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Energy- and Size-efficient Ultra-fast Plasmonic Circuits for Neuromorphic Computing Architectures

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Abstract

This document reports on the plasmoniAC consortium's exploitation and dissemination activities that were carried out during the first year 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 centre 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
HPC	high performance computing
IC	integrated circuit
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
MPW	multi-project wafer
NIC	network interface card
OIF	optical interconnect forum
SiOC	silicon oxycarbide
SSL/TLS	secure socket layer / transport layer security
TiO2	titanium dioxide
TO	thermo optic
TOC	thermo optic coefficient
TPU	tensor processing unit
WJH	what just happened

1 Executive Summary

This document reports on the plasmoniAC consortium's exploitation and dissemination activities that were carried out during the first year 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.

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.

IPR has been well managed so far and two patent applications have been already pursued. 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 over the first year of 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.

These include:

- Technology licensing for barium-titanate (BTO) based non-volatile memristors that are expected to advance analog neuromorphic photonic accelerators (IBM & Lumiphase).
- Development of 100GBd CMOS electronic front-ends for DCIs and sensing applications. (IMEC throughout its spin-off-companies "Bi-fast" and "Indigo Diabetes").
- Commercialization of specialized plasmo-photonic neuromorphic design library for complex optical neural network deployments (VPI).
- Using the plasmoniAC lookaside accelerator to perform real-time DDoS attack recognition and revolutionize security features of DCI transceiver modules (MLNX).
- Offering value-added graphene plasmo-photonic fabrication technology as a service throughout commercially available fabrication runs (AMO).

2.2 Document structure

The present deliverable is split into following major chapters:

I. Competitive analysis
II. Commercialization strategy
III. Partner individual exploitation plans
IV. Standardization
V. IPR management
VI. Dissemination and communication activities

2.3 Audience

This document is confidential.

3 Competitive Analysis

3.1 Plasmoniac partner position in market

VPIphotonics 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 is a supplier of end-to-end InfiniBand and Ethernet interconnect solutions and services for servers and storage. Mellanox offers a choice of interconnect products: adapters, switches, software, cables and silicon for a range of markets including computing, enterprise Data centers, Web 2.0, Cloud, Storage and financial services. Mellanox is well positioned in the HPC market and its equipment is preferred among HPC cluster managers: Mellanox connects 39% of TOP500 systems (192 systems) as well as all of 25G, 40G and 100G Eth. systems in the TOP500 list. MLNX accelerates 2 of the TOP5 supercomputers. In addition, Mellanox leads across industries: 5 of the top 6 global banks use Mellanox equipment, and so do 9 of the top 10 hyperscale companies, 9 of the top 10 oil and gas companies, 3 of top 5 pharmaceutical companies, 10 of top 10 automotive manufacturers.

As an end-to-end supplier, Mellanox is constantly advancing the combined hardware and software offering. Currently the company offers a full solution that includes 200 Gb/s transceivers (4×50 Gb/s), 200 Gb/s network adapters, 16 Tb/s switches alongside the enabling software. Essential part of the Mellanox software solution is centered on establishing a fresh approach to security, protecting distributed assets on-prem and in the cloud from cyber-attacks, while conforming to new regulations. To that end, Mellanox offers a variety of options including physical isolation, stateful next-gen firewall, IPsec, SSL/TLS, data-at-rest encryption protocols and intrusion detection and prevention (IDS/IPS). Those features come together with Mellanox's Ethernet/Infiniband family of Switches and Network Adapters, including the ConnectX family and the Bluefield DPU. Besides, Mellanox has been the market leader in high-speed network adapters since 2016, accounting for more than 65% of shipped ports, while the company is leading the market entry and deployment of the new Smart NIC family of products.

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.

