

# Sitoga

## SILICON CMOS COMPATIBLE TRANSITION METAL OXIDE TECHNOLOGY FOR BOOSTING HIGHLY INTEGRATED PHOTONIC DEVICES WITH DISRUPTIVE PERFORMANCE

### SPECIFIC TARGETED RESEARCH PROJECTS

#### Deliverable D7.3 Intermediate report in dissemination activities

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## **ABSTRACT**

This document is a summary of the scientific publications produced and other dissemination activities carried out until month 21 of the project.

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# 1. SITOGA Website

The SITOGA website (<http://www.sitoga.eu/>) was created during the first months of the project and is regularly updated. The website describes the project’s main objectives, the workplan and the list of partners, with a link to the partners’ websites. The public deliverables and the publications related to the project are also available for the general public. A section of news and events closes the public part of the website. The website has also a private area to share documents between partners.



Figure 1. Capture of the main page of [www.sitoga.eu](http://www.sitoga.eu)

The SITOGA website had more than 3000 visits during these months, distributed as shown in the charts below.

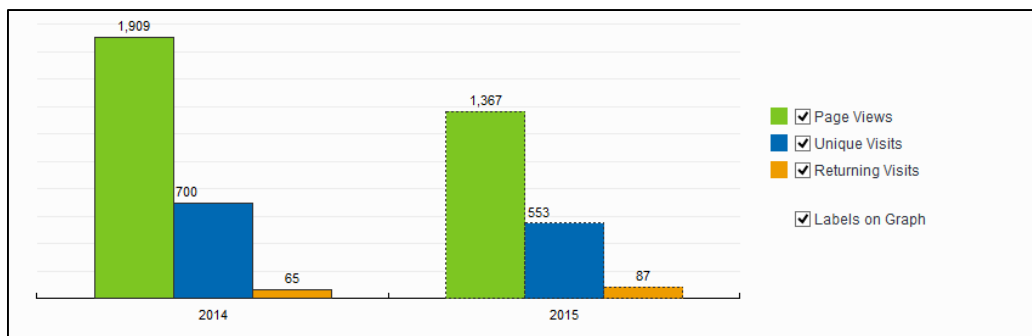


Figure 2. Visits to the website from M01 to M21.

