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Final report on market analysis, standardization activities, competitive analysis, dissemination and exploitation plans

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Abstract

This document reports on the PlasmoniAC consortium's exploitation and dissemination activities that were carried out in the last period of the project. The deliverable includes a competitive analysis and a market study on the areas relevant to PlasmoniAC, an overview of standardization activities, a list of dissemination actions and the detailed exploitation plans of the project partners.

Keywords

Dissemination, exploitation, supply chain, market study, competitive analysis.

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List of Abbreviations

AI	artificial intelligence
ASIC	application-specific-integrated-circuit
BTO	barium titanate
CAGR	compound annual growth rate
CMOS	complementary metal oxide semiconductor
CPU	central processing unit
DCI	data center interconnect
DDOS	distributed denial-of-service attack
DL	deep learning
DPU	data processing unit
EIC	electronic integrated circuit
ETL	extract transform and load
GPU	graphical processing unit
ICT	information and communications technology
IDS/IPS	intrusion detection system / intrusion prevention system
InEC	innovation and exploitation committee
IP	intellectual property
IPR	intellectual property rights
IPU	intelligence processing unit
ML	Machine Learning
MPW	multi-project wafer
OIF	optical interconnect forum
SiOC	silicon oxycarbide
SmartNIC	Smart network interface card
SSL/TLS	secure socket layer / transport layer security
TiO2	titanium dioxide
TO	thermo-optic
TOC	thermo-optic coefficient
TPU	tensor processing unit

1 Executive Summary

This document reports on the PlasmoniAC consortium's exploitation and dissemination activities that were carried out throughout the project. The deliverable includes a competitive analysis and a market study on the areas relevant to PlasmoniAC, an overview of standardization activities, a list of dissemination actions and the detailed exploitation plans of the project partners.

The PlasmoniAC partners have made substantial progress in tracking technology advances in the rapidly evolving neuromorphic computing and datacenter security application fields as well as in identifying exploitation opportunities in relevant market segments. The project has been very well disseminated through talks and publications as well as through its website and by means of high-profile press releases.

PlasmoniAC partners are either tracking or strongly engaged in international standardization activities relating to neuromorphic computing and data center interconnects.

2 Introduction

2.1 Purpose of this document

The PlasmoniAC vision has progressed strongly during the project with the definition of system level and device specifications and its overall integration concept. PlasmoniAC partners are successfully leveraging the collective know how of the consortium with some partners starting to execute strong plans for accelerated exploitation of technologies that will become more mature and further developed by the end of the project.

2.2 Document structure

The present deliverable is split into six main chapters that summarize the PlasmoniAC consortium's exploitation and dissemination activities that were carried out during the last period of the project. More specifically, Chapters 3 and 4 describe PlasmoniAC's competitive analysis and commercialization strategy, Chapter 5 reports on the individual exploitation plans for the PlasmoniAC's partners, whereas Chapters 6, and 7 include the standardization activities and the dissemination and communication activities within the project.

2.3 Audience

This document is public.

3 Competitive Analysis

3.1 PlasmoniAC partner position in market

SOTON: The Zepler Institute part of the university of Southampton is a multidisciplinary research institute for photonics and nanoelectronics. The institute is home to the Zepler cleanroom positioned as a "research clean room" enabling the transitioning from pure research to commercial foundry. As part of this effort a commercial initiative called CORNERSTONE is currently providing an MPW offer in silicon photonics. Southampton and the zepler institute have generated a number of spin-offs over the years including Lumenisity, Fibercore and Fianium (NKT photonics) and licensed IP to a wide range of companies.

VPIphotonics: VPI is a world leading computer aided design software provider specialized in photonic and optoelectronic integrated circuits, fiber optics, optical transmission systems and networks. Further, VPI offers professional consulting services to engineers and scientists addressing their design analysis and optimization requirements. The company also provides training courses on modelling techniques and design automation methods utilizing the capabilities of the powerful simulation framework of VPIphotonics Design Suite. VPIphotonics' award-winning software is in current use at more than 100 corporation and 160 academic institutions worldwide and is cited in more than 1200 technical publications.

Mellanox Technologies (NVIDIA Corp.): Mellanox Technologies (NASDAQ: MLNX) is a leading supplier of end-to-end InfiniBand and Ethernet interconnect solutions and services for servers and storage. Mellanox interconnect solutions increase data center efficiency by providing the highest throughput and lowest latency, delivering data faster to applications and unlocking system performance capability.
Mellanox offers a choice of fast interconnect products: adapters, switches, software and silicon that accelerate application run time and maximize business results for a wide range of markets including high performance computing, enterprise data centers, Web 2.0, cloud, storage and financial services [1].
In 2020, Mellanox Technologies was acquired by NVIDIA Corporation. NVIDIA's invention of the GPU (graphics processing unit) in 1999 sparked the growth of the PC gaming market, redefined computer graphics, ignited the era of modern AI and is fueling the creation of the metaverse. NVIDIA is now a full-stack computing company with data-center-scale offerings that are reshaping industry.

NVIDIA accelerated networking solutions, featuring NVIDIA Quantum InfiniBand and Spectrum Ethernet Platforms, gives enterprises infrastructure flexibility to support develop-to-deploy implementations across all modern workloads and storage requirements that enable a new era of accelerated computing to maximize AI investments.

AMO: AMO is a non-profit "research foundry" and positions itself between purely experimental labs as typically found in universities and bigger commercial foundries. AMO thus has more flexibility in terms of material and process choices than bigger foundries and more technological maturity than experimental labs. This market position is chosen to bridge the gap between fundamental research and applications by researching technologies which can lead to the formation of spin-offs like the Black Semiconductor GmbH or be licensed to other companies. Overall, the non-profit research at AMO overweighs the commercial foundry activity.

Lumiphase is a Swiss start-up founded in 2020 by former employees of IBM Research Europe. They pioneered the research field on $BaTiO_3$ integrated with silicon photonics and developed it to a high level of maturity. Their innovation brings silicon photonics into a new era characterized by the introduction of innovative materials. Today, Lumiphase is the leading manufacturer of BTO-enhanced silicon photonic chips. Our target clients are optical component and network equipment vendors, supplying equipment used to build datacenter and telecom networks. The company has setup an ambitious development plan to supply BTO-based devices to this market.

IBM: IBM is a global technology and innovation company headquartered in Armonk, New York. It is the largest technology and consulting employer in the world, with more than 350,000 employees serving clients in 175 countries. IBM lives at the intersection of technology and business, providing cognitive computing and cloud-based solutions that are changing the way the world works. Utilizing its business consulting, technology and R&D expertise, IBM helps clients become smarter as the planet becomes more digitally interconnected. IBM invests more than $5 billion each year in R&D and, for 26 consecutive years, has earned more U.S. patents than any other organization.

