Neuro-augmented 112Gbaud CMOS plasmonic transceiver platform for Intra- and Inter-DCI applications

D7.10 Final project communication kit

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1 Executive Summary

The document demonstrates the final communication kit generated after the end of the NEBULA, i.e. the final narrative text highlighting the main technology achievements succeeded within the project, the project factsheet, the project presentation, the final press release announcing the project end, a brochure, the dedicated website, and social media accounts. The narrative text targets a general audience and focuses on the technical achievements as well as on the economical and societal benefits for the EU. Additionally, updates on the newsletter and the website of NEBULA were included in this deliverable.

European Commission and the Photonics Public Private Partnership (Photonics 21) have been cited in all public dissemination efforts and may use the material of the kit for their own purposes.

2 Introduction

2.1 Purpose of this document

The objective of this deliverable is to present the final project communication kit, i.e. the narrative text showcasing the main achievements of NEBULA, the factsheet, the short project presentation, the final project press release, the brochure, the website, and the social media accounts for the NEBULA project. The updates on the NEBULA website and newsletter, along with recent activity in publications and social media have been included in this deliverable.

2.2 Document structure

The present deliverable is split into the following major parts:

- Final NEBULA narrative text
- NEBULA communication kit
- Factsheet
- Project presentation
- Final Press release
- Brochure
- Website
- Social media accounts
- Announcements
- Newsletter series updates

2.3 Audience

This content of this document is public.

3 Final NEBULA narrative text for the general public

3.1 About NEBULA

The transmission of data is the backbone of our modern society and a cornerstone of the economy since all present-day activities, i.e. Internet, Social Media, Cloud Computing, Software Platforms etc., are becoming more information-oriented day by day. As people and businesses get connected, more and more of their everyday life and work has gone online driving the requirements for data transmission and processing to higher limits every single day. This growing tsunami of data is being transmitted through optical fibers, which form the optical networks around the world, and routed (stored, managed, disseminated) via Data Centers (DC) distributed physically all over the world. Data is being exchanged both between different DCs and within the same DC facility, the so called "*Inter-DC*" and "*Intra- DC interconnection distances*" respectively. These hyperscale DCs are currently expanding following a distributed model that consists of smaller DCs. This gradually transforms the requirements for inter-DC and intra-DC connectivity calling for the development of *Optical Transceiver modules*, the devices responsible for data exchange through optical fibers between the servers. Nevertheless, different requirements by different connections impose the adoption of different technologies in terms of speed, energy efficiency and cost for intra- and inter-DCI transceiver modules.

The **H2020 NEBULA project** envisions to transform the *Silicon Nitride (SiN) photonic integration platform* into a low-cost, robust and high-speed versatile platform for optical transceiver development and to equip it with *Complementary Metal-Oxide Semiconductor (CMOS)-compatible Plasmonic Modulators, Thermal Stabilization Systems, High-speed Photodiodes co-integrated with Semiconductor Optical Amplifiers (SOA-PDs)* and *Neuro-augmented Digital Signal Processing (DSP)* capabilities realized completely in the optical domain. NEBULA will highlight its technology's unrivaled combination of benefits by deploying and demonstrating two optical transceiver prototypes addressing both intra- and inter-DCI optical communication requirements:

- **For intra-DCI interconnection:** NEBULA aims to develop an 8-channel *Optical Transmitter* prototype co-packaged with an electronic *Application-specific Integrated Circuit (ASIC)* for operation in the O- (1260-1360 nm) operational band of optical communications, delivering a 1.6 Tb/s (8 channels × 200 Gb/s) aggregate bandwidth capacity with up to 37% in energy savings for Intra-DCI applications. Co-packaging refers to the technology where the Electrical-to-Optical transformation of the signal is carried out directly at the core electronic ASIC of the switches interfaced with optical transceivers and which is responsible for data exchange and routing between the servers.
- **For inter-DC interconnection:** NEBULA aims to develop also an 8-channel *Optical Transmitter* prototype for coherent operation in the C- (1530-1565 nm) operational band of optical communications, delivering an aggregate bandwidth capacity of 3.2 Tb/s (8 channels × 400 Gb/s) with up to 93% in energy savings for inter-DC applications. NEBULA will also develop a 1-channel *Neuro-augmented Receiver Circuit (NARC)*-based Receiver that will rely on a 2-stage *optical & electrical Neuromorphic Processing* (NP) for the processing of the coherent signal.

In the following section, the NEBULA key technology terms highlighted above are further explained for the general public:

- **Silicon Nitride (SiN) photonic integration platform:** This refers to the integration platform for the realization of the photonic integrated circuits (or PICs) of the transceivers. Various platforms for photonic integration exist based on various transparent optical materials: Silicon (Si), Silicon Nitride (SiN), Indium

Phosphide (InP), Polymer, Silica (SiO_2), Lithium Niobate ($LiNbO_3$) etc. Each integration platform comes with advantages and disadvantages. SiN is selected in NEBULA as the platform of choice among the others due to its low-cost, low-loss, CMOS-compatibility and other useful credentials.

- **Complementary Metal-Oxide Semiconductor (CMOS)-compatible:** This refers to the manufacturability of the photonic integrated circuits by means of the standard process technology in state-of-the-art CMOS fabs. Employing "*CMOS-compatible*" processes is a key concept since it allows to manufacture Silicon Photonic products, both at high volumes in existing CMOS-fabs, which were used for many decades now in the manufacturing of electronic integrated circuits.
- **Plasmonic modulators:** This refers to the technology used for the realization of the NEBULA modulators, i.e. the devices that are used to imprint the data (in electrical form) onto the transmitted light beam. The NEBULA plasmonic modulators will be co-integrated on the SiN photonic platform, yielding in this way the so-called *Plasmo-photonic Integrated Circuits (PPICs)*. "*Plasmonics*" is essentially the technology that allows the coupling of light to charges (like electrons) in thin metal films. In full correspondence to photons that is Electromagnetic Oscillations, plasmons are the oscillations of the free electron plasma on the metal surfaces. Moving from photons to plasmons allows for breaking the optical diffraction limit into subwavelength dimensions for further miniaturization of PPICs by enabling strong light-matter interaction. In simple words, *Plasmonics* is the way to make more efficient, ultra-fast and way smaller modulator devices (compared to pure photonic modulators) for our optical transmitters. It should be noted that the noble metals, like Gold and Silver, feature the best plasmonic properties in terms of performance, however they are not CMOS-compatible and thus not mass manufacturable. In NEBULA we are trying to come as close as possible to these metrics working with CMOS-metals, like Copper, targeting low-cost in full-scale mass production.
- **Thermal Stabilizer Systems:** This refers to the stabilization system for the optical transceivers. As Optical Transceiver modules are closely packed together in the harsh environment of Datacenters, NEBULA will deploy a Thermal Stabilization System for the Plasmonic modulators that will comprise sensors and actuators for tuning the modulators to the optimum working point. These novel sensors will be co-integrated with the plasmonic modulators on the same chip for simplification of packaging leading to lower overall cost of the final product.
- **High-speed Photodiodes co-integrated with Semiconductor Optical Amplifiers (SOA-PDs):** This refers to a subsystem of the NEBULA Receiver. NEBULA targets to deploy a co-integrated device based on III-V materials that will combine a Semiconductor Optical Amplifier (SOA) and a Photodiode (PD) on the same structure. This will allow for increased sensitivity by co-integrating the amplification stage (the SOA) just before the detection stage (the PD) on the same structure. The SOA also feature a nonlinear response that usually is unwanted since it leads to signal degradation during reception. However, in NEBULA this nonlinearity is a big plus and is exploited by the Neuro-Augmented Circuit.
- **Neuro-augmented Digital Signal Processing (DSP):** This refers to the digital signal processing technique that is targeted to be performed by the NEBULA coherent Receiver. In coherent reception, the signal is properly processed with DSP techniques so as to remove the impairments of the transmission channel on the signal, i.e. signal quality degradation for reduced error count. Until now, this is realized by processing the signal in dedicated *Application-specific Integrated Circuits (ASICs)* in the electronic domain. NEBULA targets to implement *Optical DSP* on the incoming signal by relying on Machine Learning in the optical domain, such

as Optical Neuromorphic Processing (NP) with the exploitation of a *Photonic Reservoir Network*. In addition to the *Photonic Reservoir Network*, two *Neuromorphic Weighting Stages* with optical and electrical weighting capability, respectively, and the SOA-PD non-linear behavior come to fill in the puzzle of neuromorphic processing elements on the way to replace electronic DSP processes. This is where the terms "*Neuro(morphic)-augmented Digital Signal Processing*" and "*Neuroaugmented Receiver Circuit (NARC)*" originate for the NEBULA description.

By the end of NEBULA, the project consortium achieved major scientific breakthroughs paving the way towards the invasion of plasmo-photonic technology inside the transceiver market and the broad application of photonic reservoir computing for DSP and equalization purposes. The greatest breakthroughs that were achieved were the following:

- **The heterogeneous integration of low-loss Au plasmonic ferroelectric phase shifters with passive SiN waveguides.** The interfacing of the best modulating and passive platforms opens the path for a wide variety of applications apart from optical interconnects and computing, being the focus of this project.
- **The demonstration of polarization insensitive ultra-low-loss I/O couplers on the thick SiN platform.** This major addition to the PDK of Ligentec outperforms most already existing devices and will enable wafer measurements without the hinderance caused by increased fiber-to-chip coupling losses.
- **The realization of the first SiN/BTO plasmo-photonic Mach-Zehnder modulator enabling 216Gbaud 2-PAM and 128Gbaud 4-PAM Signal Transmission in the C-band.** This is the fastest modulator on SiN to date and constitutes one of the few electro-optic modulators on SiN.
- **The realization of the first pure SiN and SiN/BTO photonic integrated circuits for optical reservoir assisted 28Gbaud NRZ equalization and 28Gbaud QPSK DSP purposes.** This removes a large power consumption burden induced by the normally utilized electronics in intra-DC and inter-DC communications and improves the signal quality.
- **The exposition of a 200Gb/s PAM-4 travelling-wave SiGe BiCMOS transimpedance amplifier assembled with Si-photonic Ge photodetector consuming solely 2.5pJ/bit**. This electro-optic receiver element will be the foundation towards 200Gb/s per lane opto-electronic front ends and the upcoming 800G and 1.6G transceivers.

3.2 Publications

NEBULA project has been present in the following publications, including **in total 47 conference publications and 36 journal publications** as estimated on the 8th of November 2023.

Conferences

1. "Pockels coefficients in thin-film barium titanate and lithium niobate up to 300 GHz. In 2023 Conference on Lasers and Electro-Optics", Chelladurai, D., Kohli, M., Horst, Y., Winiger, J., Moor, D., Blatter, T., & Leuthold, J., (CLEO) (pp. 1-2) IEEE (2023, May).
2. D. Petousi et. al., Workshop on "Integration of novel materials into silicon photonics", 21-22 November 2022, Aachen, Germany
3. "Integrated Photonic Sigmoid Activation Function at 10 Gbaud/s for Photonic Neural Networks", T. Chrysostomidis et. al., CLEO: Science and Innovations. Optica Publishing Group, 2023.

4. "Low-Power BTO-on-SiN MZI Weights for Neuromorphic Photonics", T. Chrysostomidis et. al., European Conference on Optical Communications (ECOC), 2023.
5. "Physics-inspired End-to-End Deep Learning for High-Performance Optical Fiber Transmission Links", I. Roumpos et. al., CLEO: Science and Innovations. Optica Publishing Group, 2023.
6. "Photonic Reservoir Computing for Wavelength Multiplexed Nonlinear Fiber Distortion Mitigation", E. Gooskens et. al., 2023 IEEE Silicon Photonics Conference (SiPhotonics), Washington, DC, USA, 2023, pp. 1-2, (DOI: 10.1109/SiPhotonics55903.2023.10141896).
7. "High Efficiency/High Bandwidth Preamplified Receiver for High-Speed Networks", C. Caillaud et. al., European Conference on Optical Communications (ECOC), 2023.
8. "A 100 GBd PAM-4 Optical Receiver using a SiGe BiCMOS Traveling-Wave EIC and a Silicon Photonic Ge Photodetector", J. Declercq et. al., European Conference on Optical Communications (ECOC), 2023.
9. "Low-Complexity Balanced Quasi-Coherent Receiver with Integrated 2x2 MMI Balanced Photodiode and TIA for 50G PON", C. Wang et. al., European Conference on Optical Communications (ECOC), 2023.
10. "A memristor-controlled multilevel non-volatile phase shifter for photonic integrated circuits", Ludovico Carraria Martinotti et. al., European Conference on Integrated Optics (ECIO) 2023, Twente, Netherlands.
11. "200 Gbit/s Barium Titanate Modulator Using Weakly Guided Plasmonic Modes", D. Chelladurai et. al., 2023 Optical Fiber Communications Conference and Exhibition (OFC). IEEE, 2023.
12. "BTO-based O-band Sub-Volt CMOS Compatible Plasmonic Racetrack Modulator on Si3N4", D. Chatzitheocharis et. al., Frontiers in Optics + Laser Science (FiO-LS) 2022, Rochester, New York (USA).
13. "Improving Noise Resilience in End-to-End Deep Learning Optical Fiber Transmission Links", L. De Marinis et. al., Asia Communications and Photonics Conference (ACP) 2022, Shenzhen, China.
14. "Photonic Reservoir Computing for Nonlinear Equalization of 64-QAM Signals with a Kramers-Kronig Receiver", S. Masaad et. al., European Conference on Optical Communication (ECOC) 2022, Basel, Switzerland.
15. "Coupling interfaces between SiN photonic and CGSiN plasmonic waveguides", L. Damakoudi, D. Ketzaki, D. Chatzitheocharis, G. Patsamanis and K. Vyrsokinos, in META 2022
16. "Plasmonic slot ferroelectric MZIR modulator on Si3N4 in the O-band", D. Chatzitheocharis et. al., European Conference on Integrated Optics (ECIO) 2022
17. "Performance comparison of polarization rotator designs on 800 nm thick silicon nitride platform", G. Patsamanis et. al., European Conference on Integrated Optics (ECIO) 2022
18. "Temperature Tolerant On-Chip WDM Silicon Photonic Transmitter and AWGR-based Routing Interconnects.", I. Roumpos et. al., Optical Fiber Communication Conference. Optica Publishing Group, 2022.
19. "Experimental Demonstration of an All-Optical 2-bit Address Router Look Up Table", T. Moschos et. Al., European Conference on Optical Communication (ECOC) 2022.
20. "Efficient Polarization-Insensitive O-Band Grating Couplers for Silicon Nitride", Manuel Kohli, Daniel Chelladurai, Tatiana Buriakova, David Moor, Marco Eppenberger, Michael Zervas, Yuriy Fedoryshyn, Ueli Koch, and Juerg Leuthold, Advanced Photonics Congress 2022 accepted
21. "216 GBd Plasmonic Ferroelectric Modulator Monolithically Integrated on Silicon Nitride", Manuel Kohli, Daniel Chelladurai, Andreas Messner, Yannik Horst, David Moor,