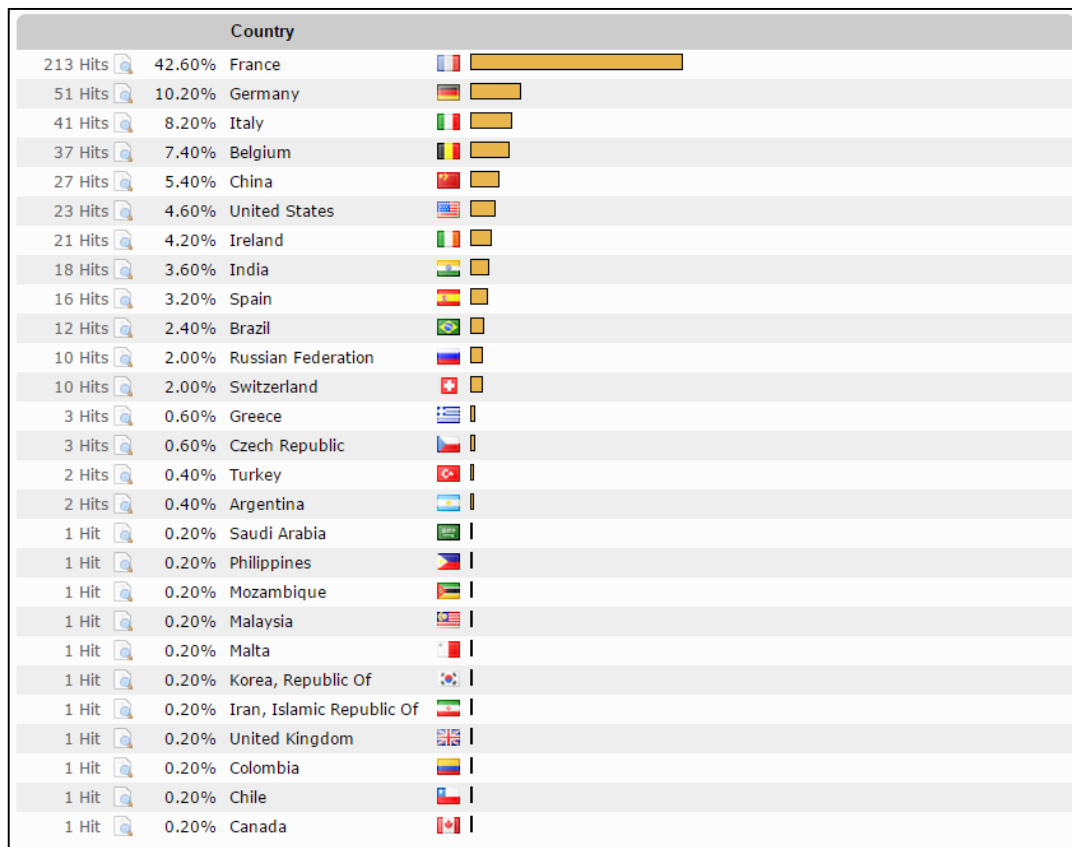


Figure 3. Origin of the visitors to the SITOGA website.

## 2. Workshops and publications

Some of the partners, Catherine Dubourdieu from CNRS-INL and Chiara Marchiori from IBM, organized a symposium on “Multifunctional binary and complex oxides films and nanostructures for nanoelectronics and energy applications - II” in the E-MRS Spring Meeting, which was held on May 2015 in Lille, France. The symposium was aimed at bringing together and bridging scientists working on different areas of synthesis, structural/physical characterization and integration of functional metal oxides for application in information and energy technologies.

Within the French network CNRS "Functional oxides: from material to device" (directed by Catherine Dubourdieu, CNRS-INL), Régis Orobchouk (CNRS-INL) co-organized the Workshop "Oxides for optics and photonics" which was held on December 2014 near Paris, France. Among the invited speakers - from both academia and industry (STMicroelectronics, Thalès TRT, HORIBA Jobin Yvon) - were two SITOGA partners (Guillaume Saint-Girons, CNRS-INL and Jean Fompeyrine, IBM Zürich).

On the other hand, we have also disseminated project results in leading international journals and conferences. The following journal publications have been carried out at the moment:

1. P. Bakalov, D. Nasr Esfahani, L. Covaci, F. M. Peeters, J. Tempere and J.-P. Locquet, “An electric-field driven Mott metal-insulator transition in correlated thin films: an inhomogeneous dynamical mean-field theory approach”, submitted to Physical Review B.

2. P. Homm, L. Dillemans, M. Menghini, B. van Bilzen, P. Bakalov, C.-Y. Su, R. Lieten, M. Houssa, J.-P. Locquet, "Collapse of the low temperature insulating state in Cr-doped V<sub>2</sub>O<sub>3</sub> thin films", submitted to Applied Physics Letters.
3. B. van Bilzen, P. Homm, L. Dillemans, C.-Y. Su, M. Menghini, M. Sousa, C. Marchiori, J. Fompeyrine, L. Zhang, J. W. Seo and J.-P. Locquet, "Production of VO<sub>2</sub> thin films through post deposition annealing of V<sub>2</sub>O<sub>3</sub> and VO<sub>x</sub> films", to be published in Thin Solid Films.
4. P. Castera, D. Tulli, A.M. Gutierrez, P. Sanchis, "Influence of BaTiO<sub>3</sub> ferroelectric orientation for electro-optic modulation on silicon", Optics Express, vol. 23, no. 12, pp. 15332-15342, 2015.
5. K. J. Kormondy, S. Abel, F. Fallegger, Y. Popoff, P. Ponath, A.B. Posadas, M. Sousa, D. Caimi, H. Siegwart, E. Uccelli, L. Czornomaz, C. Marchiori, J. Fompeyrine, A. A. Demkova, "Analysis of the Pockels effect in ferroelectric barium titanate thin films on Si(001)", Microelectronic Engineering, vol. 147, pp. 215-218, 2015.
6. L. Sánchez, S. Lechago, and P. Sanchis, "Ultra-compact TE and TM pass polarizers based on vanadium dioxide on silicon", Optics Letters, vol. 40, no. 7, pp. 1452-1455, 2015.
7. X. Hu, S. Cueff, P. Rojo Romeo, R. Orobtschouk, "Modeling the anisotropic electro-optic interaction in hybrid silicon-ferroelectric optical modulator", Optics Express, Vol. 23, Issue 2, pp. 1699-1714, 2015.

