Teaching silicon photonics using new technologies

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Abstract: To improve student learning experience in several photonics modules we teach at the University of Southampton, we use software packages for photonic circuit simulation and design, our cleanroom complex for the fabrication of the designed circuits, and experimental labs that we have developed for the characterisation.

1. Introduction

In the last several years we have introduced three photonics modules in undergraduate and postgraduate courses at the University of Southampton. The main motivation for our students is to acquire new skills required by the photonics industry. Since the University of Southampton has one of the best electronics departments in the UK and a world leading Optoelectronics Research Centre with extensive cleanroom complex (Fig. 1), and exceptional laboratory facilities, there was a clear motivation for us to utilise such an environment and introduce a photonics pathway in undergraduate and postgraduate education at the Faculty of Engineering and Physical Sciences.

Two modules have been introduced in year 2 ('Photonics I') and year 3 ('Photonics II'). In Photonics I, optical fibres and passive silicon photonic devices (waveguides, couplers, splitters, ring resonators, and interferometers) are taught, whilst in Photonics II active devices (detectors, modulators and lasers) are covered. These two modules complement an MSc 'Silicon Photonics' module with more advanced topics (multiplexers, heterogeneous modulators, modulation formats, fabrication, sensors). Here, we report on our teaching of these modules by using software packages, cleanroom tools, and virtual and real experimental labs.

2. Simulations, design, fabrication and characterisation of photonic circuits

Within the first three weeks of 'Photonics I' teaching, the students complete a simulation lab in which they learn how to design waveguides, waveguide bends, directional couplers and Mach-Zehnder interferometers using Lumerical MODE Solutions software in both 2D and 3D modes [1]. They are also given their main coursework assignment to simulate and draw a layout mask design of a silicon photonic circuit. Once they have designed the parameters, students draw their devices into a lithography mask layout using Tanner Tools L-edit [2], which are then combined with the other students' designs, and fabricated in the University of Southampton cleanroom, through the CORNERSTONE programme [3], so that they are able to measure their own devices in the subsequent characterisation lab session.

This chip fabrication is also offered to external students as a service strictly for teaching purposes at the modest cost of £100 per student. Each student is assigned a 3x6 mm^2 design area. The fabrication process is carried out on the 220 nm silicon-on-insulator (SOI) platform with a single etch depth of 120 nm. Standard devices such as grating couplers for a wavelength of 1550 nm are provided to the students. This simple process enables devices to be fabricated and shipped within two weeks of the design submission.

In the 'Photonics II' module the students move onto more complex electro-optic devices such as modulators. In the simulation lab they design a carrier injection modulator which utilises the well-known plasma-dispersion effect. The simulation model is built using the Lumerical DEVICE software package [1]. In this way the students learn all elements required to build a complex model for electro-optic simulations including electrical simulations to model the free carrier distribution across a waveguide, running scripts to calculate the change in material refractive index, and finally solving for the optical mode. Immediately after the lab, they are given their coursework assignment which builds on the model developed in the lab to create a carrier depletion device, and optimise the length, loss and position of the pn-junction.

The teaching laboratories include four experimental setups for measuring near-infrared light transmission through photonic integrated circuits, and for simultaneously applying low frequency electrical signals to the chips. Each setup includes a tuneable laser, detector, fibres, polarisation controller, stages for manipulating the fibre positions, and magnifying cameras for viewing the chip during alignment. The students work in pairs, with each lab session taking 3 hours.

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In the ‘Photonics I’ module the students characterise the waveguides, directional couplers, and passive Mach-Zehnder interferometers that they have designed themselves during their coursework. They learn how to align fibres to grating couplers and how to run wavelength versus transmission sweeps, and analyse the results. In the ‘Photonics II’ module the students go a step further and measure the low frequency behaviour of thermo-optic modulators and switches, implemented using silicon Mach-Zehnder interferometers with metal heaters above one interferometer arm, to which electrical signals are applied. They measure the modulation efficiency, the modulation bandwidth, and the adventurous are tasked with applying a PAM 4 modulated signal to the light wave.

3. Virtual Silicon Photonics Experimental Lab (V-SPELL)

In order to enhance the laboratory experience, we have developed a virtual lab environment to enable the students to familiarise themselves with the equipment prior to the lab session. V-SPELL has been developed using Articulate Storyline [4], an authoring tool that is supported by the University to easily create interactive content.

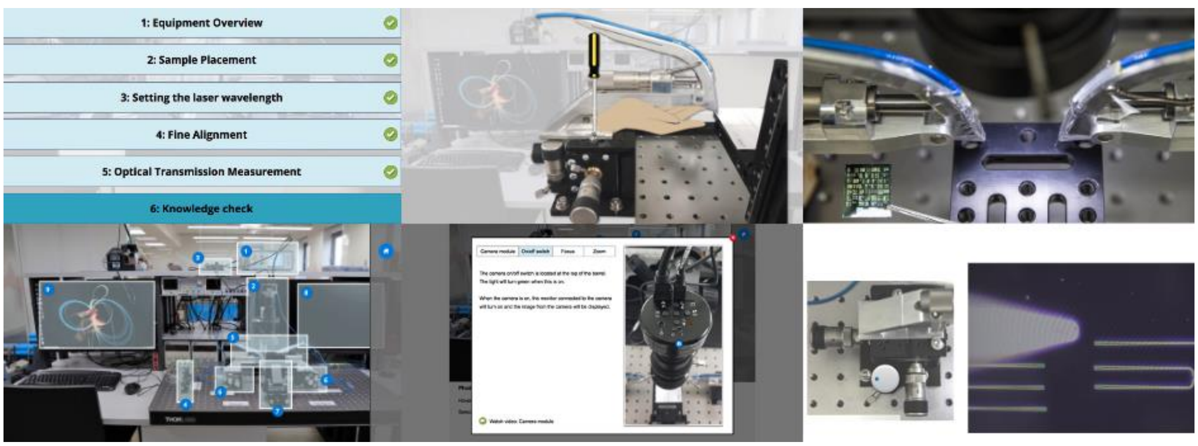

Fig. 1. Screenshots from the Virtual Silicon Photonics Experimental Lab (V-SPELL).

The main objective of this virtual lab was to acquaint students with the whole experimental set up, so that when they do get to spend valuable time in the lab, they are equipped with the essential foundations that will enable them to delve right into exploration rather than familiarisation. The Virtual Lab is divided into five sections (Fig. 1). Each section prepares the students with the necessary information to perform a standard silicon photonics measurement set up within a safe environment, with video extracts embedded into the resource to reinforce and support learning. Students work through the steps in a linear fashion as they would when setting up in the lab space. Instructions, with help buttons, are provided to guide and test them throughout the process. The last step is a quiz to check student understanding. The published Articulate Storyline file is hosted on Blackboard and for this reason, the quiz result from Step 6: Knowledge check can be stored on the Blackboard Grade Centre where the tutor is able to monitor the students’ activities. There were several challenges during the development of this resource as we wanted online version to replicate the lab space as much as possible. The biggest challenge was to develop virtual software to simulate the movement of the X, Y and Z micrometres and correlate them to the movement of the fibre tip displayed on the screen. The V-SPELL has been particularly valuable resource during the recent pandemic when students could not do the real experimental lab. We plan to introduce virtual experimental labs into other UG and PG modules in Southampton.

4. References

[1] https://www.lumerical.com

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[3] https://www.cornerstone.sotonfab.co.uk

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