3.2 Overview of PlasmoniAC main competitors

Mellanox Technologies competes with key players in the current field of intra-datacenter communications, such as Cisco (that recently acquired Luxtera), Marvell, Intel, and Avago-Broadcom. Currently, Mellanox is offering a competitive set of products enhanced with advanced security features such as physical isolation, stateful next-gen firewall, IPsec, SSL/TLS, data-at-rest encryption protocols and intrusion detection and prevention (IDS/IPS). Such portfolio makes Mellanox one of the more well-positioned vendors in the market. Nevertheless, Mellanox is constantly seeking for technology solutions that can bring disruptive functionalities to the Mellanox products, further future-proofing their potential. Along these lines, PlasmoniAC's real-time DDOS attack recognition promise is of particular interest to the company, as it can potentially bridge the gap between the line-rate pattern recognition achieved by Titac IC and the comprehensive Data Center traffic analysis offered by the What Just Happened telemetry platform. As such, following the successful outcome of the PlasmoniAC project, Mellanox will be able to exploit the benefits of the underlying technology, targeting to provide the Data Center network operators with unparalleled capabilities as respects to inherent security features against large-scale malicious attacks. Considering the constantly increasing focus on Data Center security features, spawn from the rapid cloudization of ICT applications and services, Mellanox expects to gain significant advantage against its main competitors in the field of state-of-the-art DC network equipment.

IMEC focuses on complex transmitter and receiver circuits for 100 Gbaud. In this area, IMEC competes with high-speed chip vendors such as Inphi, MACOM, Fujitsu, Micram… These industrial parties are very strong and have a broad product line for different markets, 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 front-ends and could provide such IP building blocks (unavailable on the market) or customer design services for system integrators.

IBM is establishing new technologies for analog signal processing accelerators. Our effort is focussed on analog memory elements integrated in electrical crossbar arrays on CMOS. This is a fundamentally new technological concept from which we anticipate enhanced performance and efficiency. A range of other approaches are under development, to a large extend based on existing CMOS technology. Examples are the GPU (NVIDIA), TPU (Google) or also the IPU (Graphcore).

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. VPI's extensive experience in these areas has rendered it as one of the key design software providers in the market. Given the increasing interest in optical neural networks, VPI now aims to meet the anticipated demand for a specialized simulation toolkit. Experience gained by VPI during the PlasmoniAC project will allow for the first plasmo-electronic and plasmo-photonic neuromorphic software design library to become available to its customers. 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.

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.

In PlasmoniAC, ETHZ develops plasmonic BTO modulators for ultra-fast neuromorphic applications. A focus is put on the monolithic integration of the high-speed modulators with the silicon nitride platform and on the co-integration with driver electronics. Such a technology enables ultra-fast computation and communication in both C- and O-band. ETHZ's experience on high-speed modulators recently generated the spin-off Polariton

Technologies developing plasmonic organic modulators, which creates both a competitive and cooperative environment towards the targeted applications.

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 a provisional patent at USPTO (N.Pleros et. al. *Neuromorphic photonics with coherent linear neurons*) 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 has submitted a patent application to the USPTO, considering detection of reconnaissance attacks (D. Syrivelis et. al. *"REAL-TIME DETECTION OF NETWORK ATTACKS"*). The patent application protects the DDOS attack pattern recognition that is based on the lookaside accelerator.

4 Commercialization strategy

4.1 Total addressable market (TAM)

4.1.1 Data Center environment (Ethernet Switches and SmartNICs)

Datacenter market is at an inflection point[1]-[4]. Many businesses move their IT services over to the cloud and it is estimated that the global transition to the cloud currently stands at around 20% (March 2021). Therefore, the demand for cloud services is expected to constantly rise considerably year over year for the next few years. This growth is also reflected on datacenter equipment demand, which needs to continuously improve it's performance and efficiency to cope with the ever increasing workloads. In addition, the advances on Artificial Intelligence, which tends to become pervasive in every application, imposes an additional computational and data movement overhead. Unavoidably, the network switch and smartNIC market demand are expected to continue to grow strongly following the datacenter growth (typically network equipment accounts for 20% of the datacenter cost).

Figure 1 (a) below, depicts the forecast revenues in the Ethernet Network Switch market. As it can be seen, the 25G and 100G generation are reaching a plateau in the coming years, whereas the 10G and 40G are dropping to minimum, signaling the worldwide transition to higher speeds. At the same time, the 400G generation is expected to rapidly grow in the coming years, eventually becoming the dominant speed in the market. Similar trend but a much lower scale is shown for the 50G generation, that will be limited to much smaller market share. The overall revenues of the Ethernet market switch are expected to overcome $13-14B quite soon, showing the potential of this large market.