Joel Winiger, Tobias Blatter, Tatiana Buriakova, Clarissa Convertino, Felix Eltes, Michael Zervas, Yuriy Fedoryshyn, Ueli Koch, and Juerg Leuthold, ECOC 2022 accepted
22. "Electro-Optic Frequency Response of Thin-Film Barium Titanate (BTO) from 20 to 270 GHz", Daniel Chelladurai , Manuel Kohli, Yannik Horst, Marco Eppenberger, Laurenz Kulmer, Tobias Blatter, Joel Winiger, David Moor, Andreas Messner, Clarissa Convertino, Felix Eltes, Yuriy Fedoryshyn and Juerg Leuthold, CLEO Europe 2022 accepted
23. "Is There an Ideal Plasmonic Modulator Configuration?", Tobias Blatter, Yannik Horst, Wolfgang Heni, Christos Pappas, Apostolos Tsakyridis, George Giamougiannis, Marco Eppenberger, Manuel Kohli, Ueli Koch, Miltiadis Moralis Pegios, Nikos Pleros and Juerg Leuthold, ECOC 2022 accepted
24. "Enhanced Stability of Resonant Racetrack Plasmonic-Organic-Hybrid Modulators", Marco Eppenberger, Bertold Ian Bitachon, Andreas Messner, Wolfgang Heni, David Moor, Laurenz Kulmer, Patrick Habegger, Marcel Destraz, Eva De Leo, Norbert Meier, Nino Del Medico, Claudia Hoessbacher, Benedikt Baeuerle, Juerg Leuthold, OFC 2022
25. "Plasmonic Racetrack Modulator Transmitting 220 Gbit/s OOK and 408 Gbit/s 8PAM", Marco Eppenberger, Bertold Ian Bitachon, Andreas Messner, Wolfgang Heni, Patrick Habegger, Marcel Destraz, Eva De Leo, Norbert Meier, Nino Del Medico, Claudia Hoessbacher, Benedikt Baeuerle, and Juerg Leuthold, ECOC 2021
26. "100 Gbit/s NRZ Data Modulation in Plasmonic Racetrack Modulators on the Silicon Photonic Platform", Andreas Messner, Benedikt Baeuerle, Wolfgang Heni, Eva De Leo, Joel Winiger, Patrick Habegger, Marco Eppenberger, Ueli Koch, Delwin L. Elder, Larry R. Dalton, Juerg Leuthold, ECOC 2020
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29. "Linear Burst-Mode Receivers for DSP-Enabled Passive Optical Networks", X. Yin, G. Coudyzer et al., Invited in 2021 Optical Fiber Communications Conference and Exhibition (OFC), 2021, pp. 1-3.
30. "Transceiver circuits for high-baudrate optical interconnects", J. Bauwelinck et al., SPIE OPTO, 2022.
31. "Prospects for photonic implementations of neuromorphic devices and systems", B. J. Offrein, J. Geler-Kremer, J. Weiss, R. Dangel, P. Stark, A. Sharma, Stefan Abel and F. Horst, IEEE International Electron Devices Meeting (IEDM) 2020, (Invited)
32. "Beyond Moore's Law: The role of analog signal processing for neuromorphic computing" B.J. Offrein, IEEE Photonics Conference (IPC) 2020, (Invited)
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46. "Demonstration of Low-Latency ETH-switched DataCenter and 5G Fronthaul Networks Using the 1024-port Hipolaos Optical Packet Switch", G. Giamougiannis et al., Proceedings of the European Conference in Optical Comminications (ECOC) 2020
47. "Electronics-photonics co-design for robust control of optical devices in dense integrated photonic circuits", F. Toso et al., 2021 IEEE Custom Integrated Circuits Conference (CICC), 2021, pp. 1-8

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1. "Plasmonic, photonic, or hybrid? Reviewing waveguide geometries for electro-optic modulators", Messner, A., Moor, D., Chelladurai, D., Svoboda, R., Smajic, J., & Leuthold, J., APL Photonics, 8(10), (2023).
2. "PLD Epitaxial Thin-Film BaTiO3 on MgO− Dielectric and Electro-Optic Properties", Winiger, J., et. al., Advanced Materials Interfaces: 2300665.
3. "Time-Multiplexed Control of Programmable Silicon Photonic Circuits Enabled by Monolithic CMOS Electronics", F. Zanetto et. al., Laser & Photonics Reviews (2023): 2300124, (DOI: 10.1002/lpor.202300124).
4. "Unconventional Monolithic Electronics in a Conventional Silicon Photonics Platform", F. Zanetto et. al., IEEE Transactions on Electron Devices (2023): (DOI: 10.1109/TED.2023.3304268).
5. "Timescale dependent sign of amorphous titanium dioxide thermo-optic coefficient", J. C. Weeber et. al., Optical Materials Express (2023) (DOI: 10.1364/OME.496559).
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10. "Plasmonic Ferroelectric Modulator Monolithically Integrated on SiN for 216 GBd Data Transmission", M. Kohli et. al., Journal of Lightwave Technology (2023) (DOI: 10.1109/JLT.2023.3260064).
11. "Long term experimental verification of a single chip quantum random number generator fabricated on the InP platform", T. Chrysostomidis et. al., EPJ Quantum Technology 10.1 (2023): 5.
12. "Inline photothermal surface plasmon detector integrated in titanium dioxide waveguides", Martinez, Andres, et al., IEEE Journal of Quantum Electronics (2023)
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19. "Design and Optimization of a Compact Ultra-Broadband Polarization Beam Splitter for the SCL-Band Based on a Thick Silicon Nitride Platform", G. Patsamanis, D. Ketzaki, D. Chatzitheocharis and K. Vyrsokinos, Photonics, 9(8), 552 (2022)
20. "Temperature and wavelength drift tolerant WDM transmission and routing in on-chip silicon photonic interconnects.", I. Roumpos et. al., Optics Express 30.15 (2022): 26628-26638.
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22. Design and synthesis of chromophores with enhanced electro-optic activities in both bulk and plasmonic–organic hybrid devices, Huajun Xu, Delwin L. Elder, Lewis E. Johnson, Wolfgang Heni, Yovan de Coene, Eva De Leo, Marcel Destraz, Norbert Meier,Wouter Vander Ghinst, Scott R. Hammond, Koen Clays, Juerg Leuthold, Larry R. Dalton and Bruce H. Robinson, Materials Horizon, 2021
23. F. Zanetto, E. Guglielmi, F. Toso, R. Gaudiano, F. Caruso, M. Sampietro, and G. Ferrari, "Wide Dynamic Range Multichannel Lock-In Amplifier for Contactless Optical Sensors With Sub-pS Resolution," IEEE Solid-State Circuits Lett., vol. 3, pp. 246–249, 2020, doi: 10.1109/LSSC.2020.3012920.

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26. "Broadband Metallic Fiber-to-Chip Couplers and a Low-Complexity Integrated Plasmonic Platform", A. Messner et al., Nano Letters 21 (11), 4539-4545, 2021
27. "End-to-End 1024-Port Optical Packet Switching With 25 Gb/s Burst-Mode Reception for Data Centers", N. Terzenidis et al., in IEEE Photonics Journal, vol. 13, no. 3, pp. 1-14, June 2021
28. "Performance analysis of a 1024-port Hipoλaos OPS in DCN, HPC, and 5G fronthauling Ethernet applications", N. Terzenidis et al., IEEE/OSA Journal of Optical Communications and Networking, vol. 13, no. 7, pp. 182-192, July 2021
29. "25.6 Tbps capacity and sub-μsec latency switching for Data Centers using >1000-port Optical Packet Switch architectures", A. Tsakyridis et al., IEEE Journal of Selected Topics in Quantum Electronics, vol. 27, no. 2, pp. 1-11, March-April 2021
30. "Femtojoule per MAC Neuromorphic Photonics: An Energy and Technology Roadmap", A. R. Totović, G. Dabos, N. Passalis, A. Tefas and N. Pleros, IEEE Journal of Selected Topics in Quantum Electronics, vol. 26, no. 5, pp. 1-15, Sept.-Oct. 2020
31. "Polarization-transparent silicon photonic add-drop multiplexer with wideband hitless tuneability", F. Morichetti et al., Nature Communications 12, 4324 (2021)
32. "Control and Calibration Recipes for Photonic Integrated Circuits", M. Milanizadeh et al., in IEEE Journal of Selected Topics in Quantum Electronics, vol. 26, no. 5, pp. 1-10, Sept.-Oct. 2020
33. "Automatic Tuning of Silicon Photonics Microring Filter Array for Hitless Reconfigurable Add–Drop", D. O. M. de Aguiar et al., in Journal of Lightwave Technology, vol. 37, no. 16, pp. 3939-3947, 15 Aug.15, 2020
34. "High-Value Tunable Pseudo-Resistors Design", E. Guglielmi et al., in IEEE Journal of Solid-State Circuits, vol. 55, no. 8, pp. 2094-2105, Aug. 2020
35. "Electrical conductance of silicon photonic waveguides", F. Zanetto et al., Optics Letters 46, 17-20 (2021)
36. "Dithering-based real-time control of cascaded silicon photonic devices by means of non-invasive detectors", F. Zanetto et al., IET Optoelectronics 15 111-120, (2021)

The website list with all publications acknowledging NEBULA is constantly updated upon the arrival of new publications:

http://nebula-h2020.eu/index.php/dissemination/publications

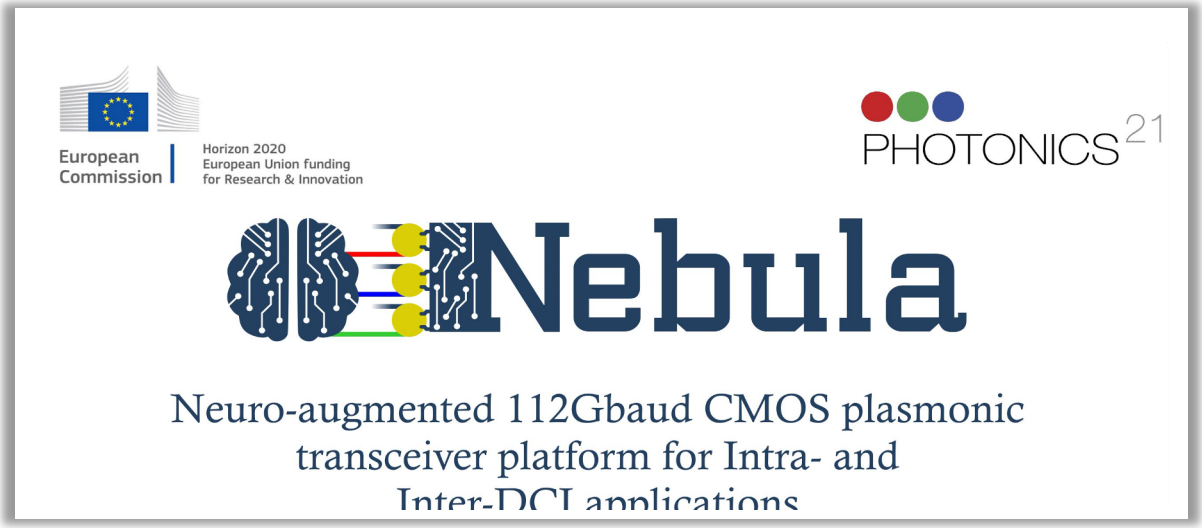
4 NEBULA communication kit

A comprehensive communication kit was developed and distributed through various mass media channels to promote the project. This kit, consisting of:

- **Project Factsheet (Section 4.1):** Provides a clear project overview, including the project logo, title, duration, funding details, and Consortium information. It summarizes the project's challenges, mission statement, objectives, and targeted technological breakthroughs. Available on the NEBULA website and promoted through social media.
- **Short Project Presentation (Section 4.2):** Offers basic project information, NEBULA's concept, vision, objectives, and anticipated technology breakthroughs. It is intended for partner use in promoting the project and enhancing visibility. Available on the NEBULA website.
- **Press Releases (Section 4.3):** Initial release announced the project's commencement on Ligentec's website and project official page social media accounts in March 2020. A final press release was published on the NEBULA website in November 2023. It has also been posted to all the project's social media.
- **Brochure (Section 4.4):** Created for visual dissemination at meetings, workshops, conferences, exhibitions, and public events. It visualizes project goals and expected outcomes. Shared online and printed for events.
- **Official NEBULA Project Website (Section 4.5):** Accessible at http://nebula-h2020.eu/. Provides project information for wide dissemination and a secure section for internal data sharing among partners. Updates on the NEBULA Website were included herein.
- **NEBULA Project Social Media Accounts (Section 4.6):** Established on LinkedIn, Facebook, and Twitter for interactive communication, discussion, and information sharing with various target groups.
- **Announcements (Section 4.7):** Collection of project launch and dissemination activity announcements through the website and social media accounts.
- **NEBULA Newsletter Updates (Section 4.8):** Intended to engage the public and highlight project outcomes when technical advancements are achieved.

All components of the communication kit are detailed in Sections 4.1-4.8 below.

4.1: Factsheet



NEBULA factsheet

Grant Agreement:
871658

Duration:
Jan 2020 – Dec 2022 (36 Months)

Coordinator:
Aristotle University of Thessaloniki

Contact:
Prof. Konstantinos Vyrsokinos (kv@auth.gr)
Prof. Nikos Pleros (npleros@csd.auth.gr)

Project website:
URL: www.nebula-h2020.eu

Total budget:
€ 5,999,191.25

Consortium:
Aristotle University of Thessaloniki (GR)
Swiss Federal Institute of Technology in Zurich (CH)
Centre National de la Recherche Scientifique (FR)
Politecnico di Milano (IT)
Interuniversitair Micro-Elektronica Centrum-IMEC (BE)
Institute of Communication and Computer Systems (GR)
Universiteit Gent (BE)
IBM Research GmbH (CH)
Ligentec SA (CH)
III-V Lab (FR)
Mellanox Technologies Ltd (IL)
ADVA Optical Networking SE (DE)

THE CHALLENGE

Data Centers (DC) have turned into the beating heart of today's digital industry, with intra-DC traffic expected to reach 21TB by 2021 increasing by >3x within only five years. An in-depth view to the traffic profiles reveals that East-West traffic exchange is not anymore constrained within a single DC facility, with hyperscale DCs being currently expanded along a distributed DC model comprised of smaller DCs. This new trend will gradually turn the inter-DC and intra-DC interconnect segments to more balanced utilization factors, without however, implying a more relaxed operational framework for the intra-DCI domain: to cope with the rapidly growing traffic demands, switches have increased their capacity faster than Moore's law, rising from 3.2Tbps to the next-generation 25.6Tbps capacity modules within 5 years. Thus, the new DC-roadmap seeks eagerly for a new CMOS-compatible photonic platform offering high bandwidth, low footprint and low power consumption towards the next transceivers' generation as well as the co-package of ASIC switches with optics.

