A Postgraduate Advanced Master of Science program in Silicon Photonics to support the rapid growth of the Integrated Photonics field

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***Abstract*—To address the skilled workforce shortage in both academia and industry in the field of integrated photonics, Ghent University is organizing a 1-year advanced Master of Science Program in Silicon Photonics. Driven by today's needs of datacenters and AI, the field of silicon photonics is rapidly growing, leading to a dearth of skilled researchers and engineers. Ghent University's new advanced master's program in Silicon Photonics aims to equip students with the necessary skills and knowledge to make their mark in this cutting-edge field, from the core technologies to the diverse applications in telecommunication and datacom, sensors and biomedicine, and quantum information processing. This paper discusses the program's curriculum, hands-on training opportunities, and its potential impact on the photonics industry.**

Keywords—advanced master, Silicon Photonics, Integrated Photonics, workforce

I. Introduction

A. What is Silicon Photonics?

Silicon photonics is a subdomain of integrated optics and is one of the dominant platforms to implement photonic integrated circuits (PICs), or "photonics on a chip". The key differentiator of silicon photonics is that the choice of materials allows the fabrication of photonic chips in the same facilities as CMOS electronics, leveraging the decades of technology development in microelectronics. This opens a path to large-volume and low-cost manufacturing. The functionality of silicon PICs is defined by diverse opto-electronic elements such as modulators, optical amplifiers, laser sources, and detectors, connected into circuits by optical waveguides.

Silicon photonics is becoming a key technology in our connected society, visible in the number of start-ups and high-tech multinationals adopting this technology. In Flanders and worldwide, Ghent University and imec have been pioneers in this field. With UGent, imec, and several industrial players (including start-up companies), a world-leading local ecosystem has developed around state-of-the-art infrastructure. This is a stimulating environment for students and professionals who want to enter this booming field, which is propelled forward by the rapidly growing need for high-speed optical interconnection in datacenters to support the breakthroughs in AI capabilities. Beyond that is a wealth of emerging applications of the technology in sensors (industrial, biomedical, environmental, …), information processing and quantum technologies that build on photonic chips. This aligns with the European Chips Act [1], in which integrated (silicon) photonics is identified as a crucial capability.

B. The need for specialized education in this field

The rapid growth of the field has exposed a dramatic shortage in researchers, engineers and technicians with a background in integrated photonics or silicon photonics. To address this shortage both in academia and industry, Ghent University launches a new specialized Advanced Master in Silicon Photonics, addressing the need for advanced education as outlined in the European Chips Act [2].

C. Target Audience

The new Ghent University Advanced Master of Science in Silicon Photonics is a postgraduate program, which corresponds to Level 7 of the European Qualifications Framework (EQF) [3] and as such targets students who have already obtained a first master's degree. This type of master can also be referred to as a subsequent master, a post-master or a master-after-master program.

The target audience are students with a degree in disciplines such as in (micro)electronics, nanoscience and nanoengineering, or (applied) physics. It also welcomes masters in photonics, telecom, or optoelectronics, particularly if their prior studies did not focus on integrated photonics. This program offers a path to specialize in Silicon Photonics, both for recent graduates and experienced industrial professionals encouraged by their current employers. Additionally, students from diverse backgrounds such as computer science, chemistry, biomedical engineering, material science, and mechanical engineering are eligible, provided they meet the required initial competencies.

II. Program of the Master in Silicon Photonics

The new Advanced Master in Silicon Photonics at Ghent University was designed based on extensive industry surveys to meet current and future industry needs. Surveys with students and recent graduates provided valuable insight into their experiences and expectations. This collective input was subsequently converted into specific topics and courses. For this new program, an entirely new set of core courses was defined, starting from the desired learning outcomes and competencies to start a career in the field of silicon photonics.

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A. *Learning Outcomes and competencies*

The following set of 8 learning outcomes [4] for the Master in Silicon Photonics has been established:

1. Advanced Knowledge and Understanding: develop a profound understanding of silicon photonic technologies and the specifics of photonic integrated circuits compared to electronic circuits.

2. Expertise in Optical Principles: obtain expertise in fundamental optical phenomena in PICs, such as light-matter interactions in both passive and active components.

3. Creative Problem-Solving Skills: learn to identify and solve complex problems in design, characterization, and manufacturing of PICs in both industrial and academic environments.

4. Design and Fabrication Proficiency: design a complete PIC from a system perspective and manage its fabrication and packaging process, with in-depth knowledge of all steps involved.

5. Critical Thinking on Opportunities and Applications: identify opportunities for PICs to enable cutting-edge solutions in research and industry, and understand the strengths and limitations of PICs for different applications, including optical communications, information processing, sensing, metrology, and quantum computing.