Figure 1 (b) illustrates similar forecast for the SmartNIC revenues. The main difference here is the lack of the 400G market, since SmartNICs are deployed at the server side. Nevertheless, the transition to higher speeds is clearly shown by the 50G, 100G and 200G trends, that are expected to grow. In fact, 100G is soon becoming the dominant speed in this market, largely replacing the previous 10G and 25G generations. The 40G appears to be much less deployed and slowly disappearing. The overall SmartNIC revenues are obviously much more

limited compared to the Ethernet Switch market, however the expected growth is significant. This is very important particularly for Mellanox that is by far the #1 company in this market. Given the increased data movement requirements, a lot of network-related functions like cybersecurity and even part of streaming analytics computations are offloaded to network hardware (in-network processing). With line rates soon reaching 400Gb/s per port, the processing of network traffic becomes challenging for classic ASIC accelerators. Neuromorphic 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 on what is happening in the network. The value proposition is to be able to determine online what needs to be looked up with priority and even have some early insights on what the problem is without doing the slow deep inspection. As datacenter 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.

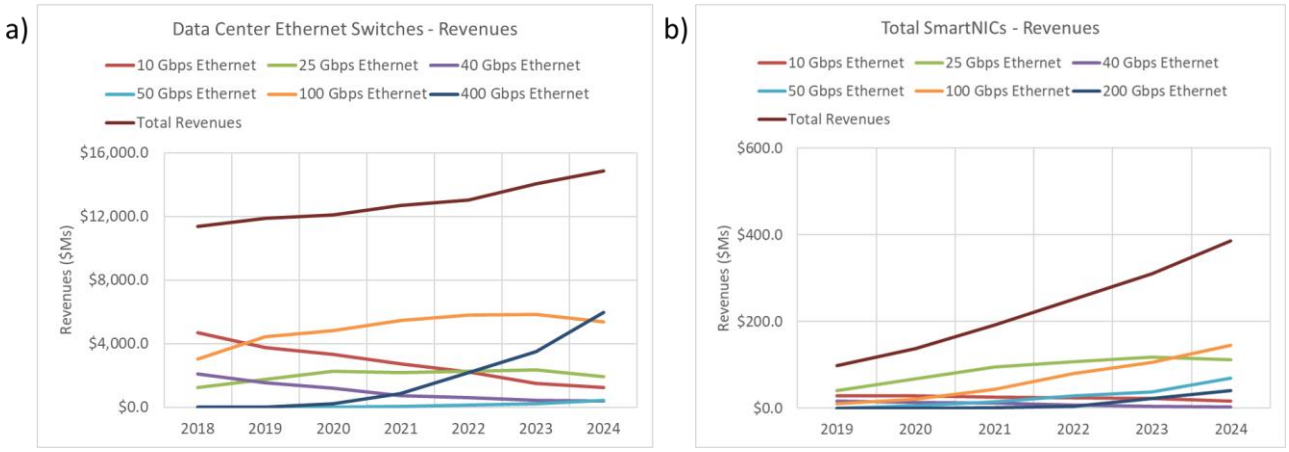

Figure 1: Forecast revenues for (a) Data Center Ethernet Switches and (b) SmartNICs.

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 are 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 on what is happening in large scale infrastructures. This is of particular importance to cybersecurity as counter measure to mitigate an attack need to be taken instantly rather than offline and the more 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

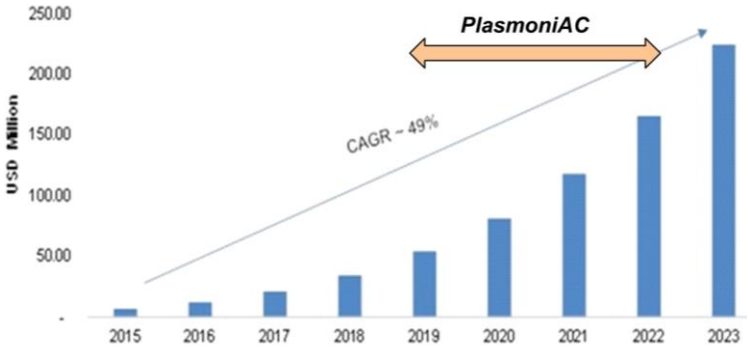

Figure 2:Market forecasts for neuromorphic computing

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 [8]-[9].