MISSION STATEMENT

This is where NEBULA steps in, aiming to turn the SiN platform in a low-cost, robust and high-speed versatile transceiver platform equipped with CMOS-compatible plasmonic modulators, thermal stabilizer systems, high-speed PDs and a neuro-augmented DSP realized entirely in the optical domain. NEBULA targets the deployment of a sub-Volt 8-channel

112Gbaud PAM4 O-band transmitter co-packaged with a data generating ASIC, offering a 1.6Tbps aggregate capacity with up to 37% energy savings in Intra-DCI applications. Regarding the Inter-DC links, NEBULA will deploy an 8-channel 112Gbaud 16QAM C-band transceiver prototype, offering an aggregate capacity of 3.2Tbps and requiring just 2.65W per single 400Gbps wavelength, providing in this way an energy efficiency of only 6.625pJ/bit with energy savings of 93%.

PROJECT OBJECTIVES

The overall objective of NEBULA is to develop all the necessary technology building blocks towards low-cost and high-bandwidth transceivers to meet the ever-increasing demands of tomorrow's intra- and inter-DC links. Specifically, the core objectives of NEBULA are to:

- **Turn low loss SiN into a low cost, high-speed versatile transceiver and processing platform for inter- and intra-DCI applications by equipping the platform with:**
  - **two-layer SiN waveguide technology**
  - **Plasmonic slot modulators**
  - **Uni-Travelling Carrier PDs**
- **Demonstrate CMOS plasmonic Resonance Enhanced Modulators (REMs) and IQ modulators on SiN for 112Gbaud intra-and inter-DC interconnects**
- **Develop a mechanism for thermal stabilization (Plasmonic Thermal Stabilizer-PTS) of plasmonic REMs**
- **Deploy an optical 112Gbaud Coherent Receiver assisted by Optical Reservoir Neuromorphic Processing (NP) for DSP free operation**
- **Deploy low cost 112Gbaud PAM4 electronics for energy efficient transceivers**
- **Deploy 8-channel arrays of O-band and C-band modulators with flip-chip compatible optical I/O coupler**
- **Deploy a C-band SiP 8x112Gbaud-16 QAM (3.2Tb/s) transceiver for inter-DC interconnects**
- **Co-package of ASIC and 1.6Tbps O-band driverless transmitter for next Generation 50Tb/s switches**
- **Validate NEBULA transceiver technology in real world intra- and inter-DCI applications**

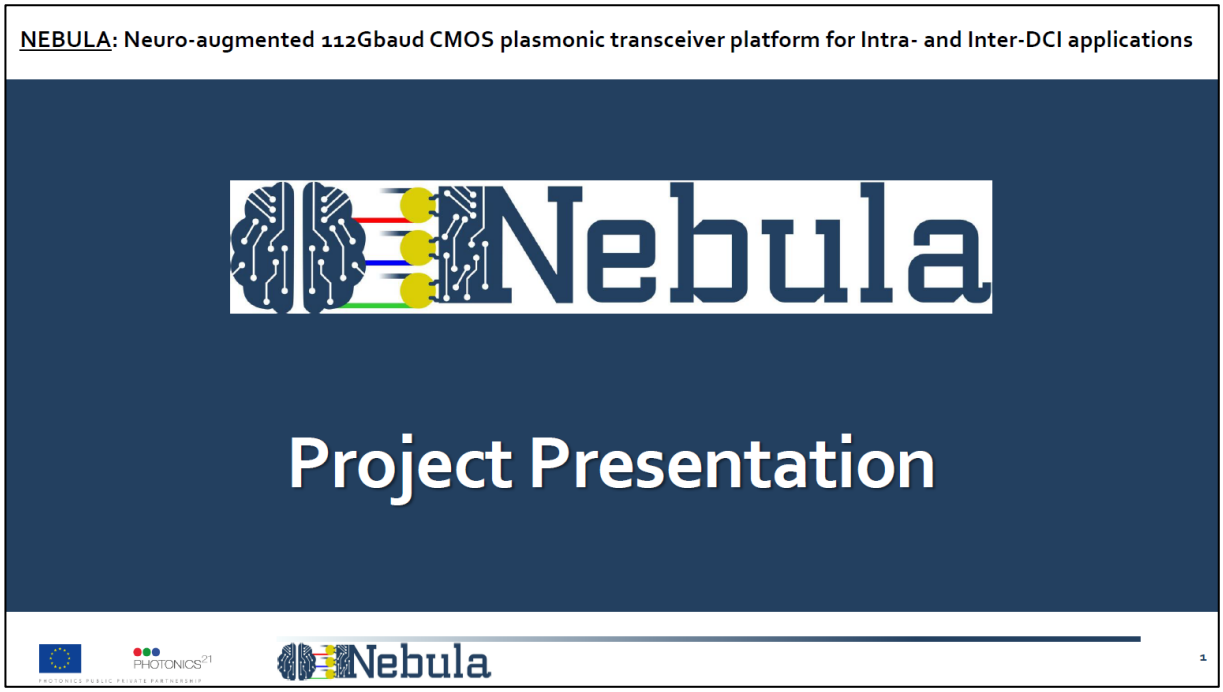
TECHNOLOGY BREAKTHROUGHS

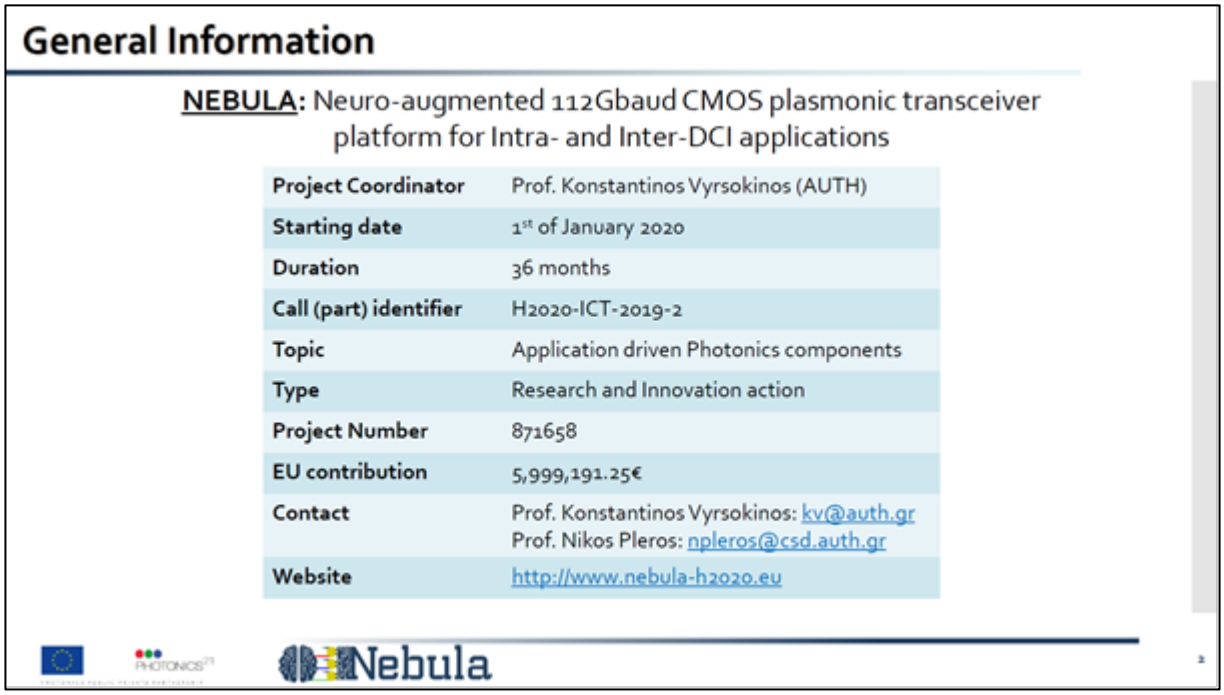
Plasmonic thermal stabilizer: Thermal stability issues and high temperature variations of co-packaged ASICs and datacom modules are among the most significant challenges that the emerging co-packaged systems need to address. To this end, NEBULA aims to develop a non-invasive thermal stabilization circuitry that will reliably handle temperature variations and thermal drifts of the Plasmonic transmitter modules, targeting to release co-packaged solutions for these harsh temperature environments.

Plasmonic micro-disk modulator: The proposed modulator will feature the most ambitious key metrics of only $5um^2$ footprint, insertion loss of 3dB and power efficiency of less than 50fJ/bit. Capable of operating up to 56Gbaud with PAM4 modulated signals by a driverless single-ended $0.7V_{pp}$ RF signal, this new modulator layout paves the way for lightweight switch engines featuring ASICs co-packaged with Plasmonic-Photonic structures without the use of any extra driving circuit.

Neuro-augmented all-optical DSP: NEBULA will showcase the first DSP-free Rx for coherent demodulation of 16QAM signals up to 112Gbaud. The Neuromorphic Augmented Reservoir Circuit (NARC) will be combined with Uni-Travelling Carrier Photodiodes co-integrated with Semiconductor Optical Amplifiers for enhanced non-linear-reservoir processing. Combing ferroelectric BTO plus HfO_2 memristor elements with a 4:1 EIC Analogue Weighted multiplexer combiner, NEBULA will realize a powerful optoelectronic weighting system, aiming to release once and for all the optical receivers from any DSPs activities.

4.2: Project presentation





Consortium

- 12 Partners
- 7 Countries
- 4 Universities
- 4 Research Institutes
- 4 Companies

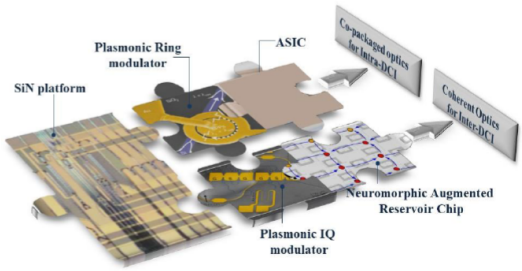
PHOTONICS21 Nebula 3

Concept

NEBULA aims to deliver a powerful neuro-augmented 112Gbaud CMOS plasmonic transceiver platform for Intra- and Inter-DCI applications with profound functional benefits

Key Technologies:

- 112GBaud plasmonic modulators on SiN based on ferroelectric BTO
- Loss-less thermal stabilization circuit
- Neuro-augmented all-optical DSP
- 112GBaud BiCMOS ultra-fast electronics

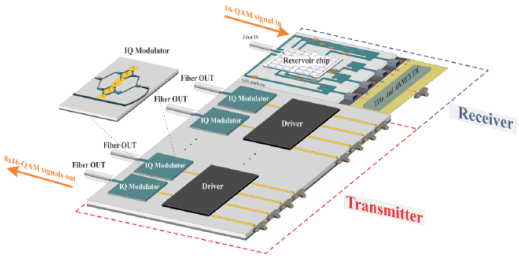


PHOTONICS21 Nebula 4

Prototypes

Inter-DCI

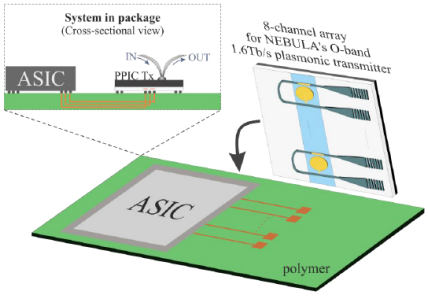
8-ch 112Gbaud 16-QAM C-band transceiver prototype



- ✓ DSP-free Rx
- ➢ 93% energy savings !

Intra-DCI

8-ch 112GBaud sub-volt O-band transmitter co-packaged with an ASIC



- ✓ 100Tb/s plasmonic EO engine
- ➢ 37% energy savings !

5

4.3: Final Press release & announcements

The link to the initial NEBULA press release, the screenshot from NEBULA's website that provides access to the press release, the screenshot from Ligentec's website and the content of the press release can be found below:

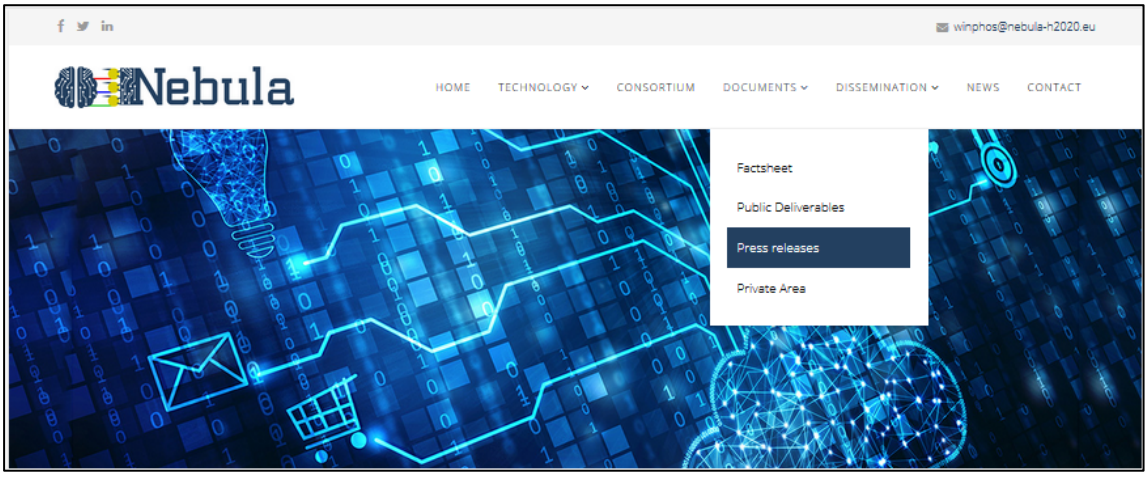
News: https://www.ligentec.com/company-ligentec/news-ligentec/