Furthermore, we have also contributed, in some cases as invited talks, in the following international conferences and workshops:

1. S. Cueff, R. Orobtschouk, P. Rojo-Romeo, B. Wague, X. Hu, R. Bachelet, P. Regreny, B. Vilquin and G. Saint-Girons, "Ferroelectric-oxide-based slot waveguides monolithically integrated on silicon for optoelectronics", submitted SPIE Photonic West, San Francisco (USA), February 13-18, 2016.
2. S. Cueff, R. Orobtschouk, P. Rojo-Romeo, B. Wague, X. Hu, R. Bachelet, P. Regreny, B. Vilquin and G. Saint-Girons, "Hybrid silicon-ferroelectric oxide slot waveguide for on-chip optoelectronics", accepted in MRS Fall Meeting, Boston (USA), 29 Nov- 4 Dec, 2015.
3. S. Abel, T. Stöferle, C. Marchiori, D. Caimi, L. Czornomaz, M. D. Rossell, R. Erni, M. Sousa, H. Siegwart, B. J. Offrein, and J. Fompeyrine, "Barium-titanate integrated with silicon photonics for ultraefficient electro-optical performance", accepted in European Conference on Optical Communication (ECOC), Valencia (Spain), 27 Sep-1 Oct, 2015.
4. P. Castera, D. Tulli, A. M. Gutierrez and P. Sanchis, "Highly efficient BaTiO<sub>3</sub> on Silicon Electro-Optic Mach-Zehnder Modulator", 12th International Conference on Group IV Photonics, Vancouver (Canada), August 26-28, 2015.
5. L. Sánchez, A. M. Gutierrez, A. Brimont and P. Sanchis, "Design of an ultra-compact hybrid VO<sub>2</sub>/silicon switch", 12th International Conference on Group IV Photonics, Vancouver (Canada), August 26-28, 2015.
6. Kristy J. Kormondy, Stefan Abel, Florian Fallegger, Youri Popoff, Patrick Ponath, Agham B. Posadas, Marilyne Sousa, Daniele Caimi, Heinz Siegwart, Emanuele Uccelli, Lukas Czornomaz, Chiara Marchiori, Jean Fompeyrine, and Alexander A. Demkov, "Analysis of the Pockels effect in ferroelectric barium titanate thin films on Si(001)," 19th Conference on "Insulating Films on Semiconductors", Udine, Italy, July 2015.
7. P. Sanchis, L.D. Sánchez, A. Griol, J. Hurtado, M. Menghini, P. Homm, B. van Bilzen, A. Brown and J.-P. Locquet, "Ultra-Low Power Hybrid VO<sub>2</sub>/Si Photonic Microring Switch", 17th International Conference on Transparent Optical Networks (ICTON), Budapest, Hungary, July 5-9, 2015 (**invited paper**).
8. P. Rojo Romeo, X. Hu, S. Cueff, R. Orobtschouk, B. Vilquin, R. Bachelet, G. Grenet, C. Dubourdieu, P. Regreny, G. Saint-Girons, P. Castera, A.M. Gutierrez, N. Sanchez, T. Angelova, P. Sanchis, S. Abel, J. Fompeyrine, "Integration of functional oxides on SOI for agile silicon photonics", , 17th