3.2 Overview of PlasmoniAC main competitors

Mellanox Technologies (NVIDIA Corp.): Mellanox Technologies competed with key players in the field of intra-datacenter communications as it was offering a competitive set of products enhanced with advanced security features. Following the NVIDIA acquisition, the product range of the company has been further expanded, with the latest hardware addition being the A30X and A100X and H100 CNX converged accelerators.

On the software side, NVIDIA is offering the Morpheus AI framework for Cybersecurity. Morpheus is a GPU-accelerated cybersecurity AI framework that makes it easy to build and scale cybersecurity applications that harness adaptive pipelines supporting a wider range of model complexity than previously feasible. As a result, the product ecosystem offered by Mellanox (NVIDIA Corp.). Nevertheless, Mellanox (NVIDIA Corp.) is constantly seeking technology solutions that can bring disruptive functionalities to the product lines, further future-proofing their potential Σφάλμα! Το αρχείο προέλευσης της αναφοράς δεν βρέθηκε..

IMEC is an R&D hub for nano- and digital technologies. Imec-IDLab is among the leading research groups on high-speed optical transmitter and receiver circuits in the EU, illustrated by a strong involvement in FP7 and H2020 projects. In this area, the main competitors are high-speed chip vendors such as InPhi, MACOM, Fujitsu, Micram etc. Their market spans from DC and metro to long-haul. These industrial parties are very strong, however, developing a tightly-integrated solution for very-high-speed applications beyond 100GBd is a huge challenge for the companies that target the commercialization of such coherent technologies. This is a great opportunity for this research project as we are developing >100GBd EIC nonlinear activation circuits for neuromorphic computing applications and could provide such IP building blocks (unavailable on the market) or customer design services for system integrators.

IBM is driving the development of memristive devices for neuromorphic computing. Memristive elements are investigated by a broad range of academic groups and institutes. Examples in Europe are CEA-LETI and IMEC but also in Asia and America there is a lot of activity. Startup companies such as NamLAB, MEMRYX, CyberSwarm, Crossbar and others are active in the field. It is also important to realise that memristors are one approach to enhance the efficiency of computing. By adapting the architecture of CMOS chips or by co-integrating existing memory technologies in a more distributed manner, advancements can be achieved. Examples of new architectures based on existing technology are the GPU (NVIDIA), TPU (Google) or also the IPU (Graphcore) and recently IBM announced the TELUM processor for AI inference applications. The advancement of technology is a roadmap where all aspects from materials, devices, and architectures play a critical role.

VPIphotonics competes with a number of design software providers which are specialized in modelling of photonic integrated circuits and optical transmission systems, such as Lumerical, Optiwave and Synopsis. Over the years, VPI has developed extensive experience in developing state-of-the-art software solutions in these areas and has become one of the key software providers. Given the increasing interest in optical neural networks, VPI intends to improve the capabilities of its Machine Learning (ML) Framework to meet the anticipated demand. The PlasmoniAC project will allow VPI to develop a strong background in the simulation of photonic neural networks and its project activities will place VPI ahead of its competitors. In addition to this, VPI will also provide professional consulting and training services to support companies and academic institutions. All these activities will increase VPI's strength and competitive value in optical neural network related markets.

AMO: In terms of foundry business AMO competes mainly with smaller foundries offering more flexibility than strict design rules of multi project wafer runs at bigger foundries like IMEC, CEA LETI, IHP, VTT, AIM Photonics, IME / AFM, Global Foundries etc. Smaller foundries offering silicon nitride technology include e.g. SOTON, Ligentec, CNM-CSIC and LioniX. For Si_3N_4 passives AMO's optical lithography (6" wafers, 365 nm i-Line illumination) is surpassed by the equipment available to some competitors, e.g. 8" wafers with 248 nm illumination at SOTON. AMO's unique advantage relevant to the exploitation of PlasmoniAC is the 2D-Pilot Line. This currently ongoing activity aims to establish 8" wafer scale processes for graphene and other 2D materials at a TRL suitable for a research foundry like AMO. To the best of our knowledge no competitor can match this today.

Lumiphase: As a newly established company, Lumiphase competitors are of different type but all active in the field of silicon photonics. Well established companies exploiting either standard (Intel, Globalfoundries) or innovative approaches to silicon photonics (Sicoya, AyarLabs), will competing with Lumiphase on the datacom markets. On the other side of the spectrum, newly established companies are exploiting novel materials integrated in silicon photonics and also represent a disruptive approach to enhance silicon photonics (Scintil, Hyperlight, Polariton). Such companies will also compete in adjacent, niche markets.

3.3 IPR and publications watch

The results stemming from the project are constantly monitored by the Innovation Committee and the Steering Committee and opportunities for IP protection for potential exploitation are evaluated.

In this context AUTH has already submitted three patent applications at USPTO
1) N.Pleros et. al. "*Neuromorphic photonics with coherent linear neurons" US Patent App. 17/305,486 2022.*
2) N. Pleros et al., "Coherent photonic computing architectures" US Patent App. 17/395,849, 2022.
3) N. Pleros et al., "Fidelity-restorable photonic linear operator" US Patent App. 17/957,731, 2023.

as means to protect the concept of phase-encoded neuromorphic engines. In the following months additional results will be evaluated and included potentially in an extended version.

MLNX (NVIDIA Corp.) has submitted a patent application to the USPTO, considering detection of reconnaissance attacks (D. Syrivelis et. al. *"REAL-TIME DETECTION OF NETWORK ATTACKS"*).

IBM submitted a patent on memristive devices: B.J. Offrein, V. Bragaglia, R. Dangel et al., CONTROLLING VOLTAGE RESISTANCE THROUGH METAL-OXIDE DEVICE, Filed at USPTO on 17-12-2020, P202003685US01

4 Commercialization strategy

4.1 Total addressable market (TAM)

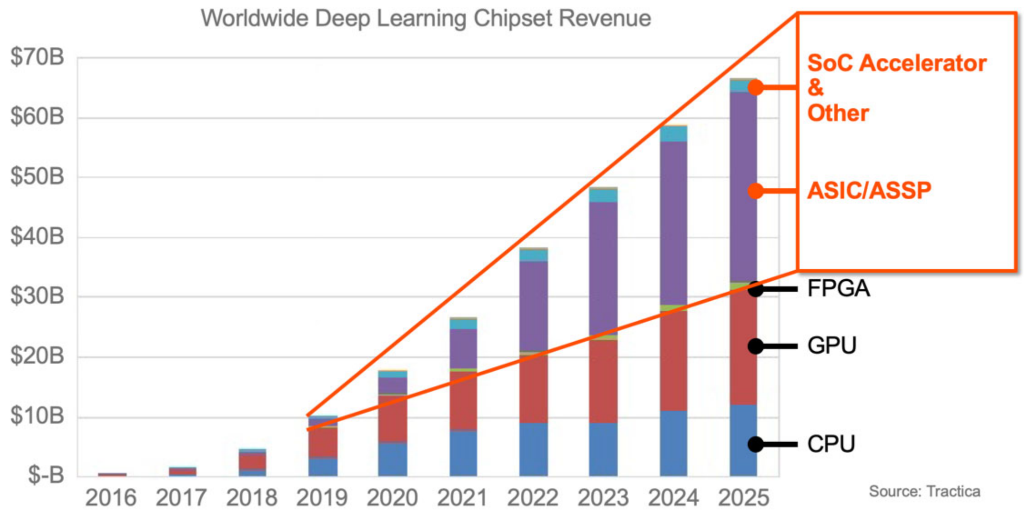

Figure 1. Worldwide chipset revenue for deep learning, split among technologies. Source: Tractica, with Arteris IP overlay. From https://semiengineering.com/ai-wheres-the-money/