Articles: https://www.ligentec.com/technology-ligentec/articles-ligentec/

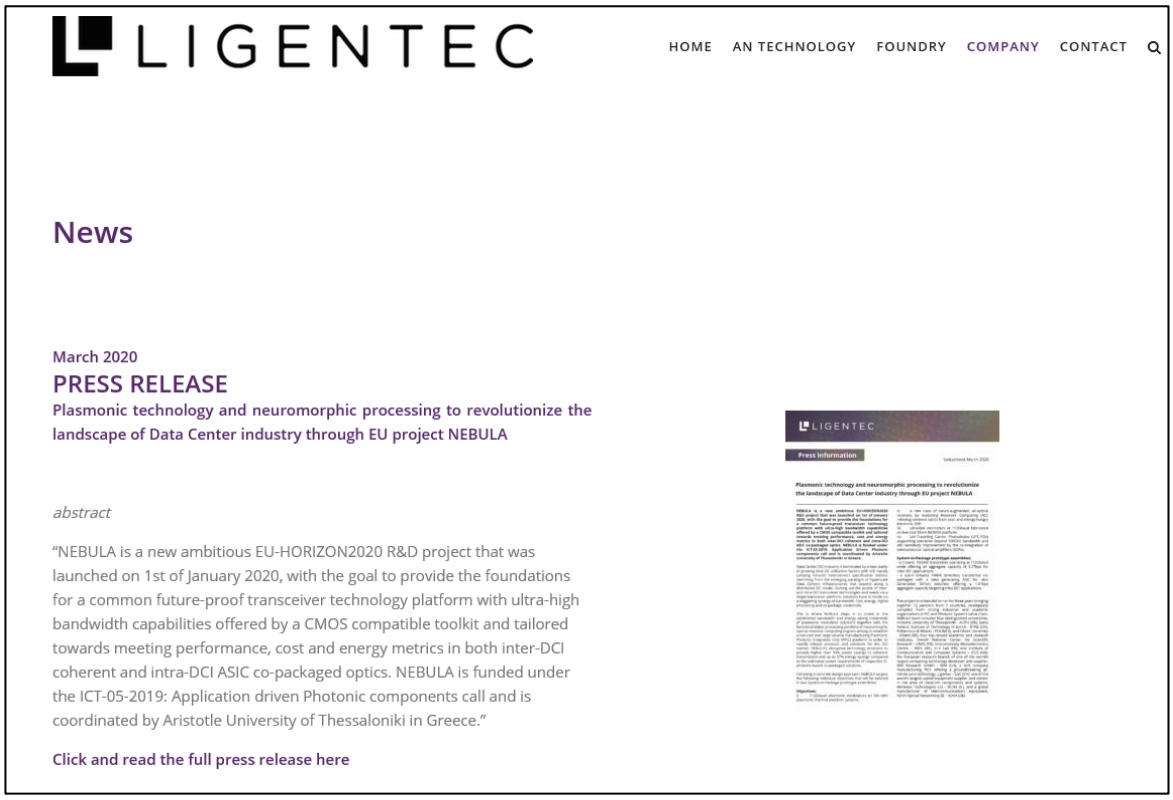
Pdf: https://www.ligentec.com/wp-content/uploads/2020/03/20200305-LIGENTEC-Nebula.pdf

CNRS and POLIMI also announced the project's launch in their respective websites.

NEBULA website



Ligentec's website



LIGENTEC

Press Information

Switzerland, March 2020

Plasmonic technology and neuromorphic processing to revolutionize the landscape of Data Center industry through EU project NEBULA

NEBULA is a new ambitious EU-HORIZON2020 R&D project that was launched on 1st of January 2020, with the goal to provide the foundations for a common future-proof transceiver technology platform with ultra-high bandwidth capabilities offered by a CMOS compatible toolkit and tailored towards meeting performance, cost and energy metrics in both inter-DCI coherent and intra-DCI ASIC co-packaged optics. NEBULA is funded under the ICT-05-2019: Application driven Photonic components call and is coordinated by Aristotle University of Thessaloniki in Greece.

Data Center (DC) industry is dominated by a new reality of growing inter-DC utilization factors with still rapidly jumping intra-DC interconnect specification metrics stemming from the emerging paradigm of hyperscale Data Centers infrastructures that expand along a distributed DC model. Sorting out the puzzle of inter- and intra-DCI transceiver technologies and needs via a single transceiver platform, solutions have to reside on a staggering synergy of bandwidth, cost, energy, digital processing and co-package credentials.

This is where NEBULA steps in to invest in the established bandwidth and energy saving credentials of plasmonic modulator solutions together with the functional digital processing portfolio of neuromorphic optical reservoir computing engines aiming to establish a low-cost and large volume manufacturing Plasmonic Photonic Integrated Chip (PPIC) platform in order to rapidly release products and solutions for the DCI market. NEBULA's disruptive technology envisions to provide higher than 93% power savings in coherent transmission and up to 37% energy savings compared to the estimated power requirements of respective Si-photonic-based co-packaged solutions.

Following a concrete design approach, NEBULA targets the following individual objectives that will be tailored in two System-in-Package prototype assemblies:

Objectives:

i) 112Gbaud plasmonic modulators on SiN with plasmonic thermal stabilizer systems.

ii) a new class of neuro-augmented, all-optical receivers by exploiting Reservoir Computing (RC), relieving coherent optics from cost- and energy-hungry electronic DSP.

iii) ultra-fast electronics at 112Gbaud fabricated on low-cost 55nm BiCMOS platform.

iv) Uni-Travelling Carrier Photodiodes (UTC-PDs) supporting operation beyond 100GHz bandwidth and x80 sensitivity improvement by the co-integration of semiconductor optical amplifiers (SOAs).

System-in-Package prototype assemblies:

- a C-band, 16QAM transceiver operating at 112Gbaud while offering an aggregate capacity of 3.2Tbps for inter-DCI applications
- a sub-V O-band, PAM4 driverless transmitter co-packaged with a data generating ASIC for next Generation 50Tb/s switches, offering a 1.6Tbps aggregate capacity targeting intra-DCI applications

The project is scheduled to run for three years bringing together 12 partners from 7 countries, strategically compiled from strong industrial and academic organizations in PIC and Photonic Systems value chain. NEBULA team includes: four distinguished universities, Aristotle University of Thessaloniki - AUTH (GR), Swiss Federal Institute of Technology in Zurich - ETHZ (CH), Politecnico di Milano - POLIMI (I), and Ghent University - UGent (BE), four top-ranked academic and research institutes, French National Center for Scientific Research - CNRS (FR), Interuniversity Microelectronics Centre – IMEC (BE), III-V Lab (FR), and Institute of Communication and Computer Systems – ICCS (GR), the European research branch of one of the world's largest computing technology developer and supplier, IBM Research GmbH - IBM (CH), a B2B company manufacturing PICs offering a groundbreaking all-nitride core technology, Ligentec – LGC (CH), one of the world's largest capital equipment supplier and vendor in the area of DataCom components and systems, Mellanox Technologies Ltd - MLNX (IL), and a global manufacturer of telecommunications equipment, ADVA Optical Networking SE – ADVA (DE).

LIGENTEC

About NEBULA

NEBULA: Neuro-augmented 112Gbaud CMOS plasmonic transceiver platform for Intra- and Inter-DCI applications (Grant Agreement:871658)

Programme: Horizon 2020 – ICT-05-2019: Application driven Photonic components
Duration: 01/01/2020 – 31/12/2022
Total budget: € 5,999,191.25
Coordinator: Aristotle University of Thessaloniki, GR

https://www.facebook.com/nebula.h2020
https://twitter.com/H2020Nebula
https://www.linkedin.com/groups/8893721/
http://nebula-h2020.eu/

About LIGENTEC SA

LIGENTEC is your manufacturing partner for low loss Photonic Integrated Circuits for customers in high-tech areas such as integrated quantum optics, LiDAR, sensors and microwave photonics. LIGENTEC commercializes all-nitride-core technology awarded with the PIC award at PIC International 2018. The technology uses thick film optical grade LPCVD deposited silicon nitride and optimized cladding to provide guaranteed performance in propagation loss. With the all-nitride (AN) technology LIGENTEC enables the customers to develop their products in the industrial revolution 4.0. The customers benefit from a clear path to volume production while obtaining the small quantities of wafers with the performance, short turn around of 2 month and high yield required at the early stage of proof of concept.

www.ligentec.com

Contact

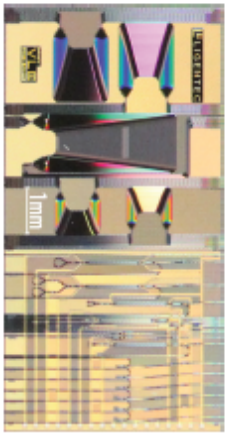
Prof. Konstantinos Vyrsokinos
kv@auth.gr

Nebula

Contact

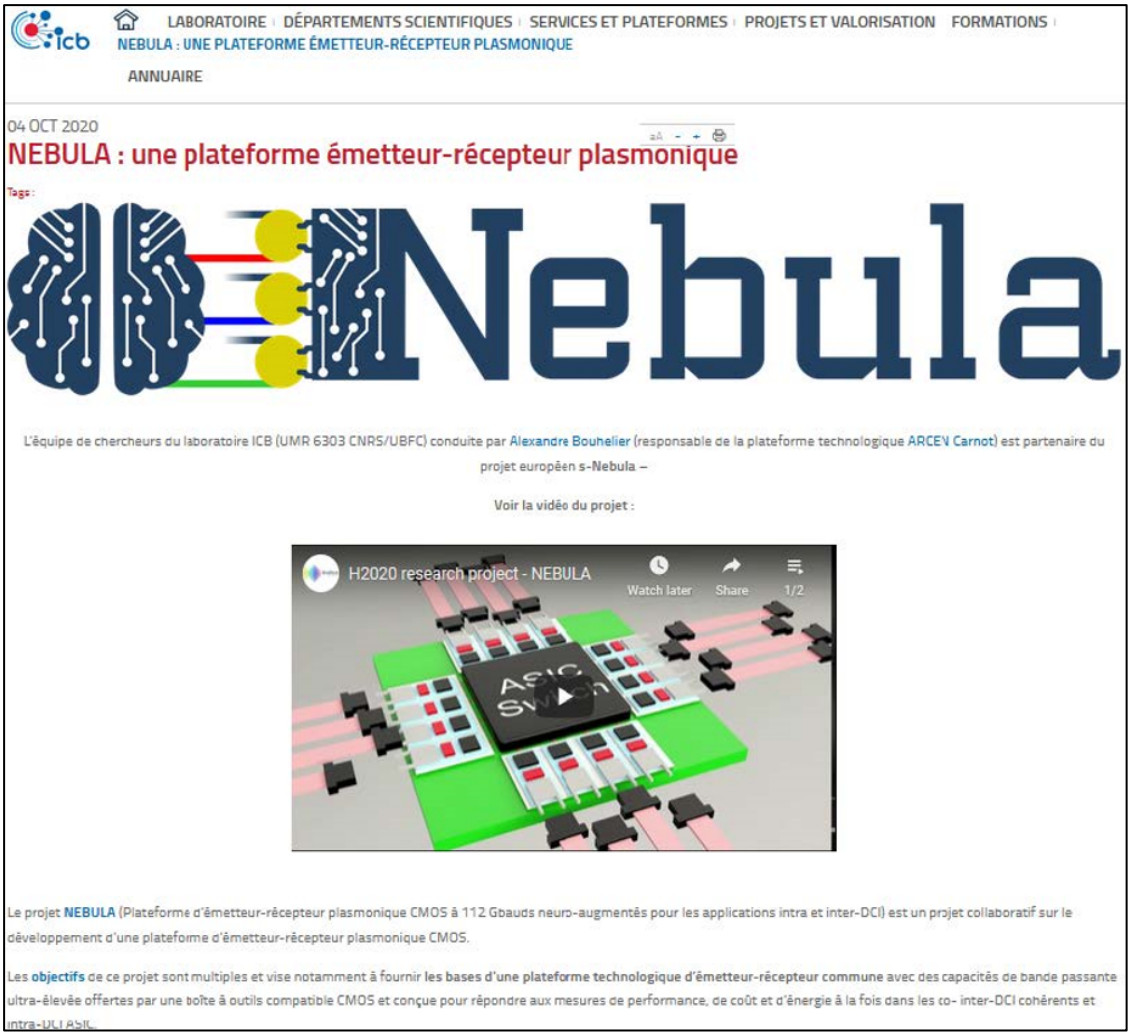
Belen Lopez-Fuchet
belen.lopez-fuchet@ligentec.com

LIGENTEC



LIGENTEC SA
EPFL Innovation Park, Bât. L
Ch. de la Dent d'Oche 1B
1024 Ecublens, Switzerland
E-Mail: info@ligentec.com
Web: www.ligentec.com

CNRS's website

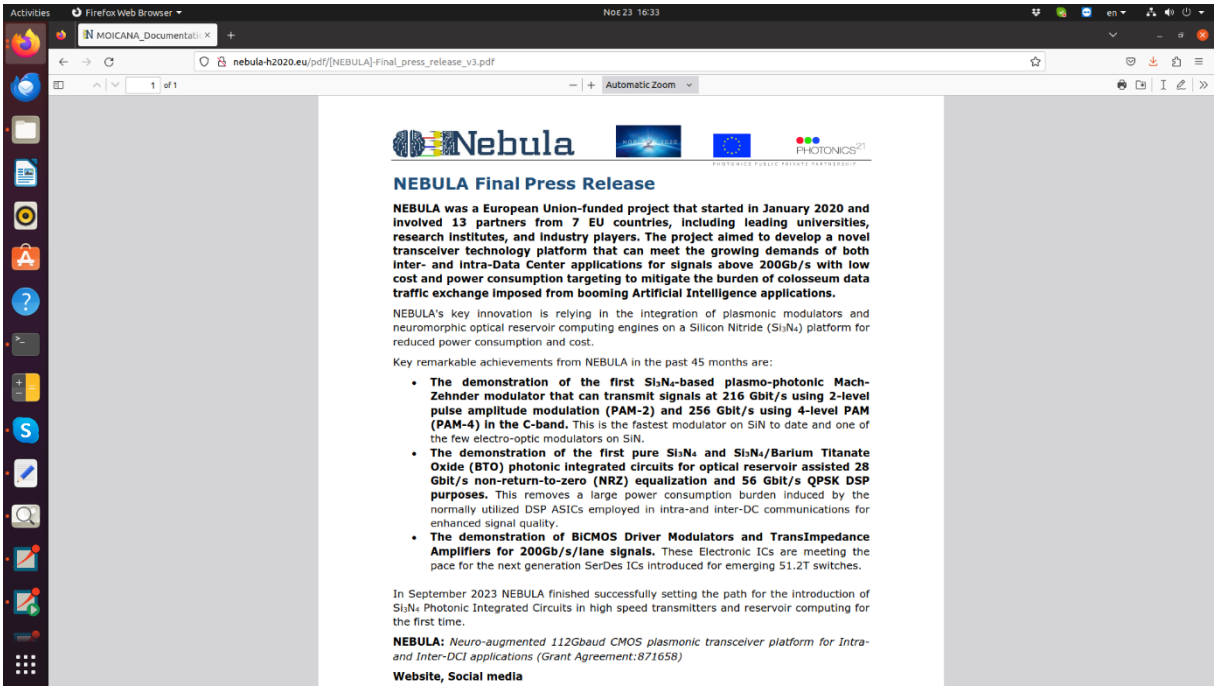


POLIMI's website

A final press release for the end of the NEBULA project was also generated and uploaded to the NEBULA Project Website.