- International Conference on Transparent Optical Networks (ICTON), Budapest, Hungary, July 5-9, 2015 **(invited paper)**.
9. Kristy J. Kormondy, Stefan Abel, Florian Fallegger, Youri Popoff, Patrick Ponath, Agham B. Posadas, Marilyne Sousa, Daniele Caimi, Heinz Siegwart, Emanuele Uccelli, Lukas Czornomaz, Chiara Marchiori, Jean Fompeyrine, and Alexander A. Demkov, "Ferroelectric BaTiO<sub>3</sub> thin films on silicon: crystalline structure and electro-optic response," Spring EMRS 2015, Lille, France, May 2015.
  10. Kristy J. Kormondy, Florian Fallegger, Stefan Abel, Youri Popoff, Patrick Ponath, Agham B. Posadas, Marilyne Sousa, Daniele Caimi, Heinz Siegwart, Emanuele Uccelli, Lukas Czornomaz, Alexander A. Demkov, Chiara Marchiori, and Jean Fompeyrine, "Barium titanate epitaxial films on silicon: structure and electro-optic properties," EuroMBE 2015, March 2015, Canazei, Italy.
  11. Kristy J. Kormondy, Florian Fallegger, Stefan Abel, Youri Popoff, Patrick Ponath, Agham B. Posadas, Marilyne Sousa, Daniele Caimi, Heinz Siegwart, Emanuele Uccelli, Lukas Czornomaz, Chiara Marchiori, Jean Fompeyrine, and Alexander A. Demkov, "Integrated silicon nanophotonics: structure and electro-optic properties of BaTiO<sub>3</sub> on Si(001)," APS March Meeting, March 2015, San Antonio, USA.
  12. X. Hu, R. Orobtcouk, "Full-vectorial finite-difference analysis of ferroelectric BaTiO<sub>3</sub> device", The XXII International Workshop on Optical Wave & Waveguide Theory and Numerical Modelling, 2014.
  13. S. Cueff, X. Hu, R. Orobtcouk, P. Rojo-Romeo, R. Bachelet, P. Regreny, B. Vilquin, L. Louahadj, L. Mazet, G. Grenet, J. Penuelas, C. Dubourdieu, C. Botella, X. Letartre and G. Saint-Girons, P. Castera, N. Sanchez, T. Angelova, L. Bellieres, A. Griol, F. Lopez-Royo, A. M. Gutierrez, P. Sanchis, "Electro-optic modulation using hybrid silicon-ferroelectric oxide slot waveguide", OXYFUN Workshop, December 2014.
  14. G. Saint-Girons, S. Cueff, B. Meunier, X. Hu, L. Louahadj, L. Mazet, R. Orobtcouk, P. Rojo-Romeo, R. Bachelet, B. Vilquin, P. Regreny, N. Chauvin, G. Grenet, J. Penuelas, A. Danescu, C. Dubourdieu, X. Letartre, G. Renaud, V. Favre-Nicolin, N. Blanc, T. Zhou, M. Silly, F. Sirotti, L. Largeau, G. Agnus, V. Pillard, D. Le Bourdais, P. Lecoeur, "Heterostructures combining functional oxides and semiconductors for integrated photonics", OXYFUN Workshop, December 2014 **(invited paper)**
  15. P. Sanchis, L. Sánchez, P. Castera, A. Rosa, A. M. Gutierrez, A. Brimont, G. Saint-Girons, R. Orobtcouk, S. Cueff, P. Rojo-Romeo, R. Bachelet, P. Regreny, B. Vilquin, C. Dubourdieu, X. Letartre, G. Grenet, J. Penuelas, X. Hu, L. Louahadj, J.-P. Locquet, L. Zimmermann, C. Marchiori, S. Abel, J. Fompeyrine, and A. Hakansson "Silicon CMOS compatible transition metal oxide technology for boosting highly integrated photonic devices with disruptive performance", 16th International Conference on Transparent Optical Networks (ICTON), Graz, Austria, July 7-10, 2014 **(invited paper)**.
  16. X. Hu, R. Orobtcouk, S. Cueff, P. R. Rojo Romeo, P. Regreny, R. Bachelet, L. Mazet, L. Louahadj, Ramah Moalla, C. Dubourdieu, B. Vilquin, G. Saint Girons, P. Castera, N. Sanchez, T. Angelova, A. Griol, A. M. Gutierrez, P. Sanchis "Slot waveguide electro-optic modulator with ferroelectric oxide BaTiO<sub>3</sub> on Silicon", 11th International Conference on Group IV Photonics, Paris (France), August 27-29, 2014.
  17. Sébastien Cueff, Xuan Hu, Régis Orobtcouk, Pedro Rojo Romeo, Romain Bachelet, B. Vilquin, M. Hayes, C. Dubourdieu, P. Regreny, G. Grenet, Guillaume Saint-Girons, Pau Castera, Nuria Sanchez, Todora Angelova, Laurent Bellieres, Amadeu Griol, Francisco López, Ana M. Gutierrez, Pablo Sanchis, "Electro-optic modulation with functional oxides monolithically integrated on silicon", Silicon Photonics Summer School organized by PLAT4M project, June 29-July 4, 2014.