Figure 1 graph above shows that GPUs are the clear market leader for deep learning (DL) today. However, other types of different hardware, architectures and chipset are emerging. ASIC/ASSP implementations, such as Google's TPUs, are gaining significant traction due to their unique performance characteristics. Nevertheless, these accelerators include specialized processors, bounded to more restricted usage compared to general purposes counterparts. NVIDIA's converged accelerators are another example of future versatile high-end architecture for AI workloads. The NVIDIA A30X [3] combines the NVIDIA A30 Tensor Core GPU with the BlueField-2 data processing unit (DPU), whereas the NVIDIA A100X brings together the power of the NVIDIA A100 Tensor Core GPU with the BlueField-2 DPU. On the other hand, the NVIDIA H100 CNX [4] combines the power of the NVIDIA H100 Tensor Core GPU with the advanced networking capabilities of the NVIDIA ConnectX-7 smart network interface cards (SmartNICs). Clearly, those accelerators combine the powerful performance of NVIDIA GPUs with the enhanced network and security of NVIDIA and DPUs SmartNICs. As such, those units will be able to power high-performance 5G application frameworks, enabling AI-on-5G on the Edge. In addition, the converged accelerators open up a new range of possibilities for AI-based cybersecurity and networking.

The neuromorphic accelerator established in PlasmoniAC fits in this new type of accelerators. Its success will depend on the ability to outperform in some key metrics critical for neuromorphic computing and signal classification. Here we see the following aspects playing an important role: Compute efficiency, form factor, accuracy, latency, bandwidth, technological maturity, and cost. We see clear prospects for the type of photonic accelerators as established in PLASMONIAC in the ability to handle high-speed signals and latency. The technical maturity is provided to a major extend as integrated optic technology and now is widely applied for high-bandwidth optical communication. Open questions remain on the total cost and power efficiency. The latter strongly depends on the integration of the accelerator into the system and the related power consumption of the periphery and data transfers. However, photonics does have several clear merits, as stated, with respect to the bandwidth and latency. In this respect, the update speed and accuracy of the BTO based weights/modulators are an important advantage as it allows a fast update of the accelerator configuration. This capability is also present in digital electronics but many electrical analog signal processing concepts, such as memristors, often show a level of stochastic behaviour in setting the weight value. This may impose the need to perform a feedback-based weight update, increasing the latency, power consumption and complexity of the system. The envisioned DDOS attack detection application as pursued in PLASMONIAC, is a good example of an ultra-high-speed application where optics can make a decisive difference. Any successful outcome of the project can be exploited in converged accelerators, either replacing existing fabrics, or most importantly, boosting the current architecture with unique real-time DDOS detection capabilities.

Figure 1 also reveals that the total DL chipset market is expected to reach a value of $70B by 2025. Only a fraction of this market is sufficient to drive further investments in PLASMONIAC technology and mature the concepts towards application.

The approach pursued by Lightmatter for performing the synaptic operation in deep neural networks is to a large extend in line with PLASMONIAC. Integrated optic architectures are implemented for performing dedicated neural network operations. Lightmatter actively uses the ability to update the accelerator matrix coefficients, allowing their statement to also calculate very large-scale neural networks. The anticipated deep neural network inference compute efficiency enhancement improvement compared to GPU based systems is a factor of 6 (https://medium.com/lightmatter/introducing-envise-idiom-and-passage-next-generation-ai-compute-compile-and-interconnect-331878d6cea5) as announced in March 2021. This moderate improvement is based on the energy required for transferring data and updating the accelerator coefficients. Still, analog signal processing provides its merits in a better signal processing power efficiency.

4.1.1 Data Center environment (Ethernet Switches and SmartNICs)

In Deliverables D7.5 and D7.6, market data on Ethernet Switch and SmartNICs revenues for DCs have been provided. The target was to identify the growth potential of the hardware products that are directly linked with the deployment of PlasmoniAC's technology. In other words, since PlasmoniAC is pursuing the development of real-time DDOS attack recognition technology, the most meaningful Data Center usage will be either in the Ethernet Switches or at the SmartNICs. This way, PlasmoniAC's potential can be fully exploited, providing protection at the massive data traffic scale of a Leaf or Spine DC switch, while securing the network all the way to the edge with Photonics-AI powered SmartNICs.

According to the updated forecast revenues in the Ethernet Network Switch market, the 25G and 100G generation have already reached a plateau and are expected to decline in the coming years, whereas the 50G will only marginally receive a market share, signaling the worldwide transition to higher speeds. At the same time, the 400G generation is expected to rapidly grow in the 1-2 coming years, eventually becoming the dominant speed in the market. Nevertheless, the deployment pace will be moderated soon, as the 800G generation is expected to kick-in and rapidly increase its market share.

The forecast for the SmartNIC revenues is similar to the forecast revenues in the Ethernet Network Switch market. The main difference here is the lack of the 800G market, since SmartNICs are deployed at the server side. Nevertheless, the transition to higher speeds is clearly shown by the 100G, 200G and 400G trends, that are expected to grow rapidly in the coming years. In fact, 100G is now becoming the dominant speed in this market, largely replacing the previous generations (such as 25G and 50G) that are now expected to slowly decrease. The overall SmartNIC revenues are obviously much more limited compared to the Ethernet Switch market, however the expected growth is significant. Given the increased data movement requirements, a lot of network-related functions like cybersecurity and even part of streaming analytics computations is offloaded to network hardware (in-network processing). With line rates soon reaching 800Gb/s per port, the processing of network traffic in real-time becomes challenging for classic accelerators. Neuromorphic photonics-based acceleration can come to the rescue and primarily be used for targeted network data pre-processing where every nanosecond matters. The PlasmoniAC approach is particularly relevant, implementing traffic pattern analytics on network flows of Billions of packets per second that go through state-of-the-art switch devices and be used for attack vector detection, application performance optimization and utilization statistics. Network analytics are primarily carried out offline today. Traces are fed to different analytics algorithms to provide insights in what is happening in the network. The value proposition is to determine online what needs to be looked up with priority and even gain some early insights into the problem, without relying on the slow deep inspection. As DC compute and network infrastructure scales, the technology explored by Plasmoniac is becoming more relevant and will enable the retainment of thorough infrastructure control which for Cloud Service Providers is of significant market value.