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 and design of the 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 SOUTHAMPTON

SOTON's major exploitation route is through the CORNERSTONE MPW foundry service [https://www.cornerstone.sotonfab.co.uk]. SOTON CORNERSTONE MPW activity is offering a range of platform as MPW and is currently expending the range of platform from SOI photonics active/passive to Ge on silicon, silicon nitride and electronic flip chip packaging. The work pursued in Plasmoniac is directly coupled to the development of the silicon nitride platform and the CORNERSTONE MPW offer.

Further exploitation at SOTON will take the form of future national or European research projects to develop further the interdisciplinary work undertaken in PlasmoniAC. This will strengthen further the integrated photonic research activity by deploying photonics devices in line with the requirements of photonic AI accelerator architectures.

5.3 ETH Zurich

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 deep learning. 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 silicon oxycarbide (SiOC) and titanium dioxide (TiO2) materials.

Through the actions conducted for PlasmoniAC, uBFC is developing a know-how in the field of highly efficient Thermo-Optical (TO) materials targeting Thermo-Optical Coefficient (ToC) in the range of $3.0x10^{-4}$ /K outperforming current state of the art advanced TO materials. Beyond the demonstration of high-ToC materials, uBFC is aiming at the fabrication of compact TO-weight modules based on those high-ToC materials. Initially implemented with organic actives materials, the TO modules fabricated by uBFC will be deployed in plasmoniAC by using solid-state materials (SiOC or TiO2) leading to aging effect robust configurations. In addition, by implementing disruptive architectures operating hybrid plasmo-photonic waveguides, fast and energy efficient devices are targeted. As a primary action for exploitation of plasmoniAC results, uBFC will consider patenting provided plasmoniAC TO devices show significant improved performances compared to existing TO technologies. Next in a second step, the dissemination of uBFC results will be achieved by standard channels including publications in peer-reviewed, technology oriented international journals and conferences.

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 it is the goal of CNRS 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

PLASMONIAC will enhance imec/IDLab-Design's world-class know-how on optical front-end ASIC design. During and after the project the exploitation of PLASMONIAC 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, imec-IDLab's expertise on advanced transceiver circuits is now being applied in optical sensing (spinoff "Indigo Diabetes", together with imec PRG and CMST) and high-speed interconnects (spinoff "BiFast"). For the purpose of the latter case, imec-IDLab became an academic member of the Optical Interconnect Forum (OIF).

5.7 IBM

IBM joined PLASMONIAC, contributing the barium titanate on silicon technology for ultra-high speed electro-optical modulators and memristive devices in support of non-volatile optical weights. At the start of the project, the barium-titanate technology was spun out of IBM to Lumiphase. The IBM employees working on this technology created the new companied and took a license. IBM supports the new company by providing access to the critical barium-titanate growth infrastructure as well as to the cleanroom and selected characterization tools. This is a gating step for further maturing the barium-titanate technology, bringing it out of research into development. Lumiphase and IBM continue to collaborate in projects that are of joint interest.

IBM pursues an open licensing and collaboration policy. The AI hardware Center, as described above, is an example of this policy. Bringing new technological concepts to maturity is a multi-facetted problem requiring breakthroughs at all levels, hardware, firmware, and algorithms. This can only be achieved through collaboration as for example pursued in the AI Hardware Center[5]. The market for dedicated accelerators is expected to increase strongly in the coming years. The emergence of such new technologies is important for delivering the required performance but also to enhance the power efficiency.

IBM is open to license the technology established in PLASMONIAC to manufacturing and other partners as a means 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. Their first commercial product is a packaged stand-alone ultrahigh speed graphene photodetector based on the pioneering work by D. Schall [10]. Black Semiconductor may benefit from the developments in PlasmoniAC if the plasmonically enhanced photodetectors achieve better performance or easier integration than their current state-of-the-art. The IP transfer between AMO and Black Semiconductor is regulated via a Joint Research Agreement. The transfer of joint IP developed within PlasmoniAC by AMO together with other partners would have to be negotiated separately.