The press release is presented in detail below:

Final Press Release on NEBULA website



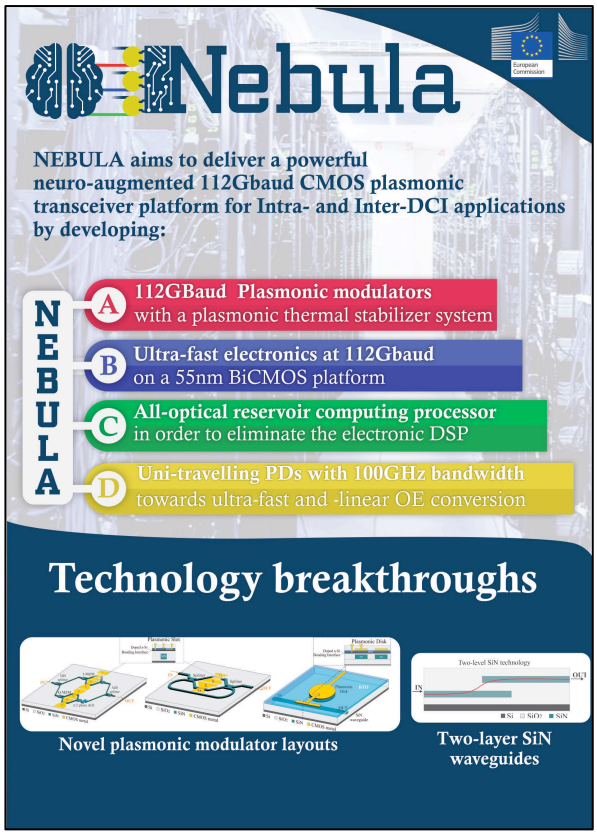
The press release was posted to the following NEBULA Social Media:

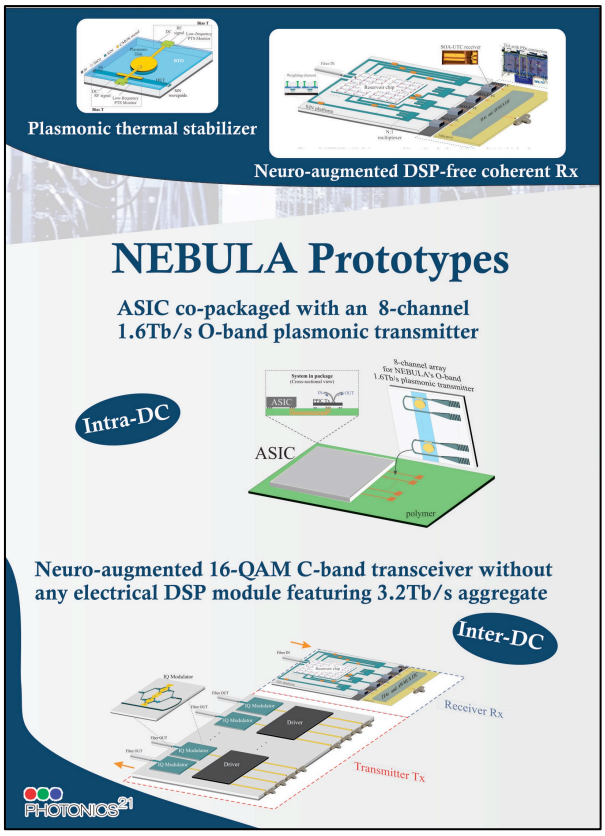
- Linkedin: https://www.linkedin.com/feed/update/urn:li:activity:7133465081585053696?utm_source=share&utm_medium=member_desktop
- Facebook: https://www.facebook.com/nebula.h2020/posts/pfbid0UWP9ukfao85ino2e8PxPNj3zX6EKhxGGuazNL4DFSfcwXW3bXZjm623BQPchWuBnl
- Twitter: https://twitter.com/H2020Nebula/status/1727698200419574069

4.4: Brochure

Cover

Inside





4.5: NEBULA Website

The NEBULA website is located at: http://nebula-h2020.eu/

By the 23rd of November 2023, the NEBULA website has accumulated more than total **19962 page views and at least 12586 visitors.**

This website was structured to accommodate all current project information and any updates that may be developed in the future. It also features a dedicated section with secure access for internal data sharing and workflow management. This special section connects to the NextCloud repository, which has received approval from the Consortium as the designated platform for exchanging project-related information. All project partners have already been provided with the necessary credentials to access this NextCloud repository.

The NEBULA website encompasses the project's visual identity, including elements like the logo and media kit, that were developed as part of WP7. Its design serves the dual purpose of providing valuable information about NEBULA to both the general public and project partners.

The website's primary objectives are twofold. Firstly, it acts as a reference point for individuals interested in learning more about the project, offering details on NEBULA's objectives, expected benefits, participating partners, and more. Secondly, it serves as a platform for distributing documents and information exclusively to authorized users, i.e., the project partners. To facilitate this, the overall NEBULA site is divided into two distinct sectors, one for public access and another restricted to authorized users. In the image below, you can see the main menu of the site along with the sub-menus for each category.

A big Follow us on… button has been added to the main webpage of NEBULA, taking into consideration the recommendations provided in the previous NEBULA review meeting. Below links to all the main NEBULA's social media have been provided.

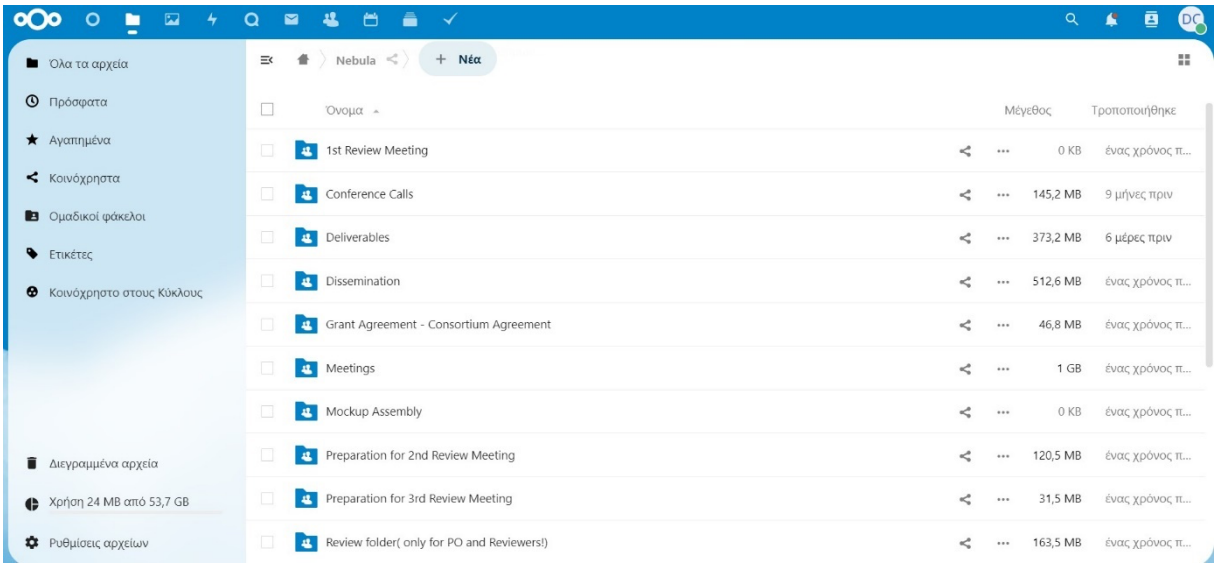
The video presentation, a text providing a brief description of the NEBULA project, along with a link providing a more technical thorough text for the objectives of NEBULA have been included in the main webpage below the Follow us on… button. This can be seen in the images provided below.

The website's structure is fairly standard, and during its latest operation period, it includes the following fundamental sections:

- **Home Page:** This serves as the main page of the website and provides an overview of its structure. It features a summary of the NEBULA project and offers links to related social media accounts in the top left corner.
- **Technology:** This section offers a general overview of NEBULA's technology and comprises two submenus:
    - **Concept:** Providing a general overview of the project and its objectives.

    - **Objectives:** Offering a detailed description of each of the project's objectives.
- **Consortium:** This section lists the members of the NEBULA Consortium and provides additional details about their expertise and contributions to the project.
- **Documents:** This section encompasses four submenus:
    - **Factsheet**
    - **Public Deliverables:** This is where all non-confidential deliverables of the NEBULA project were made available.
    - **Press Releases**
    - **Private Area:** This provides a link to the private area accessible exclusively to Consortium members. The "Private Area" main menu tab redirects users to the secure share point portal known as NextCloud, which has been approved by NEBULA Consortium members for use during the project. Each partner has received individual login credentials to access and use this platform.
- **Dissemination:** This section includes two submenus:
    - **Communication Kit:** Currently consisting of two tabs:
        - **Documents:** This tab includes links to the factsheet, project presentation, brochure, and will host any other relevant documents developed during the project's duration.
        - **Logo:** This tab offers a selection of NEBULA logos that can be downloaded.
- **Publications:** This contains all the journal and conference publications carried out within NEBULA.
- **News:** This section hosts all non-confidential news related to the NEBULA project in a user-friendly format, primarily targeting the general public.
- **Contact:** This section provides all the relevant information for contacting the project coordinator, including electronic and physical addresses, as well as phone numbers.

The image below illustrates the Private NextCloud Area of the NEBULA website.

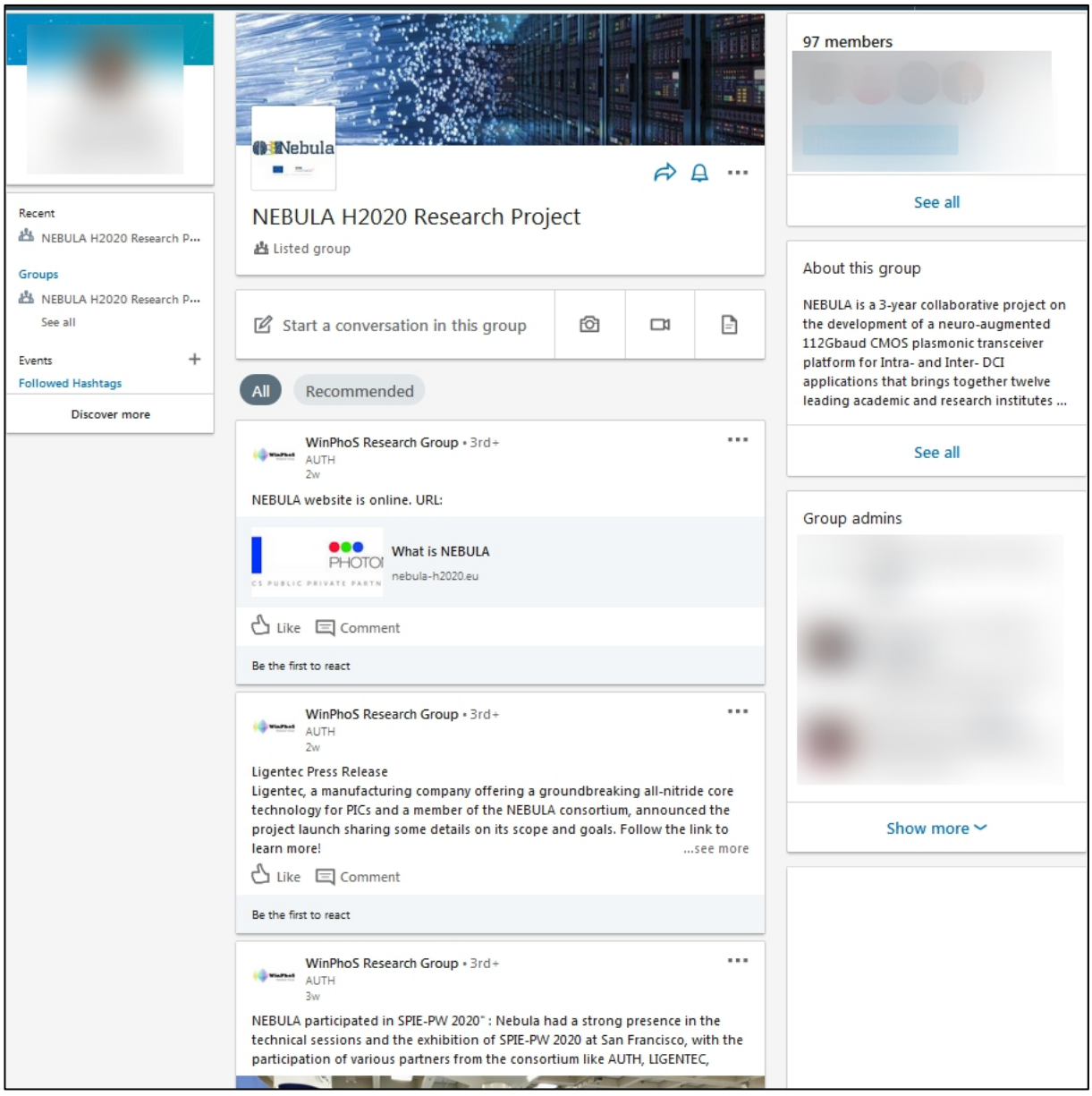


4.6: Social media accounts

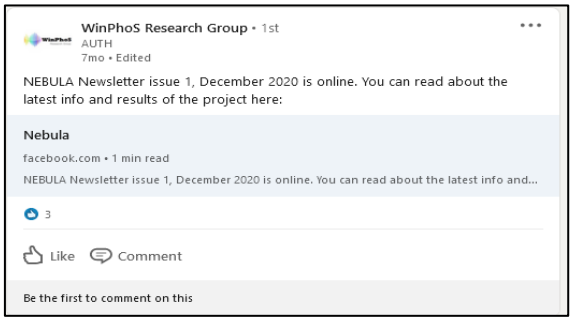
The project's three social media accounts are regularly updated with information related to project outcomes, general assembly/review meetings, and other relevant updates.

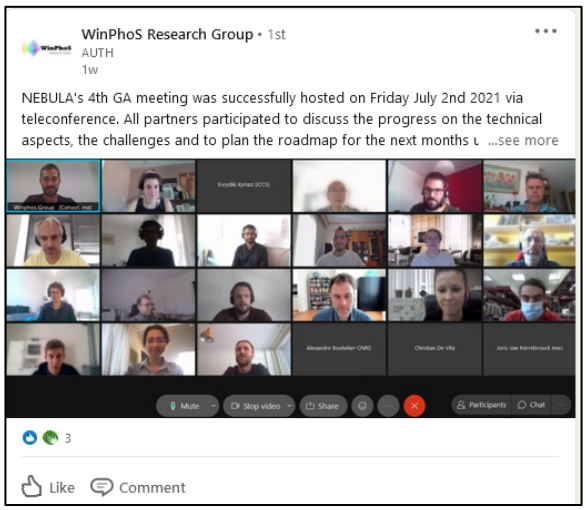
LinkedIn

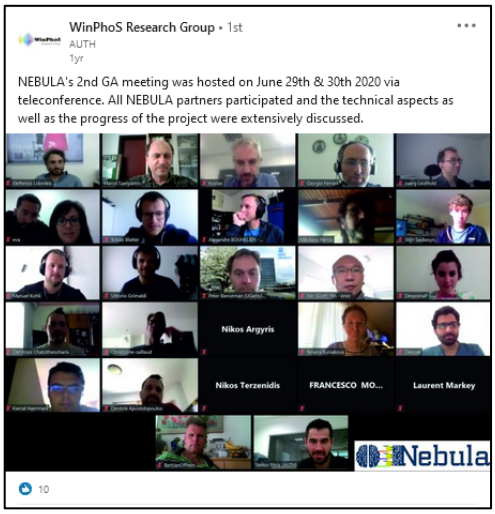
https://www.linkedin.com/groups/8893721/



As of November 8, 2023, **the group boasts 111 members**. More announcements, such as participation in conferences, are continuously shared through this channel. LinkedIn serves as the primary tool for promoting NEBULA research outcomes because it offers the audience the most pertinent context and information.