4.1.2 Analog synaptic and neuromorphic accelerators

IBM is exploring both electrical and photonic neuromorphic accelerators exploiting analog signal processing. The memristive devices developed in PLASMONIAC, for realizing non-volatile optical weights, are in line with activities in IBM's AI Hardware Center [5]. This is open collaborative effort in which technologies, algorithms and applications related to neuromorphic computing are established with partners. Analog signal processing in memristive crossbars is anticipated to improve the performance to power efficiency ratio for neural network inference and training by several orders of magnitude compared to today's digital systems.

4.1.3 Neuromorphic Computing

Neuromorphic computing has the potential to boost real-time analytics. Contrary to traditional digital accelerators which need to be materialized as distributed entities to keep up with the data rates, neuromorphic accelerators can be more centrally deployed due to the very low propagation delays, providing for a significantly faster approach to crunch data online and get some very early insights in what is happening in large scale infrastructures. This is of particular importance in cybersecurity, as countermeasures to mitigate an attack need

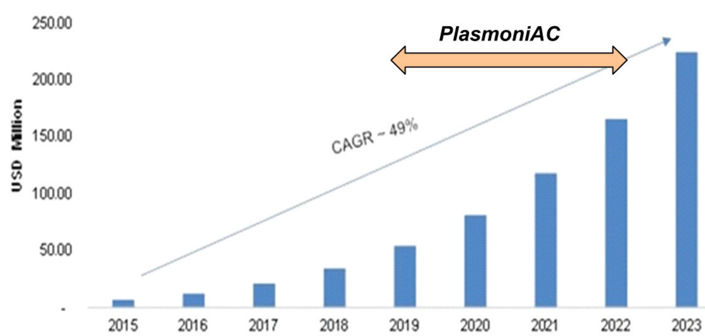

Figure 2: Market forecasts for neuromorphic computing.

to be taken instantly rather than offline. The greater the ability to crunch data, the more sophisticated the AI schemes that can be used at runtime. Given the initial detection of an event by the neuromorphic accelerator a more focused analysis can be carried out by traditional accelerators that are able perform deeper analytics, which will now be able to cope with the traffic as they will be only looking at a subset of the data that is annotated/pre-processed by neuromorphic accelerators. As the data movement ability of future datacenter systems increases significantly with each generation, PlasmoniAC expects neuromorphic solutions to be attractive for cybersecurity and AI applications that can heavily benefit from in-network but more centralized processing, running inside routers and switches that handle large volumes of traffic. Though still being in its infancy as a market sector, market forecasts expect a dramatic growth with Figure 2 revealing a CAGR of ~49% between 2015-2023 with a total market size reaching almost USD 250 Million. These values are projected to reach even higher metrics when extending the period until 2025, projecting a CAGR of ~86.3% to reach a total market of USD 1.78 billion, confirming not only a constant growth but also a constantly increasing exponential growth rate [6][7].

5 Partner individual exploitation plans

5.1 AUTH

The academic exploitation plans include mainly the support of PhD student research, the enrichment of the lecturing materials in relevant courses, and the creation of training programs for young students and researchers.

Master and PhD students have been involved in the theory, design and experimental testing of PlasmoniAC's neuromorphic computing architectures gaining significant experience in the design of the silicon photonic elements and the system level evaluation strategies targeted within PlasmoniAC, aiming at highly rated publications to both scientific journals and conferences.

Research aspects:

AUTH exploitation plans include the reinforcement of new R&D activities in the field of neuromorphic photonics and DCIs. The activity in PlasmoniAC has already led to new ideas capable to form the basis of new research proposals and patent fillings. In this rationale, AUTH intends to take advantage of the expertise gained in PlasmoniAC in order to pursue new research contracts within H2020 and to sustain the group's leading position in the field.

5.2 SOTON

Development of CMOS compatible high efficiency photonic building blocks serving application for interconnects and compute is fully in line with SOTON's strategy. The Silicon nitride photonic platform developed in SOTON enables material and process enhancement which are made available to end users through the CORNERSTONE MPW initiative (https://www.cornerstone.sotonfab.co.uk). The exploitation of IP established in SOTON is realised through licensing, technology transfer and joint development collaborations, both internally and externally.

5.3 ETHZ

In one of ETHZ's research fields, the focus is on designing and developing of the fastest and most efficient modulators. Plasmonics is the key technology that makes this possible. New materials like barium titanate together with sophisticated design may pave the way to next-generation modulators. The newly acquired knowledge can be beneficial in building neurons during PLASMONIAC but also in other applications like for example, THz and optical communication. With strengthened relationships within the partners, novel collaborations within the realm of spin-offs (Polariton Technologies) might emerge.

From an academic perspective, ETHZ will exploit the acquired know-how for performing advanced research and producing results that could be published in high-level conferences and journals in computing, nanoelectronics, plasmonics, nano-photonics and DL. In particular, the results will be published to top scientific journals, magazines, and conferences. Finally, ETHZ also focuses on enhancing the Ph.D. students' knowledge and expertise in the PlasmoniAC's technology fields. This knowledge will be transferred to the industry, after the completion of their degree.

5.4 UBFC

The specific tasks uBFC is in charge of in the framework of plasmoniAC leads to the development of new fabrication process for deposition and micro-structuration of thermo-optic (TO) materials on top of a temperature insensitive low-loss optical circuitry. This "add-on-top" approach for the fabrication of phase shifters and thus thermo-optic weights is highly versatile and allows for the deployment of different TO materials onto the same phase shifter. For example, materials featuring opposite sign thermo-optic coefficients such as titanium dioxide (TiO_2) and Si-rich silicon nitride SiN can be deployed on each arm of a 1x1 Mach-Zehnder interferometer leading to an additive contribution of the phase shift applied on each arm of the interferometer. In addition, the opto-geometrical parameters of the "add-on-top" configuration developed by uBFC can be readily tuned to achieve state-of-the art Si-based linear phase-shifter energy efficiency (pi-power below 20mW) and activation voltages (around 1V) compatible with CMOS technology. Furthermore, the demonstration of 3dB-bandwidth of phase shifters in the range of 150 kHZ make the “add-on-top” approach relevant for fast reconfiguration. The dissemination of uBFC results has been achieved by standard channels including publications in peer-reviewed, technology oriented international journals and conferences. The results obtained by uBFC in the context of plasmoniAC have been reported in an article co-authored by Ioannina and Thessaloniki universities in Optics Material Express and through the C-Nano Conference held in France in March 2023. Further dissemination activities in collaboration with SOTON are conducted at the time of writing of this report.

5.5 CNRS

PLASMONIAC will allow CNRS to develop novel technologies for neural networks based on InP on SOI photonics crystal cavities. As an academic partner the goal of CNRS is to push radically new approaches and gain knowledge. To pass on this knowledge to PhD students and use it to pursue new research within European projects are CNRS priorities. CNRS exploitation plan also includes patent filling as well as pushing researchers towards the creation of spin off companies in order to exploit the generated intellectual property.