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 offers one of industry's broadest portfolios of end-to-end InfiniBand and Ethernet interconnect solutions and services for servers and storage, including adapters, smartNICs, DPUs, switches, cables, silicon, and software. Particularly in the security front, Mellanox is offering a competitive set of products enhanced with advanced security features such as physical isolation, stateful next-gen firewall, IPsec, SSL/TLS, data-at-rest encryption protocols and intrusion detection and prevention (IDS/IPS). Such portfolio makes Mellanox one of the more well-positioned vendors in the market.

Nevertheless, Mellanox is actively investigating future technologies solutions targeting to further enhance the line of products with future-proof disruptive functionalities. In this respect, PlasmoniAC's real-time DDOS attack recognition objectives are very interesting to the company. In particular, Mellanox believes that the research demonstrators to be implemented within the project, will open a new hardware path that can potentially bridge the gap between the line-rate pattern recognition achieved by Titan IC [3] and the comprehensive Data Center traffic analysis offered by the What Just Happened telemetry platform. To that end, the main exploitation path

of the company, is centered on enhancing the WJH[2] platform with the unparalleled photonics capabilities offered by PlasmoniAC's core technology.

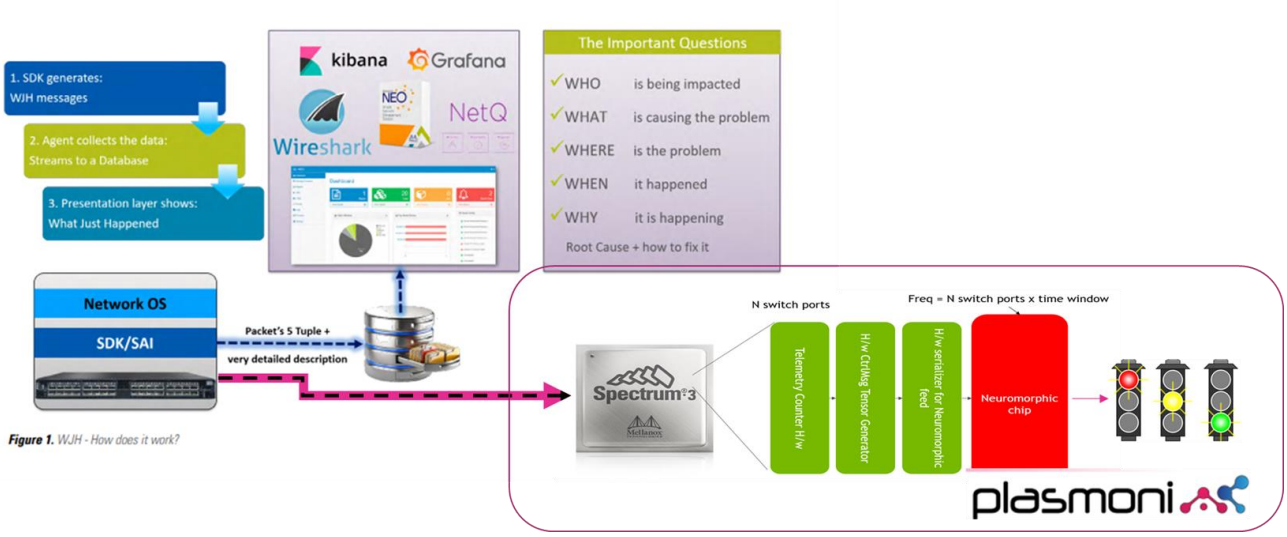

Figure 3: Mellanox's exploitation concept, involving the collaboration between the What Just Happened (WJH) framework and the PlasmoniAC pattern recognition technology.

3 below illustrates Mellanox's vision, comprising a photonics-based lookaside accelerator capable of performing DDOS attack recognition at the serial line rate. The accelerator will be able to work tightly with the WJH telemetry system, obtaining the necessary inputs through the hardware, and giving valuable feedback to the framework, raising red flags in case of malicious attack recognition. This way Mellanox expects to reduce the time interval between the initiation of a DDOS attack and the deployment of mitigation measures. As such, if successful, the PlasmoniAC technology will not only enhance the security features against malicious Data Center attacks[6]-[7], but it will also enable the DC operators to block an attack at a very early stage, with minimum impact on the overall performance of the DC pod/cluster.

Throughout the project Mellanox aims to evaluate the PlasmoniAC technology in realistic application scenarios and assess the performance and commercial potential. After the end of the project and subject to the project's achievements, the company will undertake further R&D steps towards the demo hardware implementation of the lookaside accelerator, paving the way for product development.

