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

Narrative text for the general public

The transmission of data is the backbone of our modern society and a cornerstone of the economy since all present-day activities, i.e. Internet, Social Media, Cloud Computing, Software Platforms etc., are becoming more information-oriented day by day. As people and businesses get connected, more and more of their everyday life and work has gone online driving the requirements for data transmission and processing to higher limits every single day. This growing tsunami of data is being transmitted through optical fibers, which form the optical networks around the world, and routed (stored, managed, disseminated) via Data Centers (DC) distributed physically all over the world.

Data is being exchanged both between different DCs and within the same DC facility, the so called "*Inter-DC*" and "*Intra- DC interconnection distances*" respectively. These hyperscale DCs are currently expanding following a distributed model that consists of smaller DCs. This gradually transforms the requirements for *inter-DC* and *intra-DC* connectivity calling for the development of *Optical Transceiver modules*, the devices responsible for data exchange through optical fibers between the servers. Nevertheless, different requirements by different connections impose the adoption of different technologies in terms of speed, energy efficiency and cost for intra- and inter-DCI transceiver modules.

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

- **For intra-DCI interconnection**: NEBULA aims to develop an 8-channel *Optical Transmitter* prototype co-packaged with an electronic s*Application-specific Integrated Circuit (ASIC)* for operation in the O- (1260-1360 nm) operational band of optical communications, delivering a 1.6 Tb/s (8 channels × 200 Gb/s) aggregate bandwidth capacity with up to 37% in energy savings for Intra-DCI applications. Co-packaging refers to the technology where the Electrical-to-Optical transformation of the signal is carried out directly at the core electronic ASIC of the switches interfaced with optical transceivers and which is responsible for data exchange and routing between the servers.

- **For inter-DC interconnection**: NEBULA aims to develop also an 8-channel *Optical Transmitter* prototype for coherent operation in the C- (1530-1565 nm) operational band of optical communications, delivering an aggregate bandwidth capacity of 3.2 Tb/s (8 channels × 400 Gb/s) with up to 93% in energy savings for inter-DC applications. NEBULA will also develop a 1-

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channel *Neuro-augmented Receiver Circuit* (NARC)-based Receiver that will rely on a 2-stage *optical & electrical Neuromorphic Processing* (NP) for the processing of the coherent signal.

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

- **Silicon Nitride (SiN) photonic integration platform**: This refers to the integration platform for the realization of the photonic integrated circuits (or PICs) of the transceivers. Various platforms for photonic integration exist based on various transparent optical materials: Silicon (Si), Silicon Nitride (SiN), Indium Phosphide (InP), Polymer, Silica (SiO_2), Lithium Niobate ($LiNbO_3$) etc. Each integration platform comes with advantages and disadvantages. SiN is selected in NEBULA as the platform of choice among the others due to its low-cost, low-loss, CMOS-compatibility and other useful credentials.
- **Complementary Metal-Oxide Semiconductor (CMOS)-compatible:** This refers to the manufacturability of the photonic integrated circuits by means of the standard process technology in state-of-the-art CMOS fabs. Employing "CMOS-compatible" processes is a key concept since it allows to manufacture Silicon Photonic products, both at high volumes in existing CMOS-fabs, which were used for many decades now in the manufacturing of electronic integrated circuits.
- **Plasmonic modulators:** This refers to the technology used for the realization of the NEBULA modulators, i.e. the devices that are used to imprint the data (in electrical form) onto the transmitted light beam. The NEBULA plasmonic modulators will be co-integrated on the SiN photonic platform, yielding in this way the so-called *Plasmo-photonic Integrated Circuits (PPICs)*. *"Plasmonics"* is essentially the technology that allows the coupling of light to charges (like electrons) in thin metal films. In full correspondence to photons that is Electromagnetic Oscillations, plasmons are the oscillations of the free electron plasma on the metal surfaces. Moving from photons to plasmons allows for breaking the optical diffraction limit into sub-wavelength dimensions for further miniaturization of PPICs by enabling strong light-matter interaction. In simple words, *Plasmonics* is the way to make more efficient, ultra-fast and way-smaller modulator devices (compared to pure photonic modulators) for our optical transmitters. It should be noted that the noble metals, like Gold and Silver, feature the best plasmonic properties in terms of performance, however they are not CMOS-compatible and thus not mass-manufacturable. In NEBULA we are trying to come as close as possible to these metrics working with CMOS-metals, like Copper, targeting low-cost in full-scale mass production.
- **Thermal Stabilizer Systems:** This refers to the stabilization system for the optical transceivers. As Optical Transceiver modules are closely packed together in the harsh environment of Datacenters, NEBULA will deploy a Thermal Stabilization System for the Plasmonic modulators that will comprise sensors and actuators for tuning the modulators to the optimum working point. These novel sensors will be co-integrated with the plasmonic modulators on the same chip for simplification of packaging leading to lower overall cost of the final product.
- **High-speed Photodiodes co-integrated with Semiconductor Optical Amplifiers (SOA-PDs):** This refers to a subsystem of the NEBULA Receiver. NEBULA targets to deploy a co-integrated device based on IIIV materials that will combine a Semiconductor Optical Amplifier (SOA) and a Photodiode (PD) on the same structure. This will allow for increased sensitivity by co-integrating the amplification stage (the SOA) just before the detection stage (the PD) on the same structure.

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The SOA also feature a nonlinear response that usually is unwanted since it leads to signal degradation during reception. However, in NEBULA this nonlinearity is a big plus and is exploited by the Neuro-Augmented Circuit.

- **Neuro-augmented Digital Signal Processing (DSP):** This refers to the digital signal processing technique that is targeted to be performed by the NEBULA coherent Receiver. In coherent reception, the signal is properly processed with DSP techniques so as to remove the impairments of the transmission channel on the signal, i.e. signal quality degradation for reduced error count. Until now, this is realized by processing the signal in dedicated *Application-specific Integrated Circuits (ASICs)* in the electronic domain. NEBULA targets to implement *Optical DSP* on the incoming signal by relying on Machine Learning in the optical domain, such as Optical Neuromorphic Processing (NP) with the exploitation of a *Photonic Reservoir Network*. In addition to the *Photonic Reservoir Network*, two *Neuromorphic Weighting Stages* with optical and electrical weighting capability, respectively, and the SOA-PD non-linear behavior come to fill in the puzzle of neuromorphic processing elements on the way to replace electronic DSP processes. This is where the terms *"Neuro(morphic)-augmented Digital Signal Processing" and Neuro-augmented Receiver Circuit (NARC)" originate for the NEBULA description*.

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