5.6 IMEC

In PlasmoniAC, imec-IDLab worked on high-speed nonlinear activation circuits for neuromorphic computing applications. PlasmoniAC enhances the imec – IDLab – design know-how on optical front-end ASIC design and leads to a new application research domain in the group. This world-class expertise will contribute to the IDLab - design courses and Master thesis proposals on high-speed electronics and high-frequency design and reach more than 25 Master students in electronics engineering at Ghent University yearly. The project cooperation has helped us to attract new PhD students and to perform high-level PhD research. The recruitment of such high-tech post-docs by industry is a very effective form of knowledge transfer.

Exploitation and valorisation of imec’s research results can be realized by a direct technology transfer to industrial partners, by a license agreement, by a bilateral contract to develop a more industrial prototype, and by creating spin-off activities. For example, our expertise on high-sensitivity linear optical receiver circuits is now being applied in optical sensors for glucose. In this context, in December 2016, our group co-founded a spinoff “Indigo Diabetes” aiming to exploit silicon-photonics spectrometer sensor systems for glucose measurements. In the area of high-speed optical transceivers, the BiFAST team was spinned off from imec-Ghent University in April 2017. For this purpose, imec-IDLab became an academic member of the Optical Interconnect Forum (OIF).

5.7 IBM

Neuromorphic hardware is one of IBM’s strategic initiatives to advance and exploit novel computing paradigms. The “AI Hardware Center” (https://www.research.ibm.com/artificial-intelligence/ai-hardware-center/) is fully in-line with this strategy. Building on IBM’s tradition in open collaboration, the AI Hardware Center provides a global platform for companies at all levels of the supply chain to interact and contribute to establishing neuromorphic technology. Analog signal processing is a key element of the AI Center, with a focus on memristive devices. IBM Research also invests in other technology platforms such as integrated photonics to evaluate and demonstrate the dedicated potential for neuromorphic hardware. The exploitation of IP established in IBM Research is realised through licensing, technology transfer and joint development collaborations, both internally and externally.

IBM is open to licensing the technology established in PLASMONIAC to manufacturing and other partners to bring it to the market for application in its own as well as in other systems.

5.8 AMO

AMO’s main exploitation route is through its spin-off Black Semiconductor GmbH, which was founded in 01/2020. The startup focusses on the convergence of photonics and electronics to combine the best of both worlds into revolutionary microchips. Black Semiconductor may benefit from licensing the developments in PlasmoniAC if the plasmonically enhanced photodetectors achieve better performance or easier integration than their current state-of-the-art. AMO is open to cooperate with other companies for exploitation, as there is no exclusive agreement with Black Semiconductor.

A second major exploitation route is through AMO's open-to-all foundry services, including contract research. AMO's Photonic Foundry activities have been strongly growing in recent years. Within the Graphene Flagship AMO is participating in building up an 8" Pilot Line for commercial graphene devices. These activities can benefit greatly from a highlight device like a high-performance photodetector resulting from PlasmoniAC. Further exploitation at AMO is planned in the form of future national or European research projects based on the PlasmoniAC outcomes. The purpose of these activities is to accelerate the technology transfer into industry. Such projects benefit the two largest research groups in AMO, Nanophotonics and Graphene.

5.9 MLNX

Mellanox Technologies (NVIDIA Corp.) offers one of industry's broadest portfolios of end-to-end InfiniBand and Ethernet interconnect solutions and services for servers and storage. Since the acquisition by NVIDIA, the product lines have been further expanded, with the latest addition being the A30X, A100X and H100 CNX converged accelerators described in the previous paragraphs.

On the software side, Mellanox as part of the NVIDIA Corporation, offers Morpheus [8], GPU-accelerated cybersecurity AI framework that make it easier for developers to build cybersecurity solutions. NVIDIA Morpheus, shown in Figure 3, is an open application framework that enables cybersecurity developers to create optimized AI pipelines for filtering, processing, and classifying large volumes of real-time data. Bringing a new level of information security to the DC, cloud, and edge, Morpheus uses AI to identify, capture, and act on threats and anomalies that were previously impossible to identify. Morpheus makes it possible to analyse up to 100 percent of your data in real-time, for more accurate detection and faster remediation of threats as they occur. Morpheus also provides the ability to leverage AI to adjust to threats and compensate on the fly, at line rate. With Morpheus organizations can attack the issue of cybersecurity head on.

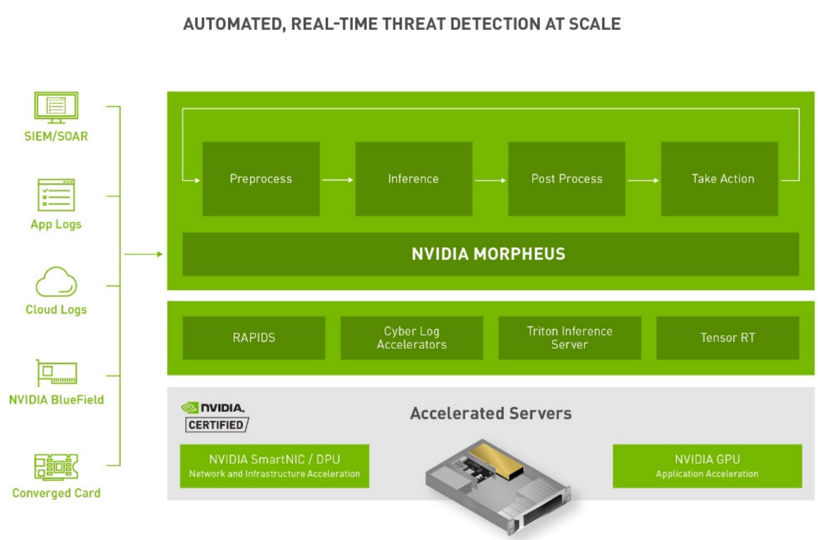

Figure 2: NVIDIA Morpheus Open AI Framework for Cybersecurity Providers

With the world in a "discover and respond" state, where companies are finding breaches much too late, in a way that is way behind the curve, NVIDIA's Morpheus cybersecurity AI framework enables any organization to warp to the present and begin to defend itself in real time [9].

- Massive Performance and Scale - Morpheus is GPU-accelerated enabling, for the first time, the ability to inspect all network traffic in real-time, flag anomalies, and provide insights on these anomalies so that threats can be addressed quickly. It enables AI inference and real-time monitoring of every server and packet across the entire network.

- Rapid Development and Deployment - Morpheus integrates AI frameworks and tools that make it easier for developers to build cybersecurity solutions. Organizations that lack AI expertise can still leverage AI for cybersecurity because Morpheus leverages tools for every stage of the AI workflow, from data preparation to training, inference, and deploying at scale.

- Real-time Telemetry - The Morpheus native graph streaming engine can receive rich, real-time network telemetry from every NVIDIA BlueField DPU-accelerated server or NVIDIA AppShield in the DC without impacting performance. Integrating the framework into a third-party cybersecurity offering brings the world's best AI computing to communication networks.