## 4. Other dissemination activities

The following dissemination activities have also been carried out:

- A press release was launched at the beginning of the project by UPVLC (project coordinator). The press release appeared in more than 20 media in Spain and also on the Nanotechnology Now website, as shown in the left side of Figure 4, which covers not only general public but also academic and industrial communities. Furthermore, a video was also filmed and disseminated by UPVLC-TV. The video appeared for instance in the public urban bus network of the city of Valencia, as shown in the right side of Figure 4, which transports a mean of 300.000 travelers per day.



Figure 4. Dissemination of press release of SITOGA project.

- A LinkedIn group of the SITOGA project (<http://www.linkedin.com/groups/SITOGA-Silicon-CMOS-compatible-transition-7453878>) has been created. A capture is shown in Figure 5. Project main findings are disseminated through this channel. Furthermore, this group is also intended as a reference site to share any information and news related with Transition Metal Oxides (TMO) on silicon technology for photonic applications. On the upper right corner of SITOGA website, a link to the Linked-In group has also been added.



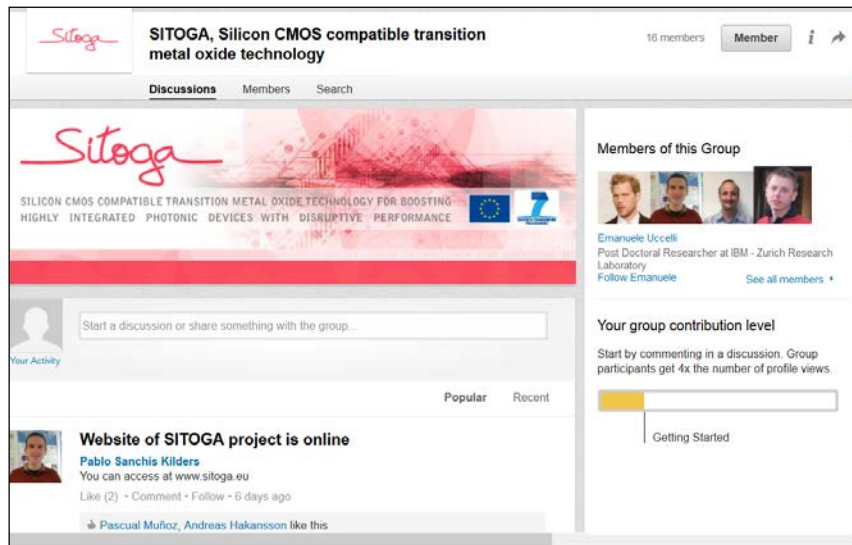


Figure 5. Capture of LinkedIn group of the SITOGA project.

- A specific section to Innovation and Technology has been created in the SITOGA website (in Documents) with two white papers describing BaTiO<sub>3</sub>/Si and VO<sub>2</sub>/Si technologies and their impact for photonic applications. The two white paper are annexed to this report.
- We are in contact with the PHOXTROT European Project (<http://www.phoxtrot.eu>) for organizing a joint workshop in 2016. The PHOXTROT project has a strong industrial consortium focused on high performance computing which could benefit from the technology that is being developed in SITOGA.

## 5. Conclusions

The SITOGA website is regularly updated with all the dissemination information and activities related with the project, which includes publications, public deliverables and related publications repositories. In term of publications, we have contributed with 24 publications (3 submitted) in international journals, conferences and workshops. Several invited talks have also been given.

# Annex I: White papers on BaTiO<sub>3</sub>/Si technology

# Annex II: White papers on VO<sub>2</sub>/Si technology