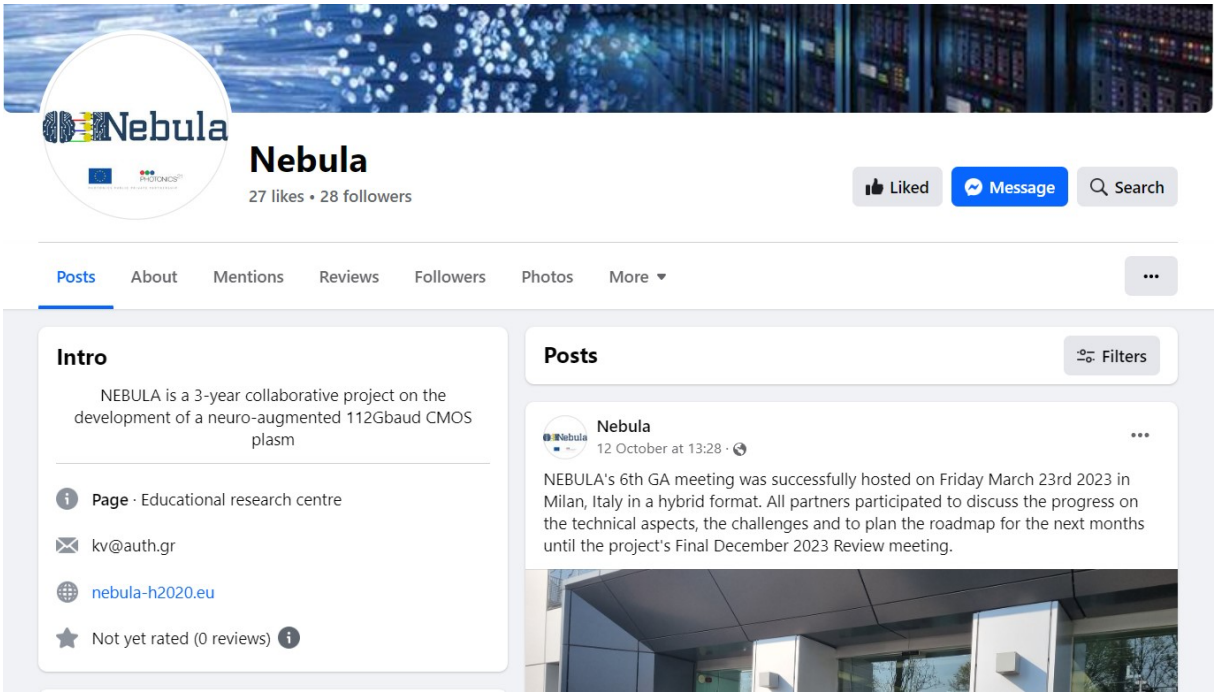






Facebook

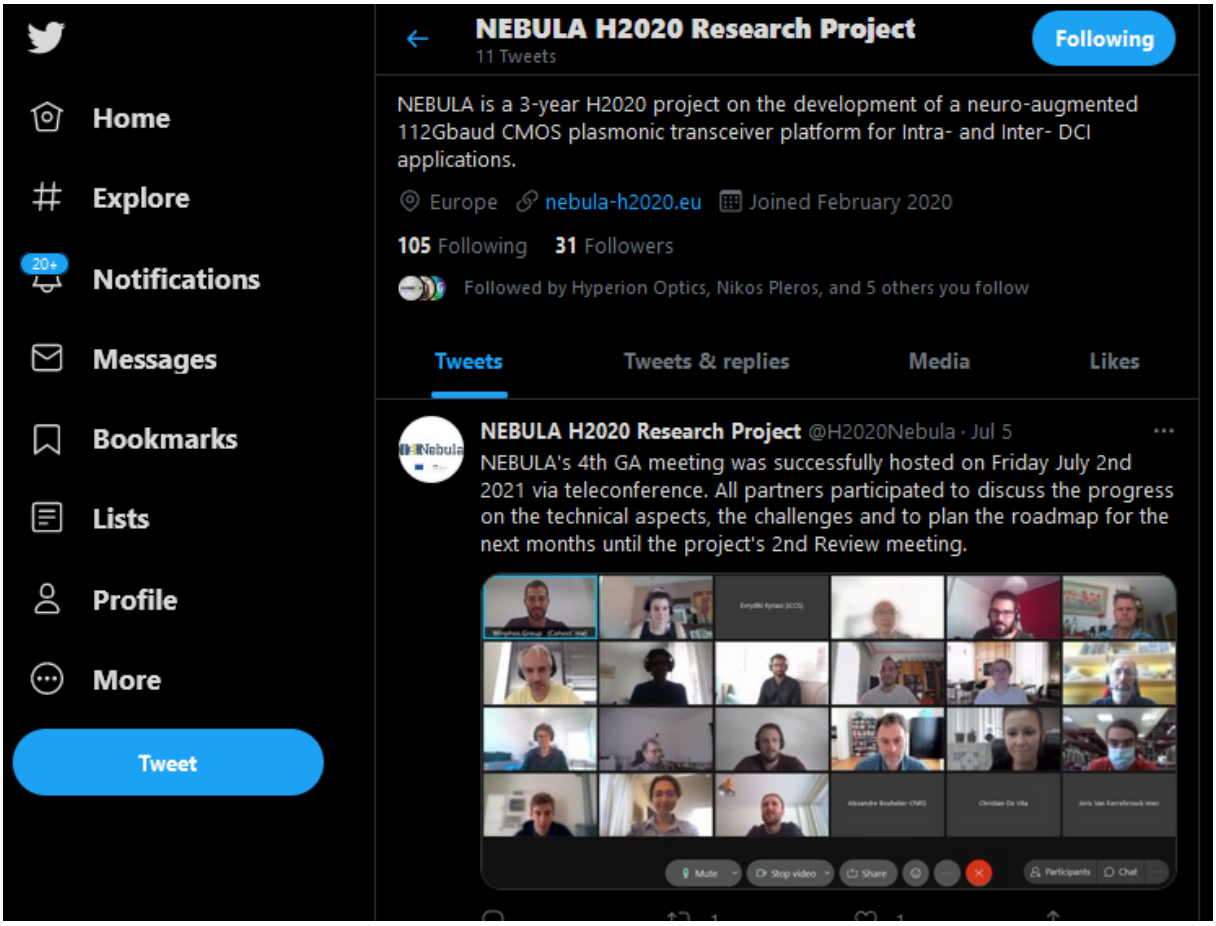
https://www.facebook.com/nebula.h2020



As of November 8, 2023, the **group currently has 28 followers**. Throughout the project's duration more announcements, such as those related to conference participation, are shared through this channel.

Twitter

https://twitter.com/H2020Nebula



As of November 8, 2023, the NEBULA Twitter account **currently boasts 38 followers**. Over the course of the project more announcements, regarding conference participation, major project publications, and general assembly or review meetings are shared through this channel.

4.7: Website announcements

Website Initiation Announcement

20 JANUARY 2020

Welcome to our site!

We are pleased to announce the launch of **NEBULA** website! Our aim was to provide to the users an easy to navigate platform, that will be offering all the relevant information related to the project. Visitors can browse the information on project scope, aims and progress, as well as events and workshops in relation to NEBULA. The user interface is designed to allow easy access to the information that our colleagues and partners may need. We invite you to browse the already available material, and to stop by from time to time – our content will be constantly updated with the news from the project! For any questions, suggestions, feedback or comments, please email us at winphos@nebula-h2020.eu

Kick-of meeting (January 2020)

Nebula HOME TECHNOLOGY CONSORTIUM DOCUMENTS DISSEMINATION NEWS CONTACT

22 JANUARY 2020

NEBULA kick-off meeting

NEBULA kick-off meeting was held on January 20th and 21st, 2020, at the premises of the WinPhoS Research Group from the Aristotle University of Thessaloniki (AUTH) in Thessaloniki, Greece. NEBULA is a 3-year collaborative project on the development of a neuro-augmented 112Gbaud CMOS plasmonic transceiver platform for Intra- and Inter- DCI applications that brings together twelve leading academic and research institutes and companies. The project was launched in January 2020 and it is funded by the European Commission through HORIZON 2020 framework targeting the topic ICT-05-2019: Application driven Photonics components. Representatives of 12 partners of the consortium gathered in Thessaloniki in a highly inspiring atmosphere and successfully launched the project's activities.

Ligentec Press Release (March 2020)

09 MARCH 2020

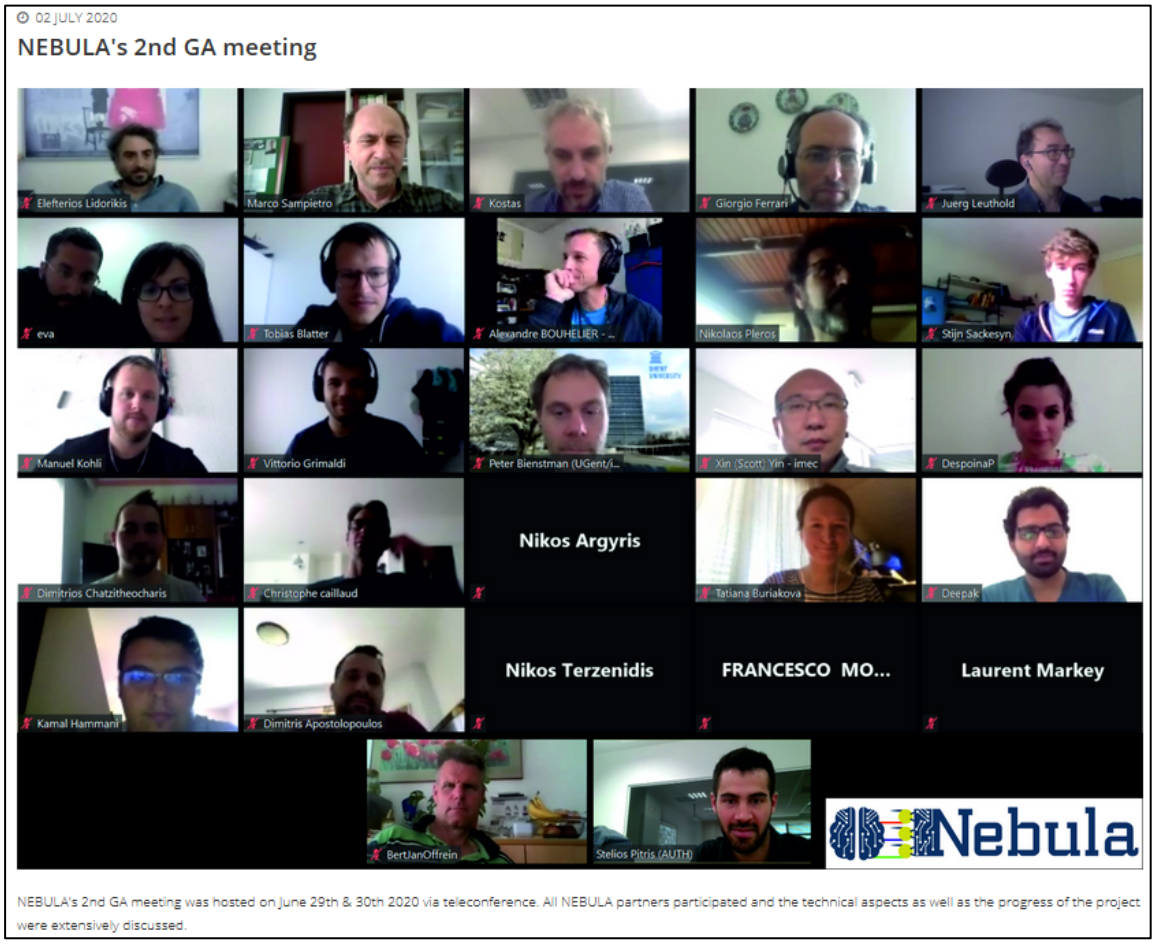
Ligentec Press Release

Ligentec, a manufacturing company offering a groundbreaking all-nitride core technology for PICs and a member of the NEBULA consortium, announced the project launch sharing some details on its scope and goals. Follow the link to learn more!