- AI Cybersecurity Capabilities – Deploy your own models using common DLframeworks. Or use a Morpheus pre-trained and tested model to get a jump-start in building applications to identify leaked sensitive information, detect malware or fraud, do network mapping, flag user behavior changes, and/or identify errors via logs.

Throughout the project Mellanox (NVIDIA Corp.) aims to evaluate the PlasmoniAC technology in realistic application scenarios and assess the performance and future potential.

5.10 VPI

VPIphotonics aims to extend its product capabilities in the area of plasmonics, neuromorphic circuits and novel computing applications. VPI intends to apply its experience in the field of the simulation of photonic neural networks and extend its state-of-the-art DL Framework with advanced capabilities of system-level modelling features of photonic neural networks defined during the project period. This will include adding an integrated control software tool to obtain automated control options to create and manage photonic neural networks, as depicted in Figure 4. The framework will be enriched with novel demo examples and noise-aware training features. Photonic neural network-based computing methods are expected to take the attention of different industry areas and as a result, there will be increasing demand for such software solutions. VPI will be able to fulfil these market needs, and this will place VPI in a leading position. VPI will also offer product training and technical consulting services to its new or existing customers. New modules and application examples are expected to be ready for release as prototypes shortly after the project completion date.

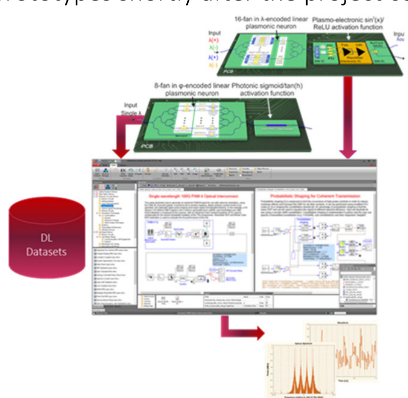

Figure 3.VPI's suite synergizing plasmo-photonic neuron architectures and state-of-the-art DL algorithms.

5.11 Lumiphase

In the context of PlasmoniAC, Lumiphase is developing the BTO technology and support its integration in plasmonic devices or together with memristive devices. The foreground developed in PlasmoniAC relates to materials innovation and integration processes for BTO. As such, it will find a direct exploitation path in Lumiphase's photonic technology platform. This platform is currently exploited in Lumiphase's product but is also leveraged in several government funded projects. Lumiphase can therefore also exploit PlasmoniAC's foreground to enable other European companies or research institution to innovate.

6 Standardization

Network analytics stack is fast growing, and several vendors are building components in the space. For instance, Mellanox (NVIDIA Corp.) offers Morpheus, a GPU-accelerated cybersecurity AI framework, shown in Figure 5, that makes it easy to build and scale cybersecurity applications that harness adaptive pipelines supporting a wider range of model complexity than previously feasible.

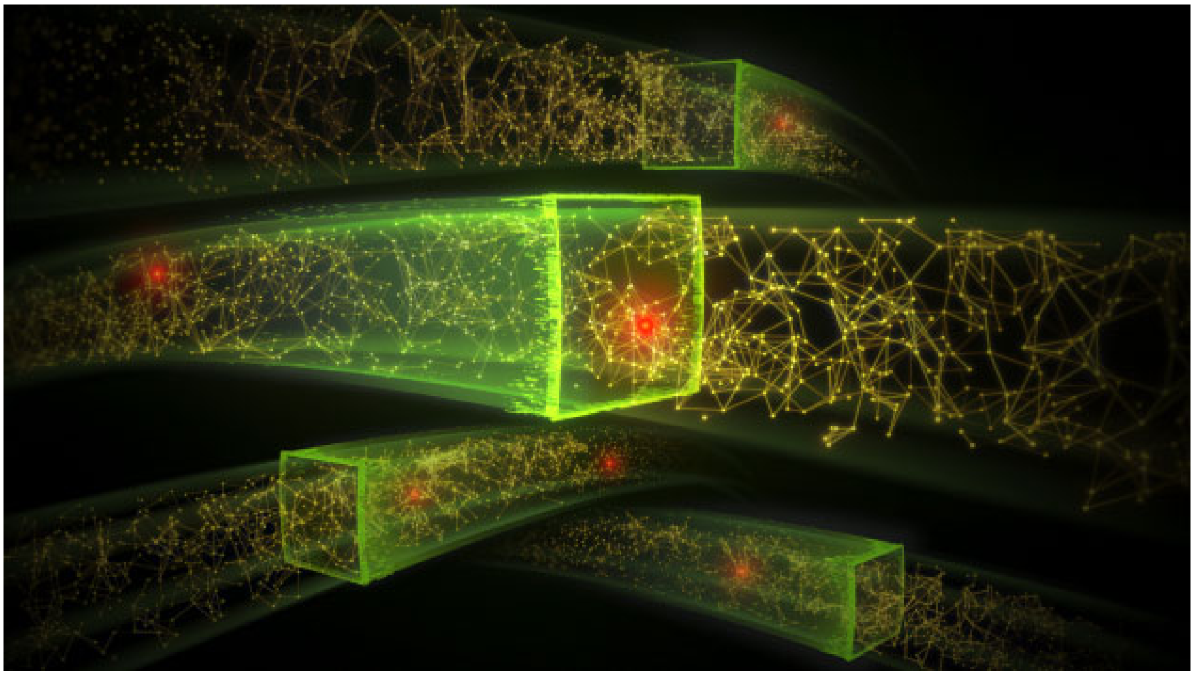

Figure 4: NVIDIA Morpheus application framework

As datacenters scale, network analytics are becoming very important and they are becoming integral part of the Artificial Intelligence for IT operations (AIOps), where AI is employed to understand and assist with IT problems that have become intractable for humans detect/understand on a large-scale system. AIOps is a new field and there are several different approaches that are proposed currently, but given the plurality of the IT operations centralized standards start to appear, for the time being at the higher levels of the stack e.g. for analytics data representation. Typical AIOps pipeline performs the ETL scheme, “Extract, Transform and Load” and currently the data Extract step which is amenable to PlasmoniAC technologies currently custom for most network devices.

The data extraction and light pre-processing from logging devices will unavoidably have to be governed by a standard as more AIOps solutions emerge. The consortium aims to look in the standardization efforts in this space and introduce the necessary hooks for the integration of neuromorphic acceleration in AIOps data extraction pipelines.

7 Dissemination and communication activities

A series of communication activities have been pursued during the project for public and scientific community awareness. Those are summarized as follows:

Organization of #2 workshops on Neuromorphic photonics

PlasmoniAC consortium in collaboration with other H2020 EU projects co-organized tow highly appealing workshops in the field of neuromorphic photonics. The organization committee comprised of several individual project partners.