5.10 VPI

VPIphotonics is aiming to extend its product capabilities in the area of plasmonics, neuromorphic circuits and novel computing applications. As a result of the PlasmoniAC project activities, VPI will provide simulation and modelling software supporting novel application solutions for such technologies. VPI will supply the market with the first plasmo-electronic and plasmo-photonic neuromorphic software design library thus fulfilling the increasing demand for such software capability while also offering professional consulting services. This will place VPI in a market-leading position in such areas. New modules and application examples will be ready for release as prototypes shortly after the project completion date.

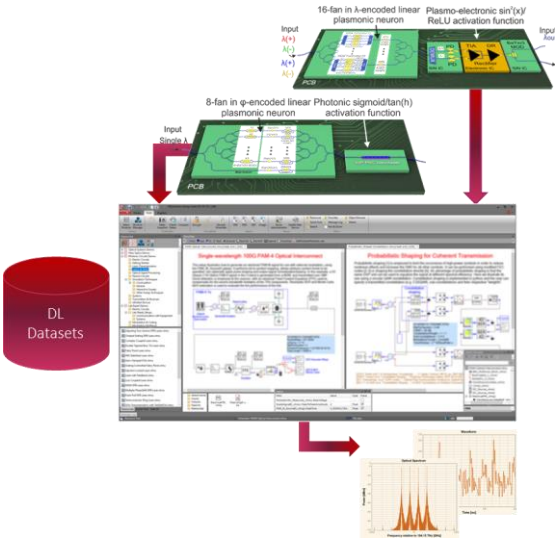

Figure 4: VPI's suite synergizing plasmo-photonic neuron architectures and state-of-the-art DL algorithms.

5.11 Lumiphase

In the context of PlasmoniAC, Lumiphase is developing the BaTiO3 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 BaTiO3. 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 growing very fast and several vendors are building components in the space. For instance Mellanox has the "What Just Happened" or WJH platform that starts with h/w components in the chip that logs traffic according to a received configuration, and scales up to software components that do analytics on the database that collects the data. The WJH solution leverages the unique hardware capabilities of Mellanox ASICs to inspect packets at multi-terabit speeds – faster than software or firmware-based solutions. WJH can help in diagnosing and repair of your Datacenter network including software problems, as it inspects packets across all ports at line-rate, at speeds that overwhelm traditional Deep Packet Inspection solutions. WJH is an Open Ethernet solution that can be integrated into open source tools like Grafana, and Kibana, but it also works with turn-key data center wide monitoring solutions like Mellanox NEO and Cumulus' NetQ.

In parallel Mellanox has recently acquired Titan IC, a company offering a highly sophisticated RXP hardware network intelligence engine that accelerates complex pattern matching and performs real-time Internet traffic inspection for advanced cybersecurity and data analytics applications. The engine allows for offloading regular expressions (RegEx) string and malware matching, freeing up CPU cores and delivering faster throughput and increased efficiency. The RXP engine's unique ability to simultaneously handle high throughput, rule depth, and complexity are integrated into the advanced ConnectX and BlueField families of SmartNIC and I/O Processing Unit (IPU) solutions to accelerate complete searches and pattern detection.

Figure 5: The Mellanox What Just Happened (WJH) and Titan IC products

As datacenters scale, network analytics are becoming very important and there 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 IPR management

Internally generated IP may be highlighted at any time via email but is officially discussed in the Innovation and Exploitation Committee (InEC). The key question is: "Is the IP being protected by the owner". If no, then the IP Committee comprising the lead researchers will be invoked to discuss the options and decide how the material is to be protected.

All generated IP will be formally reported as part of the partner survey, which contributes to each exploitation deliverable.

- The responsibility for identification and management of internally generated IP is devolved to the Principle Investigators.
- The InEC itself is also used to identify newly created IP.
- The protection mechanism is identified as: Patent, Trade Secret and Open.

8 Dissemination and communication activities

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

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)

- Invited Talks

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

[2] 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.