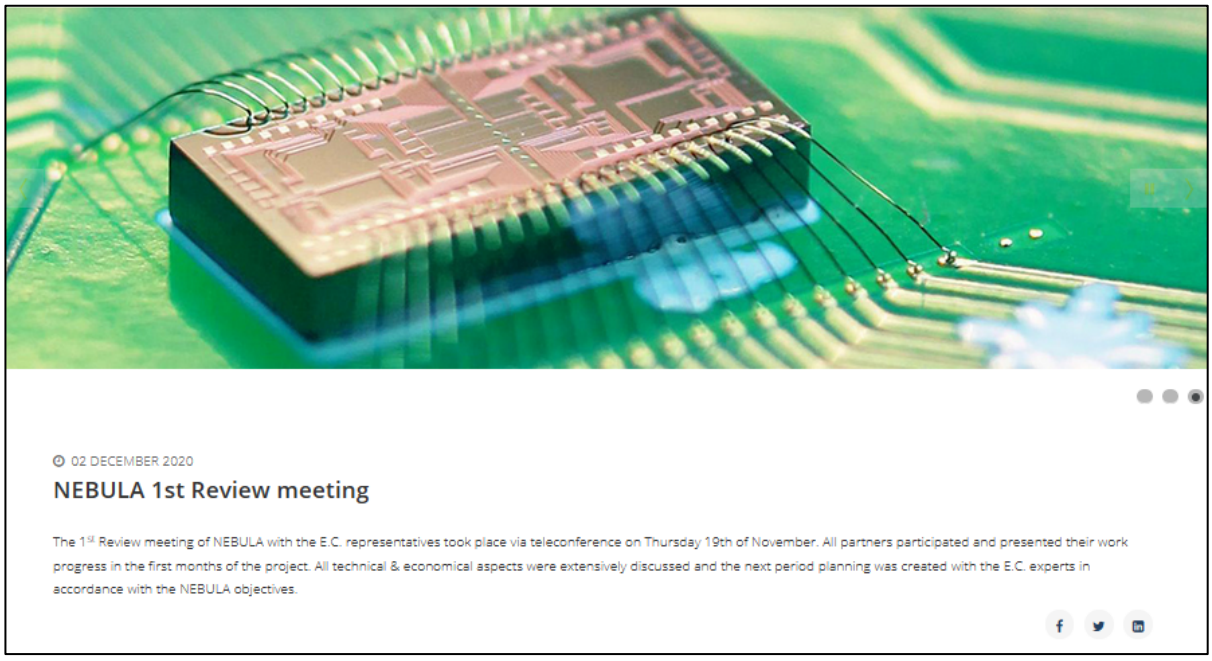
https://www.ligentec.com/company-ligentec/news-ligentec/

https://www.ligentec.com/wp-content/uploads/2020/03/20200305-LIGENTEC-Nebula.pdf

2nd GA meeting (June 2020)



1st Review meeting (November 2020)



1st Newsletter issue (December 2020)

15 DECEMBER 2020

NEBULA Newsletter issue 1

NEBULA Newsletter *issue 1, December 2020* is online. You can read about the latest info and results of the project here:

3rd GA meeting (January 2021)

02 FEBRUARY 2021

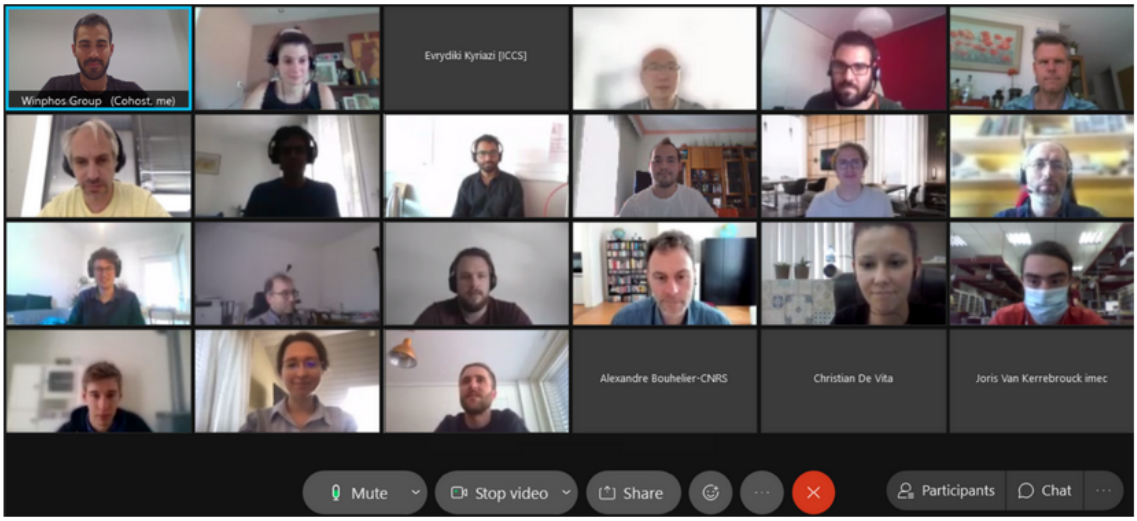
NEBULA's 3rd GA meeting

NEBULA's 3rd GA meeting was hosted on January 29th 2021 via teleconference. All NEBULA partners participated to discuss the technical aspects as well as the progress of the project.

4th GA meeting (July 2021)

05 JULY 2021

NEBULA's 4th GA meeting



NEBULA's 4th GA meeting was successfully hosted on Friday July 2nd 2021 via teleconference. All partners participated to discuss the progress on the technical aspects, the challenges and to plan the roadmap for the next months until the project's 2nd Review meeting.

2nd Review meeting (November 2021)

30 NOVEMBER 2021

NEBULA 2nd Review meeting

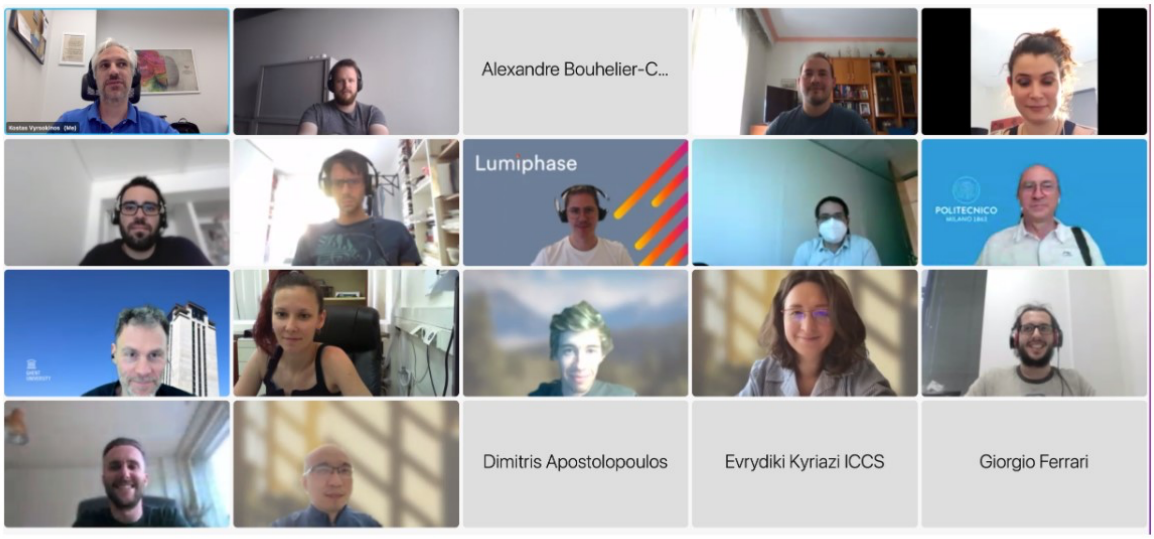
The 2nd Review meeting of NEBULA with the E.C. representatives took place via teleconference on Tuesday 30th of November 2021. All partners participated and presented their work progress in the first 20 months of the project. All technical & economical aspects were extensively discussed and the next period planning was created with the E.C. experts in accordance with the NEBULA objectives.

5th GA Meeting (July 2022)

09 NOVEMBER 2022

NEBULA's 5th GA meeting

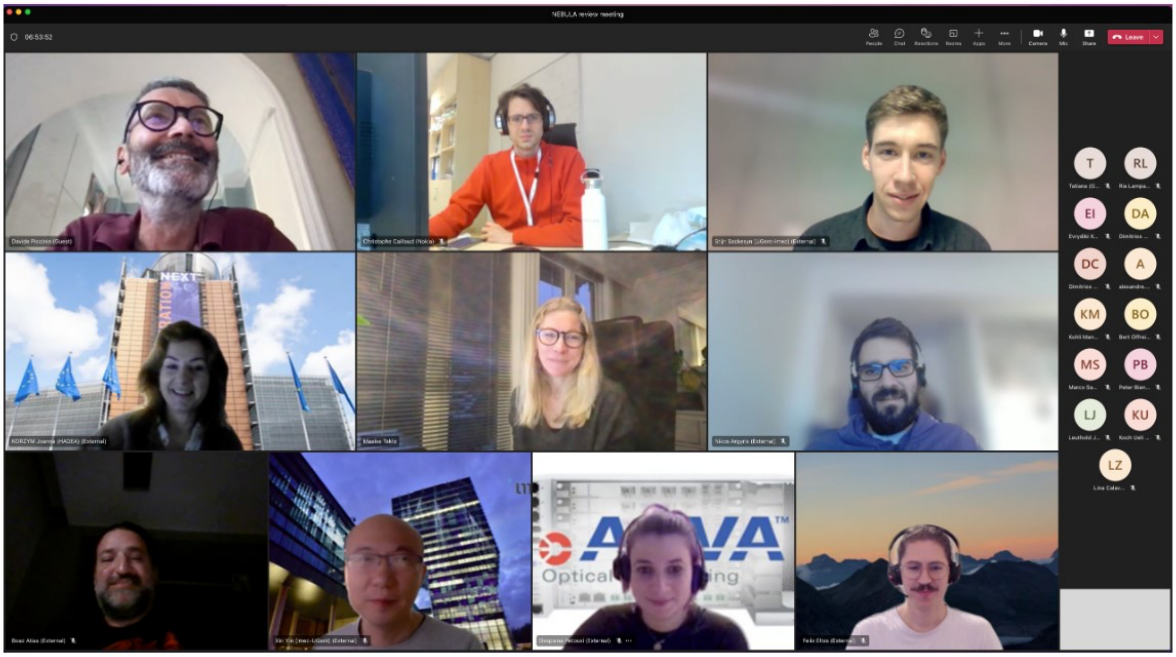
NEBULA's **5th GA meeting** was successfully hosted on Friday July 4th 2022 via teleconference. All partners participated to discuss the progress on the technical aspects, the challenges and to plan the roadmap for the next months until the project's 3rd-November Review meeting.



3rd Review meeting (November 2022)

3rd NEBULA Interim Review

The 3rd NEBULA Interim Review meeting was completed successfully on 24th of November 2022 via zoom. Within the last period of the project it was achieved great progress in fabrication of BTO plasmonic modulators on SiN and neuromorphic processing of optical signals with SiN reservoir chips.



6th GA meeting (November 2022)

12 OCTOBER 2023

NEBULA's 6th GA meeting

NEBULA's **6th GA meeting** was successfully hosted on Friday March 23rd 2023 in Milan, Italy in a hybrid format. All partners participated to discuss the progress on the technical aspects, the challenges and to plan the roadmap for the next months until the project's Final December 2023 Review meeting.

NEBULA participation in SPIE Photonics West 2020

08 FEBRUARY 2020

NEBULA participated in SPIE-PW 2020

Nebula had a strong presence in the technical sessions and the exhibition of SPIE-PW 2020 at San Francisco, with the participation of various partners from the consortium like AUTH, LIGENTEC, POLIMI.

Ligentec Press Release

Ligentec, a manufacturing company offering a groundbreaking all-nitride core technology for PICs and a member of the NEBULA consortium, announced the project launch sharing some details on its scope and goals. Follow the link to learn more!

https://www.ligentec.com/company-ligentec/news-ligentec/

https://www.ligentec.com/wp-content/uploads/2020/03/20200305-LIGENTEC-Nebula.pdf

NEBULA Newsletter

15 DECEMBER 2020

NEBULA Newsletter issue 1

NEBULA Newsletter *issue 1, December 2020* is online. You can read about the latest info and results of the project here:

Workshop in Neuromorphic Photonics 2021

19 OCTOBER 2021

Workshop in Neuromorphic Photonics

Nebula is co-organizing the **"Workshop in Neuromorphic Photonics"**, that will be virtually held during December 6-7th 2021. The workshop is co-organized together with the European research projects **H2020-PLASMONIAC** (http://www.plasmoniac.eu) and **H2020-NEOTERIC** (https://neoterich2020.eu/). For registration, the list of the speakers and further info, please visit: http://www.plasmoniac.eu/news/28-workshop-in-neuromoprhic-photonics

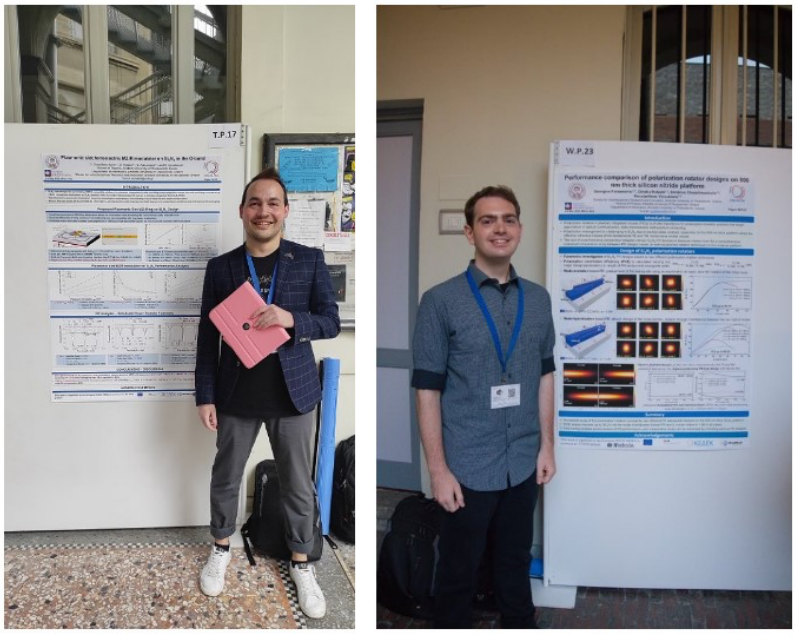
NEBULA participation in ECIO 2022

01 JUNE 2022

European Conference on Integrated Optics 2022

WinPhoS research group was present with two papers at the **ECIO European Conference on Integrated Optics** that was held from 4 to 6 May 2022 in Milan, Italy.

https://www.ecio-conference.org/2022-proceedings/

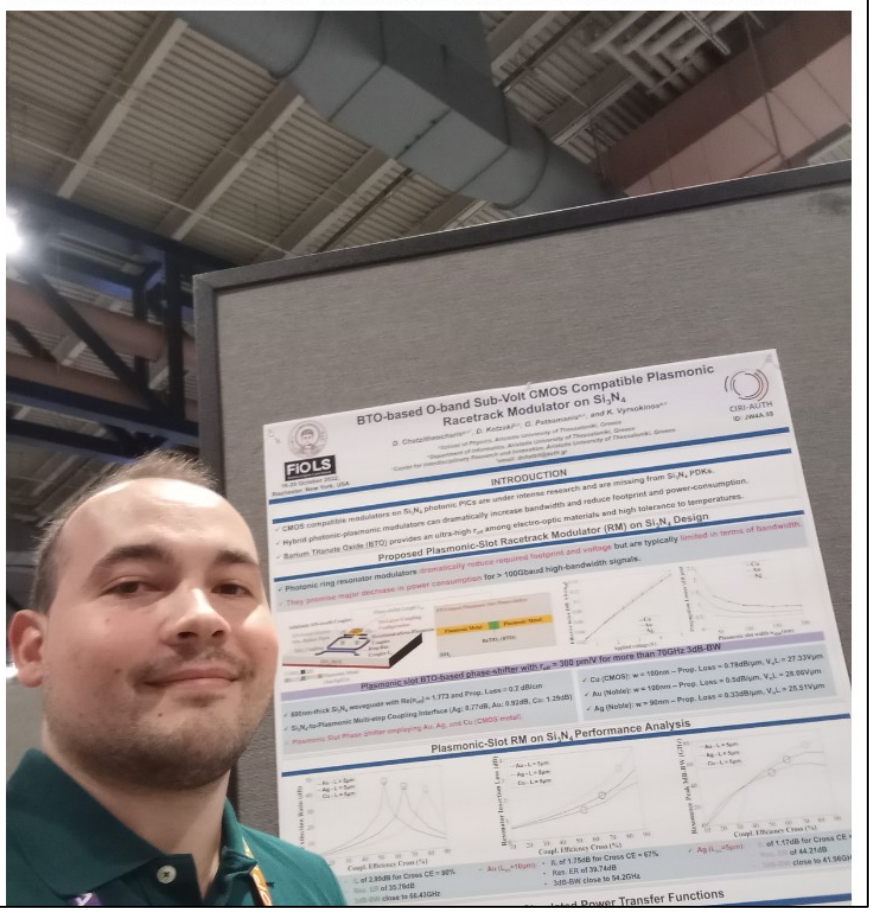


NEBULA participation in FiO-LS 2022

09 NOVEMBER 2022

NEBULA @ FiO-LS 2022

EU NEBULA was present with a paper at the **Frontiers in Optics + Laser Science 2022** (FiO-LS 2022) that was held from 17 to 20 October 2022 in Rochester, New York (USA)



NEBULA participation in the Photonics Partnership Annual Meeting of 2023

06 JUNE 2023

Photonics Partnership Annual Meeting 2023

On April 26-27th, the NEBULA project was present at the **Photonics Partnership Annual Meeting 2023** in Brussels. Researchers from Aristotle University of Thessaloniki coordinating NEBULA presented the project to Work Group 1 – Digital Infrastructure.