Specifically, the "1st Workshop on Neuromorphic photonics" was held online during the COVID-19 pandemic period (6-7 December 2021) and was organized in the frame of the H2020 EU projects PLASMONIAC (http://www.plasmoniac.eu/), NEBULA (http://nebula-h2020.eu/) and NEOTERIC (https://neoterich2020.eu/). A total of 15 invited talks were given from distinguished academic and industry experts. A parallel young research poster session was held during the last day of the event, with the participants in the whole workshop surpassing 100, with more than 70 connected at the same time. The proceeding of the workshop in both pdf and video format are accessible on-line through AUTH's file sharing platform, allowing the distillation of the acquired knowledge across the photonic scientific community. The site of the workshop where more relevant information is accessible online at: http://plasmoniac.eu/workshops/home.html.

The "2nd Workshop on Neuromorphic photonics" was held on-site (12-14 July 2023) in the University of West Attica and was organized in the frame of the H2020 EU projects PLASMONIAC (http://www.plasmoniac.eu/), PROMETHEUS (https://prometheus-he.eu/) and NEOTERIC (https://neoterich2020.eu/). A total of 20 invited talks were given from distinguished academic and industry renowned speakers from all over the globe, that covered the subject in different aspects presenting the latest achievements in the fields of neuromorphic photonic engineering and optical neural networks. The site with the workshop details can be retrieved by: https://rncp.eu/workshop/.

Additionally, PlasmoniAC's achievements were disseminated in prestigious workshops, journals and conferences:

Dissemination activities

- Workshops/Symposia/Booths

[1] N. Pleros, "Plasmonics in CMOS foundries: a new toolkit for PICs", PIC International Conference, Nov. 2020 (online)

[2] G. Dabos, A. Totovic and N. Pleros "Neuromorphic Photonic Architectures" DATE Conference 2020, Grenoble (online)

[3] Workshop "Integration of novel materials into silicon photonics", November 21-22, 2022, Axchen, Germany.

[4] A. Tsakyridis, "Universal Linear Optics in Neuromorphic Photonics", ECOC, Basel 2022

[5] M. Moralis-Pegios, "Silicon Photonics for Data Center interconnects and security applications", ECOC Basel 2022

[6] M. Moralis-Pegios, "High-speed Silicon Photonic neuromorphic computing enabled by hardware-aware deep learning methods", Mini-symposium "Photonic Neuromorphic Computing" AOP, Guimaraes 2022

[7] M. Moralis-Pegios, "Compute with Light: Architectures, Technologies and Training Models for Neuromorphic Photonic Circuits", 1st workshop on Neuromorphic Photonics 2022

[8] G. Giamougiannis, "Universal linear optics for neuromorphic computing", EPFL-Swiss photonics 2023

[9] M. Moralis-Pegios, "High-speed Silicon Photonic neuromorphic computing enhanced by hardware-aware deep learning methods", 2nd workshop on Neuromorphic Photonics 2022

[10] J.-C. Weeber, A. Andrieux, J. Arocas, L. Markey, K. Hammani, A. Bouhelier, D. Bellas, E. Lidorikis, N. Pleros, "Time-scale dependent sign of Titanium dioxide thermos-optic coefficient", Conference C'Nano, 15-17 March 2023, Poitiers, France

- Invited Talks

[1] B.J. Offrein, "Integrated Photonics for Neuromorphic Computing, PIC International", Brussels 8-11-2021 (Invited)
[2] B.J. Offrein, "Neuromorphic Computing on integrated Photonic Circuits, Group IV Photonics", 7-12-2021 (Invited)
[3] B.J. Offrein, J. Geler-Kremer, J. Weiss, R. Dangel, P. Stark, A. Sharma, S. Abel and F. Horst, "Volatile and non-volatile optical weights in photonic neuromorphic computing", CLEO2021, 10-5-2021 (Invited)
[4] G Dabos, G Mourgias-Alexandris, A Totovic, M Kirtas, N Passalis, A Tefas, N Pleros, "End-to-end deep learning with neuromorphic photonics", SPIE Photonics West OPTO 2021.
[5] N. Pleros and A. Tefas, "", IEEE Photonics Summer Topicals, July 2021 (online)
[6] N. Pleros et.al, "Compute with Light: Architectures, Technologies and Training Models for Neuromorphic Photonic Circuits" ECOC 2021
[7] M. Moralis-Pegios et. al., "Coherent Photonic neuromorphic computing for high-speed Deep Learning applications", SPIE Photonics West 2022
[8] M. Moralis-Pegios et al., "Photonic Neuromorphic Computing: Architectures, Technologies, and Training Models," 2022 Optical Fiber Communications Conference and Exhibition (OFC), San Diego, CA, USA, 2022, pp. 01-03.
[9] M. Lemme "Two-Dimensional Materials for Nanolectronics and Photonics", IU.NET Days, Modena, Italy, September 10-11, 2020
[10] M. Lemme "Graphen und weitere zweidimensionale Materialien aus der Nanotechnologie", Rotary Club Aachen, 22.09.2020
[11] M. Lemme "A European Experimental Pilot Line for Wafer-scale Integration of Graphene and 2D Materials", Pacific Rim Meeting on Electrochemical and Solid State Science, PRIME, Hawaii, USA, October 4-9, 2020
[12] M. Lemme "Two-dimensional Materials and Devices: Promising Concepts for Emerging IT Applications", International Conference on Solid-State Devices and Materials, SSDM, Toyama, Japan, September 27-30, 2020
[13] M. Lemme "Anwendungspotenziale zweidimensionaler Materialien in der Mikro- und Nanotechnologie", 8. GMM-Workshop und BMBF-Workshop des VDE Verband der Elektrotechnik Elektronik Informationstechnik e.V., Bochum, September 15-16, 2020
[14] M. Lemme, "2D Materials for Artificial Intelligence Systems - Eyes, Ears, Nose and Brain?", Graphene Canada 2020
[15] G. Rinke, "Wafer Scale Integration of Graphene - 2D Experimental Pilot Line at AMO", Graphene4US 2020.
[16] Z. Wang, "Wafer Scale Integration of Graphene", GO2021.
[17] M. Lemme, "European Experimental Pilot Line for 2-Dimensional Materials", NIL Industrial Day 2021.
[18] M. Lemme, "2-Dimensional Materials for Silicon Integration", 2021 NSF Workshop on CMOS+X Technologies.
[19] A. Tsakyridis et. al., "Accelerating linear operations with light", IEEE Photonics Summer Topicals, July 2023
[20] A. Totovic, A. Tsakyridis, G. Giamougiannis, M. Moralis-Pegios, G. Dabos, G. Mourgias-Alexandris, N. Pleros, "On-Chip > 100 TMAC/sec Neuromorphic Photonics Turning into Reality", (Invited), IEEE Photonics in Switching conf., Sept. 2021
[21] A. Tsakyridis, G. Giamougiannis, A. R. Totovic, M. Moralis-Pegios, N. Pleros, "Fidelity-Restorable Universal Linear Optics and Neuromorphic Photonics", (Invited), Conf. on Lasers and Electro-Optics (CLEO) 2022, San Jose, CA, USA, May 2022
[22] S. Suckow, "2D-material based photodetectors for mid-IR sensing", Graphene 2022, Aachen
[23] Z. wang, "2D/3D Heterostructure Diodes for High Performance Electronics and Optoelectronics", Graphene 2022, Aachen