- Conference Proceedings

[1] M. Lemme "Two-Dimensional Materials for Nanolectronics and Photonics", IU.NET Days, Modena, Italy, September 10-11, 2020

[2] M. Lemme "Graphen und weitere zweidimensionale Materialien aus der Nanotechnologie", Rotary Club Aachen, 22.09.2020

[3] 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

[4] 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

[5] 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

[6] Bert Jan 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)

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

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

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

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

[11] 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

[12] 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

[13] G. Mourgias-Alexandris, A. Totovic, N. Passalis, G. Dabos, A. Tefas, and N. Pleros "Neuromorphic computing through photonic integrated circuits", Proc. SPIE 11284, Smart Photonic and Optoelectronic Integrated Circuits XXII, 1128403 (26 February 2020); https://doi.org/10.1117/12.2543781

[14] G. Dabos, A. Totovic, N. Passalis, A. Tefas, and N. Pleros, "Femtojoule Technology Roadmap for TeraMAC Neuromorphic Photonic Accelerators", accepted in IEEE Photonic Conference 2020 (IPC2020)

[15] N. Passalis, G. Mourgias-Alexandris, N. Pleros and A. Tefas, "Adaptive Initialization for Recurrent Photonic Networks using Sigmoidal Activations" 2020 IEEE International Symposium on Circuits and Systems (ISCAS), Sevilla, 2020, pp. 1-5, doi: 10.1109/ISCAS45731.2020.9181106

[16] 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)

[17] 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

[18] George Mourgias-Alexandris et al, "A Silicon Photonic Coherent Neuron with 10GMAC/sec processing line-rate" to be presented at OFC 2021.

- Journals

[1] G. Mourgias-Alexandris, G. Dabos, N. Passalis, A. R. Totovic, A. Tefas and N. Pleros, "All-optical WDM Recurrent Neural Networks with Gating," in IEEE Journal of Selected Topics in Quantum Electronics, doi: 10.1109/JSTQE.2020.2995830.

[2] A. R. Totović, G. Dabos, N. Passalis, A. Tefas and N. Pleros, "Femtojoule per MAC Neuromorphic Photonics: An Energy and Technology Roadmap," in IEEE Journal of Selected Topics in Quantum Electronics, vol. 26, no. 5, pp. 1-15, Sept.-Oct. 2020, Art no. 8800115, doi: 10.1109/JSTQE.2020.2975579.

[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.

[4] G. Mourgias-Alexandris, N. Passalis, G. Dabos, A. Totović, A. Tefas and N. Pleros, "A Photonic Recurrent Neuron for Time-Series Classification," in Journal of Lightwave Technology, vol. 39, no. 5, pp. 1340-1347, 1 March1, 2021, doi: 10.1109/JLT.2020.3038890.

[5] Vangelidis Ioannis, Bellas Dimitris, Suckow Stephan, Dabos George, Koppens Frank, Ferrari Andrea, Pleros Nikos and Lidorikis Elefterios, "Unbiased plasmonic-assisted integrated graphene photodetectors" submitted at ACS Nano.

[6] T. Rutirawut, W. Talataisong and F. Y. Gardes, "Designs of Silicon Nitride Slot Waveguide Modulators With Electro-Optic Polymer and the Effect of Induced Charges in Si-Substrate on Their Performance," in IEEE Photonics Journal, vol. 13, no.2, pp. 1-15, doi: 10.1109/JPHOT.2021.3059276.

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 (689) 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

At the moment KPIs for public engagement with PlasmoniAC social accounts are already met for LinkedIn group and are keep growing for Facebook and Twitter. We have thus oriented also towards scientific community, and are intensively sharing the results of PlasmoniAC project via ResearchGate group, for which significant interest has been shown.

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 while it will be updated after the end of the second year of the project.
- Two **newsletter volumes** of the project were created. The newsletters include main project features (**factsheet**) and a **project presentation narrative**. The newsletters can be downloaded from the project website and will be continuously updated every three months.
- 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 next section (Project Management), as well as in D7.3.

9 Summary and Conclusions

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.

IPR has been well managed so far and two patent applications have been already pursued. 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. Exploitation planning and project dissemination activities are running continuously during the project by all partners. An updated version of the current report on dissemination and exploitation will be submitted in M24, with title "D7.6: 2nd year report on market analysis, standardization activities, competitive analysis, dissemination & exploitation plans".

10 References

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11 List of Figures