NEBULA participation in ECOC 2023

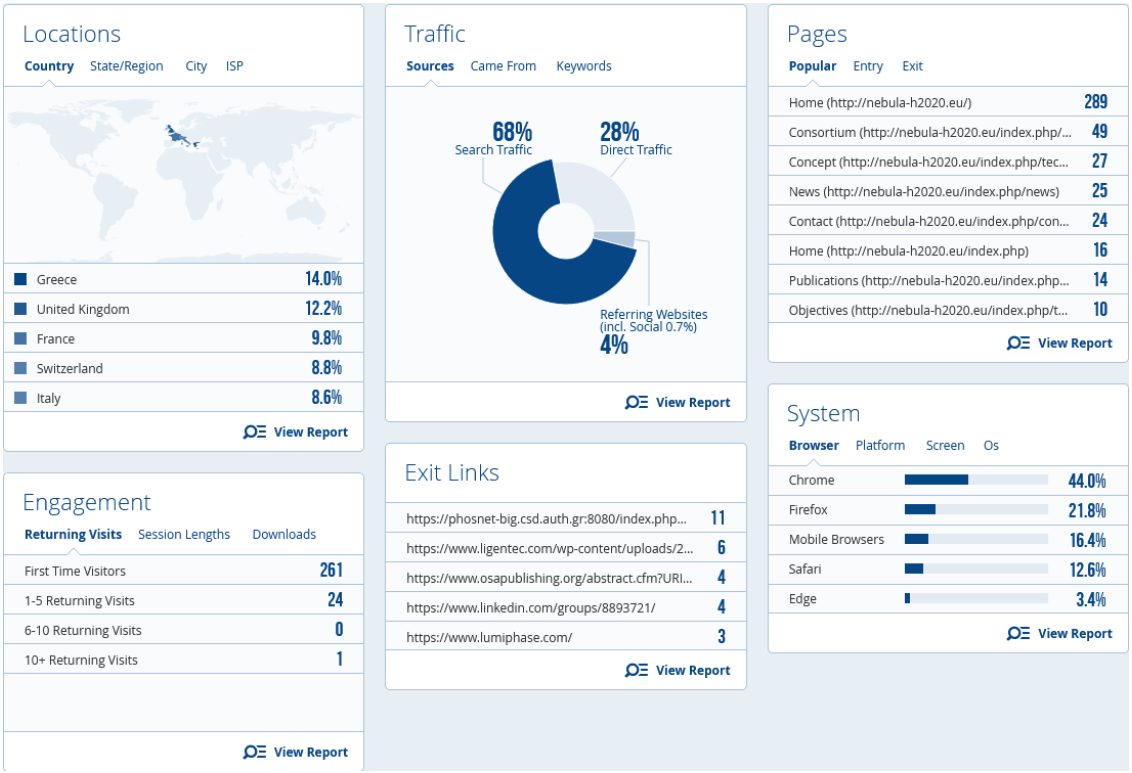
11 OCTOBER 2023

NEBULA @ ECOC 2023

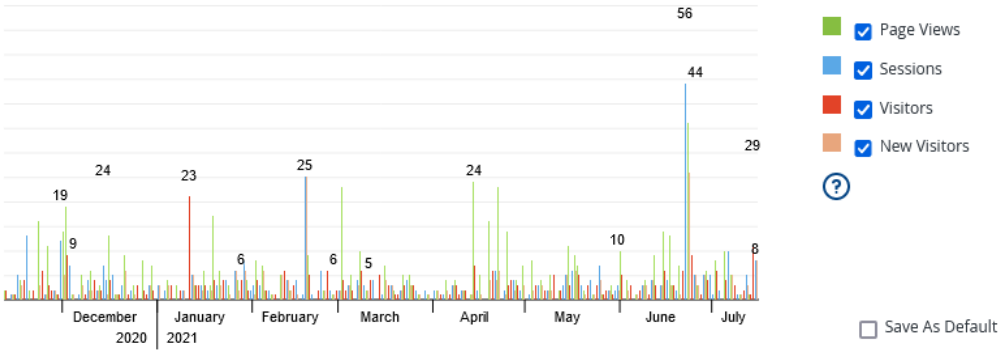
EU NEBULA was present at the ECOC 2023 conference. Themistoklis Chrysostomidis from Aristotle University of Thessaloniki, Greece presented his work on "Low-Power BTO on SiN MZI Weights for Neuromorphic Photonics" in Glasgow, Scotland (UK).

Website visiting statistics

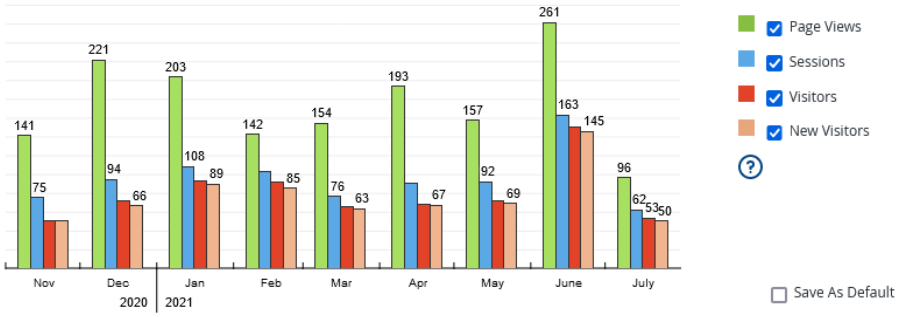
The website statistics (overall, weekly, monthly) were included also in the previous report on the communication kit and are demonstrated in detail below. As of November 23, 2023, the website has accumulated more than **19962 page views and at least 12586 visitors.**



Overall website visiting statistics of the website (Jan 2020-July 2021)



Daily visiting statistics of the website (Nov 2020-July 2021)



Weekly visiting statistics of the website (Nov 2020-July 2021)

4.8: Newsletter series

NEBULA newsletter series – issue 1 (December 2020)

The inaugural installment (consisting of 5 pages) of the newsletter series was published on the internet and shared via NEBULA's social media channels.


NEWSLETTER

ISSUE
01
DEC 2020

Nebula

Neuro-augmented 112Gbaud CMOS plasmonic transceiver platform for Intra and Inter-DCI applications

In this issue:

- NEBULA project targets overview
- Lumiphase AG enters NEBULA as a new partner
- Dissemination activities & Communication channels
- NEBULA meetings updates

Contacts

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Prof. Nikos Pleros
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Dr. Stelios Pitris
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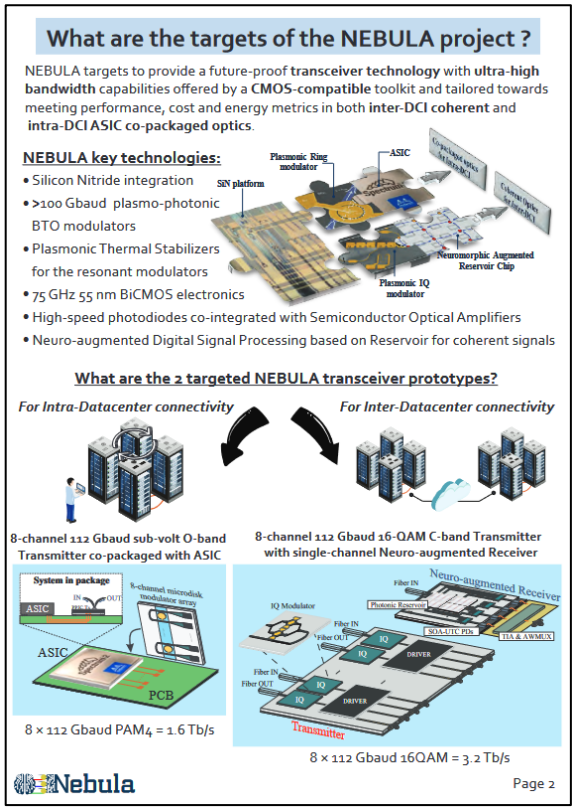
http://nebula-h2020.eu/

The NEBULA project is an initiative of the Photonics Public Private Partnership and has received funding from the European Union's Horizon 2020 Research and Innovation Programme under Grant Agreement No. 871658.


What are the targets of the NEBULA project ?

NEBULA targets to provide a future-proof **transceiver technology** with **ultra-high bandwidth** capabilities offered by a **CMOS-compatible** toolkit and tailored towards meeting performance, cost and energy metrics in both **inter-DCI coherent** and **intra-DCI ASIC co-packaged optics**.

NEBULA key technologies:

- Silicon Nitride integration
- >100 Gbaud plasmo-photonic BTO modulators
- Plasmonic Thermal Stabilizers for the resonant modulators
- 75 GHz 55 nm BiCMOS electronics
- High-speed photodiodes co-integrated with Semiconductor Optical Amplifiers
- Neuro-augmented Digital Signal Processing based on Reservoir for coherent signals

What are the 2 targeted NEBULA transceiver prototypes?

For Intra-Datacenter connectivity

8-channel 112 Gbaud sub-volt O-band Transmitter co-packaged with ASIC

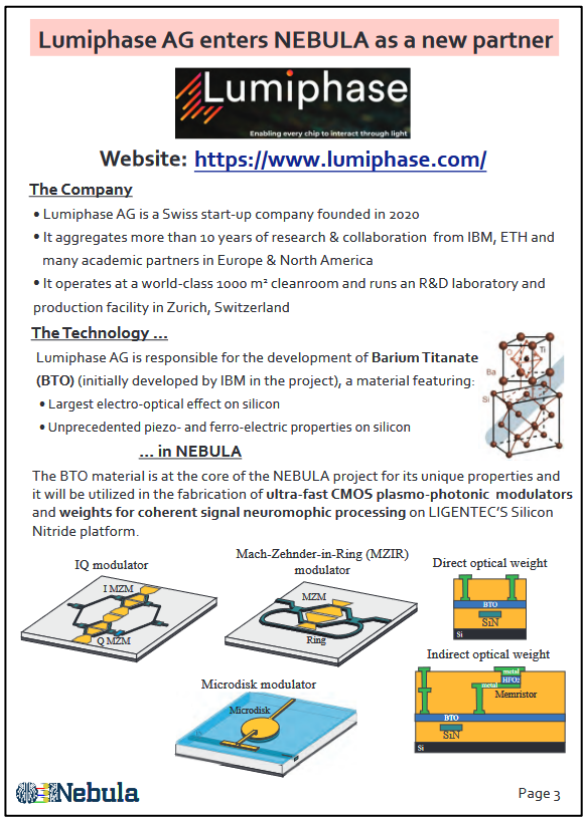
8 × 112 Gbaud PAM4 = 1.6 Tb/s

For Inter-Datacenter connectivity

8-channel 112 Gbaud 16-QAM C-band Transmitter with single-channel Neuro-augmented Receiver

8 × 112 Gbaud 16QAM = 3.2 Tb/s

Nebula Page 2


Lumiphase AG enters NEBULA as a new partner

Lumiphase
Enabling every chip to interact through light

Website: https://www.lumiphase.com/

The Company

- Lumiphase AG is a Swiss start-up company founded in 2020
- It aggregates more than 10 years of research & collaboration from IBM, ETH and many academic partners in Europe & North America
- It operates at a world-class 1000 m² cleanroom and runs an R&D laboratory and production facility in Zurich, Switzerland

The Technology …

Lumiphase AG is responsible for the development of **Barium Titanate (BTO)** (initially developed by IBM in the project), a material featuring:

- Largest electro-optical effect on silicon
- Unprecedented piezo- and ferro-electric properties on silicon

… in NEBULA

The BTO material is at the core of the NEBULA project for its unique properties and it will be utilized in the fabrication of **ultra-fast CMOS plasmo-photonic modulators** and **weights for coherent signal neuromophic processing** on LIGENTEC'S Silicon Nitride platform.

IQ modulator

Mach-Zehnder-in-Ring (MZIR) modulator

Direct optical weight

Microdisk modulator

Indirect optical weight

Nebula Page 3


Dissemination activities

NEBULA was present in 2020 Conferences & Summerschools

NEBULA in the ePIXfab Summerschool

"Prof. Peter Bienstman (UGENT) gave a lecture on Silicon Photonics entitled *Neuromorphic Computing in Si Photonics*"

NEBULA invited talks in Conferences

"Dr. Bert Offrein (IBM) gave 3 invited presentations on Neuromorphic computing in the IPC, ECIO & IEDM Conferences"

NEBULA in Photonics Days BB 2020

"Dr.Stelios Pitris (AUTH) presented the NEBULA objectives and progress in the Photonics Days BB 2020 Conference"

NEBULA in SPIE PW 2020 Conference

"AUTH, LGC & POLIMI participated in SPIE PW 2020 and had a strong presence both in the technical sessions and the exhibition"

NEBULA in ECOC 2020

"Dr. Christophe Caillaud (III-V Lab) gave a presentation on preamplified receivers in ECOC 2020 Conference"

Upcoming in 2021

"Prof. Xin (Scott) Yin (IMEC/UGENT) will give an invited talk in SPIE PW 2021 Conference : "RFIC front-ends for broadband access technologies", 6-11 March 2021

Nebula Page 4

For the ease of access, instead of providing a newsletter pdf, the major subsequent developments of the project regarding technology and dissemination activities were announced in publications (journal and conference papers), presentations, and the NEBULA website.