[24] Z. Wang, “Wafer-Scale Integration of 2D Materials for Application in Electronics”, LIMNI Workshop KULeuven, 2022

[25] S. Suckow, Opening of AMO workshop on “Integration of novel materials into silicon photonics”, 2022

[26] S. Suckow, “Neuromorphic Computing - At the intersection between Electronics and Photonics”, ICOS Workshop on Sustainable Electronics & International Cooperation on Semiconductors, 2023

- Conference Proceedings

[1] B.J. Offrein, Jacqueline Geler-Kremer, Jonas Weiss, Roger Dangel, Pascal Stark, Ankita Sharma, Stefan Abel, Folkert Horst, "Prospects for photonic implementations of neuromorphic devices and systems", IEDM 2020 (Invited)

[2] B.J. Offrein, "Ferroelectric Phase Shifters in Silicon Photonics for novel Types of Optical Computing", MRS Fall Meeting, 2020

[3] B.J. Offrein, "Opportunities for integrated optics in neuromorphic computing", PIC International II, 2020

[4] P. Stark, B.J. Offrein, "Opportunities for analog signal processing in the electrical and the optical domain", WS5, ECOC 2020

[5] G. Dabos, A. Totovic, N. Passalis, A. Tefas, and N. Pleros, “Femtojoule Technology Roadmap for TeraMAC Neuromorphic Photonic Accelerators”, IEEE Photonic Conference 2020 (IPC2020)

[6] B.J. Offrein, "Analog optical accelerators for neuromorphic computing", Cadence Photonics Summit, 2020

[7] G. Mourgias-Alexandris, N. Passalis, G. Dabos, A. Totovic, A. Tefas, and N. Pleros, "Time-series classification with an all-optical recurrent neuron", ECOC 2020, Brussels, 6-10 December 2020

[8] G. Mourgias-Alexandris, G. Dabos, N. Passalis, A. Tefas, A. Totovic, and N. Pleros, "All-optical recurrent neural network with sigmoid activation function", in Optical Fiber Communication Conference (OFC) 2020, OSA Technical Digest (Optical Society of America, 2020), paper W3A.5

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[12] George Dabos, George Mourgias-Alexandris, Angelina Totović, Nikolaos Passalis, Anastasios Tefas and Nikos Pleros, "Photonic Recurrent Neural Networks with Gating Circuit" CLEO 2020 OSA (Virtual Conference)

[13] N. Passalis, M. Kirtas. G. Mourgias-Alexandris, G. Dabos, N. Pleros and A. Tefas, "Training noise-resilient recurrent photonic networks for financial time series analysis", in EUSIPCO 2020

[14] George Mourgias-Alexandris et al, “A Silicon Photonic Coherent Neuron with 10GMAC/sec processing line-rate”, OFC 2021.

[15] B.J. Offrein, Integrated Photonics for Neuromorphic Computing, PIC International, Brussels 8-11-2021 (Invited)

[16] B.J. Offrein, Neuromorphic Computing on integrated Photonic Circuits, Group IV Photonics, 7-12-2021 (Invited)

[17] B.J. Offrein, J. Geler-Kremer, J. Weiss, R. Dangel, P. Stark, A. Sharma, S. Abel and F. Horst, Volatile and non-volatile optical weights in photonic neuromorphic computing, CLEO2021, 10-5-2021 (Invited)

[18] B.J. Offrein, Photonic Integrated Circuits for Neural Network Inference and Training, OFC2021 in Symposium The Role of Machine Learning in Optical Systems and The Role of Optics in Machine Learning Systems (Invited)

[19] P. Stark, J. Weiss, R. Dangel, F. Horst, J. Geler-Kremer and B.J. Offrein, High-Performance Neuromorphic Computing Based on Photonic Technologies (Invited)

[20] A. Messner, et. al, "100 Gbit/s NRZ Data Modulation in Plasmonic Racetrack Modulators on the Silicon Photonic Platform", ECOC 2020, doi: 10.3929/ethz-b-000459799.

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[22] G. Giamougiannis et. al, "Silicon-integrated coherent neurons with 32GMAC/sec/axon compute line-rates using EAM-based input and weighting cells", ECOC 2021.

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[3] G. Mourgias-Alexandris et al., "Neuromorphic Photonics With Coherent Linear Neurons Using Dual-IQ Modulation Cells," in Journal of Lightwave Technology, vol. 38, no. 4, pp. 811-819, 15 Feb.15, 2020, doi: 10.1109/JLT.2019.2949133.

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Communication Activities

- The project presentation video has been made publicly available on M06, via YouTube and shared via PlasmoniAC social media channels. The video targets both the general public, through minute-long introductory part, and later focuses on specifics of technology, aimed at industry and scientific community. It has attracted a lot of attention and KPI for video views (1.1k) has been fulfilled. More details about the script and the intention behind the video can be found in D7.4.
- Social accounts have been set up in popular social networks including, Facebook, Twitter, LinkedIn and ResearchGate. The project accounts may be found in the following links:
  - https://www.facebook.com/plasmoniac
  - https://twitter.com/Plasmoniac
  - https://www.linkedin.com/groups/8901360/
  - https://www.researchgate.net/project/H2020-PlasmoniAC

  More details about the social media accounts and their initial content can be found in D7.3.
- The project brochure for the initial phase of the project was produced, printed and handed out at SPIE Photonics West 2020. The brochure can also be downloaded from the project website. Additionally, AMO featured PlasmoniAC in their "AMO brochure" "nanovate!": nanovate!, 16.12.2020, PlasmoniAC – Plasmonen für neuromorphe Daten, https://www.amo.de/wp-content/uploads/2020/12/nanovate_01122020.pdf
- Four newsletter volumes of the project were created towards keeping PlasmoniAC's followers updated with the project's achievements. The newsletters can be downloaded from the project website.
- A press release was generated presenting the project consortium and objectives. The press release was displayed at the partners' webpages:
  - https://www.vpiphotonics.com/News/2020/index.php#PlasmoniAC

   - https://www.amo.de/blog/2020/03/11/plasmoniac-harnessing-plasmons-for-neuromorphic-computing/
- Project Website: The PlasmoniAC website was developed and released during the first months of the project, and it is constantly maintained and updated. The website of the project is http://www.plasmoniac.eu/. A more detailed description of the website can be found in in the deliverable D7.3.

8 Summary and Conclusions

This document reported on the PlasmoniAC consortium's exploitation and dissemination activities that were carried out during the last year of the project. The progress in tracking technology advances in the rapidly evolving neuromorphic computing and DC security application fields as well as in identifying exploitation opportunities in relevant market segments, was summarized. The project has been disseminated through talks and publications as well as through its website and by means of high-profile press releases. Exploitation planning and project dissemination activities had been running continuously during the project by all partners.

9 List of Figures

10 References

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