6. Forward-Thinking on Industry Needs: understand the needs of the PIC industry for new integration technologies and applications, and apply a problem-solving and multi-perspective attitude to tackle future challenges.

7. Research Capabilities: conduct methodical and analytical research within state-of-the-art infrastructure, including simulation, characterization, and fabrication facilities.

8. Collaboration and Communication Skills: work within international, multidisciplinary teams and effectively communicate in English with all stakeholders in the silicon photonics ecosystem.

These expected outcomes emphasize:

- Advanced knowledge of prevailing technologies
- Expertise in fundamental optical effects and underlying working principles
- Cultivation of system-engineering thinking, emphasizing holistic perspectives over individual components.
- Application versatility, acknowledging the dynamic nature of the field and the constant evolution of new applications, materials, and technologies

The Learning Outcomes are defined in collaboration with and checked by both industry and students and have been officially approved by the authorized government agency [4].

B. *Building Blocks*

The building blocks are the components, from the basic concepts, working principles at play, optical effects, materials and technologies needed to truly understand silicon photonics and to start a career in this field. Taking into account this fundamental theoretical knowledge and taking into account the Key Stages of PIC Development which are displayed in figure 1, a set of building blocks, which we consider to be essential, were defined.

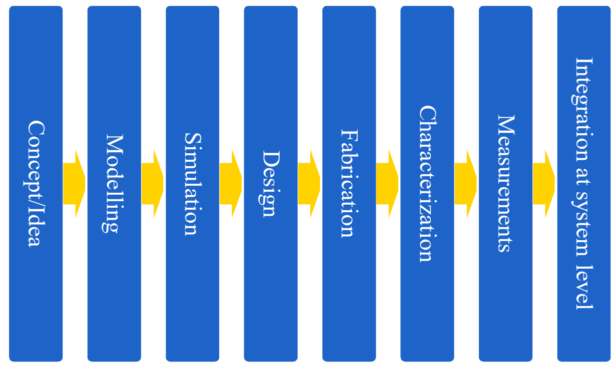

Fig. 1: Key Stages of PIC Development

Building blocks:

- Semiconductor Physics
- Passive components
- Active components: integrated sources, modulators, and detectors
- Materials needed for PICs
- PIC Modelling techniques
- PIC Simulation techniques
- PIC Design methods
- Fabrication technology
- Characterization techniques
- Electro-optical co-integration
- Packaging
- Testing and reliability
- Applications (among others; sensing, transceivers, quantum computing)

C. *From Learning Outcomes and Building Blocks to Courses*

By establishing the Learning Outcomes and defining the building blocks, a set of courses were defined which covers all building blocks and which ensures that all Learning Outcomes will be met at the end of the program.

The set of courses can be divided into (1) core courses, which are mandatory for all students to take up; (2) a set of elective courses and (3) a master thesis project. Throughout the master program, either embedded in core courses or in parallel with the educational study plan, there is a strong emphasis on the professional development of the students. The schematic overview of the master program, semester overview with the different courses can be found in figure 2.

Semester 1	Semester 2
Core Courses	**30 ECTS**
Photonics Integrated Circuits: from Concept to Application (8)	
Theory of Photonic Integrated Circuit Devices (6)	*Processing and Packaging Technologies for Photonic Integration (4)*
Integrated Lasers (4)	
Materials for Photonic Integrated Circuits (4)	
Electronics for Photonic Integrated Circuits (4)	
Elective Courses (3 to choose from list)	**12 ECTS**
Quantum Optics (4)	*Optical Communication and Information Processing (4)*
Non-linear Optics (4)	*Integrated Photonic (Bio)Sensing (4)*
	Micro- and Nanophotonic Semiconductor Devices (4)
Technological Processes for Photonics and Electronics: Laboratory (4)	
Master Thesis	**18 ECTS**
Master Thesis (18)	
Professional Development	
Guest lectures, company visits, ePIXfab training activities, ...	

Fig. 2: Overview of the program (number of ECTS credits per course unit between brackets)

1. Core courses:

The core courses are the mandatory courses which all students must take up in their curriculum.

Throughout the one-year program, we run a flagship course "Photonics Integrated Circuits: from Concept to Application" (8 ECTS). This course encompasses the full spectrum of PIC development, from design over fabrication to characterization, including lectures delivered by industry experts focusing on major PIC application areas.

In the first semester, the curriculum aims to establish a foundational understanding of working principles, optical effects, materials and technologies, through the courses:

- Materials for Photonic Integrated Circuits (4 ECTS)
- Theory of Photonic Integrated Circuit Devices (6 ECTS)
- Integrated Lasers (4 ECTS)

Recognizing that photonic circuits are almost always working together with electronics, the crucial aspect of electro-optical integration is covered in the "Electronics for Photonic Integrated Circuits" (4 ECTS) course, which is also positioned in the first semester.

