------|------------------------|----------------------|---------------|
| 33 | <i>Conference: SPIE Photonic West</i> | Sébastien Cueff | <i>Ferroelectric-oxide-based slot waveguides monolithically integrated on silicon for optoelectronics</i> | February 13-18, 2016 | San Francisco (USA) | Scientific Community | International |
| 34 | <i>Conference: APS, March Meeting 2016P.</i> | P. Homm | <i>Vanadium dioxide thin films prepared on silicon by low temperature MBE growth and ex-situ annealing</i> | 14-18 March 2016 | Baltimore (USA) | Scientific Community | International |
| 35 | <i>Workshop: Applications. Colloque National 2016 du GDR OXYFUN</i> | Pedro Rojo Romeo | <i>Functional Oxides for on-chip Silicon Photonics</i> | 20-23 March 2016 | Autrans-Isère (France) | Scientific Community | International |
| 36 | <i>Conference: SPIE Photonics Europe</i> | Sébastien Cueff | <i>Low-loss ferroelectric oxide slot waveguides monolithically integrated on silicon for on-chip photonics</i> | 3-7 April 2016 | Brussels (Belgium) | Scientific Community | International |
| 37 | <i>Conference: 18th European Conference on Integrated Optics</i> | Pau Castera | <i>Optimization of a BaTiO₃ on Silicon Waveguide Structure for Electro-Optic Modulation</i> | 18-20 May 2016 | Warsaw (Poland) | Scientific Community | International |
| 38 | <i>Conference: CMOS Emerging Technologies Conference</i> | Pedro Rojo Romeo | <i>Low loss hybrid Silicon/ferroelectric oxides integrated optical devices on SOI (invited paper)</i> | May 25-27, 2016 | Montreal (Canada) | Scientific Community | International |
| 39 | <i>Session: "New materials for photonics" 5th edition of the Spanish Nanophotonics Conference</i> | Pau Castera | <i>Optimization of a hybrid BaTiO₃/Si Waveguide Structure for Electro-optic Modulation</i> | June 2016 | Valencia (Spain) | Scientific Community | International |
| 40 | <i>Conference: 18th International Conference on Transparent Optical Networks (ICTON)</i> | Luis Sánchez | <i>Electrical switching in hybrid VO₂/Si photonic structures (invited paper)</i> | 10-12 July 2016 | Trento (Italy) | Scientific Community | International |
| 41 | <i>Conference: 18th International Conference on Transparent Optical Networks (ICTON)</i> | Sébastien Cueff | <i>Active and tunable nanophotonics with functional oxides on silicon (invited paper)</i> | 10-12 July 2016 | Trento (Italy) | Scientific Community | International |
| 42 | <i>Conference: 18th International Conference on Transparent Optical Networks (ICTON)</i> | Sébastien Cueff | <i>Hybrid Silicon-Ferroelectric Oxide Platform for Tunable Nanophotonics on Silicon (invited paper)</i> | 10-12 July 2016 | Trento (Italy) | Scientific Community | International |
| 43 | <i>Conference: IEEE 13th International Conference on Group IV Photonics</i> | Pau Castera | <i>Towards High-Speed Electro-Optical Performance in a Hybrid BaTiO₃/Si Mach-Zehnder Modulator</i> | 24-26 August 2016 | Shanghai (China) | Scientific Community | International |
| 44 | <i>Workshop on Memristive Networks for Future Computing</i> | Mariela Menghini | <i>The metal insulator transition and resistance switch in vanadium oxide (invited paper)</i> | 29 Ag. – 2 Sept-2016 | Ghent (Belgium) | Scientific Community | International |
| 45 | <i>Conference: E-MRS 2016 Fall Meeting</i> | Guillaume Saint-Girons | <i>Functional oxides for optical devices (invited paper)</i> | 19-22 September 2016 | Warsaw (Poland) | Scientific Community | International |
| 46 | <i>Presentation of SITOGA</i> | IBM | <i>Presentation of the project in the post-ECOC workshop "Network Systems and Devices for IoT Era"</i> | September 2016 | Karlsruhe IT (Germany) | Scientific Community | International |
| 47 | <i>Website: Sitoga website</i> | Pablo Sanchis Kilders | <i>Creation of an Innovation and Technology section in the SITOGA website, focusing the industry</i> | - | - | Industry | International |
| 48 | <i>Promotional video for the Day of Photonics</i> | IBM | https://www.youtube.com/watch?v=zC3knz_WY2c&feature=youtu.be | - | - | All | International |
| 49 | <i>Conference: SPIE Photonics West</i> | Pablo Sanchis Kilders | <i>Recent advances in hybrid VO₂/Si devices for enabling electro-optical functionalities (invited paper)</i> | January 29 – February 2, 2017 | San Francisco, USA | Scientific Community | International |
| 50 | <i>Press release</i> | UPV | <i>Press release on final results of SITOGA</i> | May 2017 | - | Media | National |