In the second semester, the course "Processing and Packaging Technologies for Photonic Integration" (4 ECTS) introduces photonic device fabrication processes, material properties, and device design principles.

2. Elective courses:

The core program is supplemented with a set of elective courses that allow for specialization in specific application domains or advanced technology aspects. Each student must total 12 ECTS elective credits within their curriculum. Currently six elective courses, each worth 4 ECTS credits, are on offer. As such, each student must take up three elective courses.

- Integrated Photonic (Bio)Sensing
- Optical Communication and Information Processing
- Quantum Optics
- Non-linear Optics
- Micro- and Nanophotonic Semiconductor Devices
- Technological Processes for Photonics and Electronics: Laboratory; which is a full-year, pure hands-on cleanroom course to master advanced cleanroom processes.

Elective courses may change over time, with cancellations or additions based on emerging trends or technologies, guided by the Study Program Committee and the Advisory Board.

3. Master thesis:

Throughout the year, but with an emphasis in in the second semester, the Master thesis (18 ECTS) takes place, as a significant capstone project focusing on independent research and engineering.

D. Management of the Program

The program is administered (Fig. 3) by a Study Program Committee (SPC). The SPC is composed, and functions in accordance with Ghent University's Education and Examination Code. The SPC meets regularly and analyses and discusses the results of the study program quality measurements and other forms of evaluation on a regular basis.

An Advisory Board will be established to ensure the program's ongoing relevance. The board will evaluate the curriculum's alignment with current expectations and consider long-term strategies. Annually, it will meet to recommend changes or explore new directions, with coordination by the SPC.

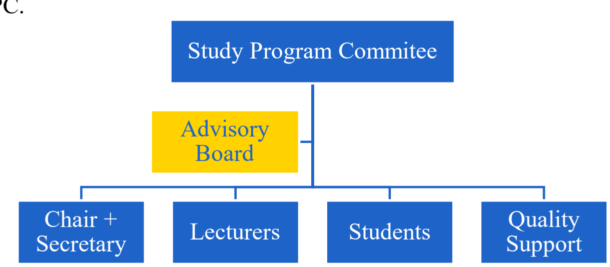

Fig. 3: Program Management

III. Program Specifics

A. Structure and duration of the program

The Advanced Master in Silicon Photonics is a 60 ECTS program that can be completed in one full academic year, with 1 ECTS representing typically 25-30 hours of work (lectures, labs, projects, exams) [5]. Recognizing the diverse needs of candidate students, including working professionals, the program offers flexible trajectories to spread the program over two to four years. This ensures that students can integrate their professional and academic commitments. With this extended duration, the master thesis project (18 ECTS) can be conducted in their workplace, providing a practical and immersive learning experience.

B. Professional Development

The Advanced Master in Silicon Photonics at Ghent University offers a professional development component to expose students to future opportunities in academia and industry. This includes guest lectures by industry partners, providing insights into the latest advancements and industry trends. Additionally, students benefit from the connection to imec¨[6], the PhotonDelta [7] ecosystem, and ePIXfab [8] training activities, exposing them to a local, European and global network.

IV. Conclusion and Outlook

The new Advanced Master of Science in Silicon Photonics at Ghent University is a unique program that addresses a critical need for skilled professionals in the rapidly growing field of integrated photonics. With the combination of academic excellence, practical industry experience and flexible study formats, the program aims to train a new generation of engineers and researchers to drive innovation in silicon photonics.

The program provides students with a comprehensive and cutting-edge curriculum, integrating theoretical knowledge with hands-on experience in state-of-the-art laboratories. Our commitment is to empower students with the skills and insights needed to address the complex challenges of this fast-evolving and rapidly growing field. This way, our master program aims for a large impact by developing a highly skilled workforce in Silicon Photonics, educate students who can define new and multidisciplinary directions in PIC research, and who can function in international and multidisciplinary teams, communicating with all relevant stakeholders.

With the growing demand for silicon photonics professionals exceeding supply, this program addresses the shortage by preparing highly qualified specialists to meet the industry's evolving technical and practical needs. By combining in-depth theoretical instruction with hands-on training in cutting-edge facilities, the program ensures graduates are well-equipped to seamlessly transition into professional roles, effectively linking academic expertise with industry demands.

In the future we will complement this program with Life-Long Learning [8] initiatives. To this aim, we will modularize several courses within the master program to make them available as Micro-Credentials. This will allow learners to take these modules independently, providing flexibility and accessibility for continuous professional development.

In conclusion, the Advanced Master of Science in Silicon Photonics at Ghent University is a vital step toward building a highly skilled workforce that bridges the gap between academia and industry, addressing both immediate demands and long-term advancements in silicon photonics.

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