SCHOOL OF ENGINEERING
INSTITUTE OF ELECTRICAL & MICROENGINEERING
LABORATORY OF APPLIED PHOTONICS DEVICES

Lausanne, November 30th 2023

Report on the thesis work of Mr. Adria Grabulosa I Vallmajó titled "*3D printed photonic circuits towards efficient and scalable integration of hybrid photonic platforms*"

Dear thesis Committee,

It is my pleasure to report on the thesis of Mr. Adria Grabulosa I Vallmajó.

Chapter 1 is the introduction that motivates the thesis work. The high connectivity between neurons in digital neural networks scale quadratically with the number of input output in a 2 dimensional electronic chip whereas if a third dimension could be added – via a photonic link – the scalability would be linear with the number of input and output nodes and latency would be reduced. Adria thus motivates the necessity of building three dimensional connection using photons as carriers and 3d manufactured waveguides in polymers. Adria reviews the 3D optical manufacturing platforms such as direct laser writing with femtosecond pulses or single photon micro stereolithography.
He then introduces the theory of mode guiding in a waveguide using the full EM description. This part is typically found in text books and could be moved to an appendix. He introduces the conditions for coupling light between waveguides or splitting the light to multiple waveguides. The experimental 2PP fabrication tool (Nanoscribe) is presented along with the capabilities to form long graded index and step index waveguides using the Dip in mode. He also presents his characterization set-up.

In chapter 2, Adria discusses his first contribution which is combining single photon polymerization (using UV light) for the cladding and support and 2PP for fabricating the waveguides. The so-called Flash -2PP decreases the fabrication time of core and cladding waveguide by essentially just the time of 2PP fabrication since the flood exposure is very fast. He achieved results of optical guiding losses of 1dB/mm and demonstrated tapered fabrication showing one order of magnitude less injection loss than in glass waveguide. He showed the waveguide properties are maintained under continuous use for more than 100 days with an optical power level expected in applications. This work is well executed. This work was published in the journal of Nanophotonics in which Adria is first author.

In chapter 3, Adria designs a broad band - one input to many output- coupler. He chooses an inverse taper design and optimizes the adiabatic taper length for light coupling efficiency. His experimental fabrication is really impressive – a tour de force - as he achieves coupling loss around 1dB on a large spectral bandwidth from 520 to 1000 nm with near perfect Gaussian mode outputs. From this first experimental splitter, he designed cascaded splitters with the same split configuration (fractal splitting). Starting with a 1x4 splitter, he achieved 1 x16 splitting. This is quite

École polytechnique fédérale de Lausanne
LAPD
EPFL STI IMT LAPD
BM 4.111
Station 17
CH - 1015 Lausanne
Phone : +4121 69 36110 / 35185
Fax : + 4121 69 33701
E-mail : christophe.moser@epfl.ch
Website : https://lapd.epfl.ch/

remarkable that he achieved a 1dB coupling loss. He published this work as first author in Optics Express.

In chapter 4, Adria investigates the use of single mode air-clad waveguide which is much more challenging due to the high confinement and therefore the higher resolution required to fabricate the single mode guides. He develops a simulation using EM modes of the waveguide to engineer the tapered length that minimizes coupling loss and ensure single mode guiding. He also investigates the bending shape that minimizes losses. Experimentally fabricating the bend shape with such a small waveguide core is very challenging. However, he found a way by adding support structure on top and bottom that allows him to test different bent shapes. The experimental results are also very impressive, reaching between 0.5 and 1.5 dB with a small radius of curvature - 10 um. He has also experimentally demonstrated a air-clad 1x4 splitter that results in 4 single mode output. Very impressive results. This work is part of a manuscript that will be sent for a publication.

Overall, this thesis is of high quality, very well executed both by simulation and especially experimentally validated. This thesis work is practical and of great relevance for opto-electronic chip to chip or chip in chip interconnects in particular well suited for the digital neural networks. I have no doubt this work will be impactful in the community.

Therefore, it is my pleasure to allow Mr. Adria Grabulosa I Vallmajó to present his work during the thesis defense.

Best regards,

Professor Christophe Moser

Director Laboratory of Applied Photonics Devices
Director of the MicroEngineering Section

École polytechnique fédérale de Lausanne

LAPD

EPFL STI IMT LAPD
BM 4.111
Station 17
CH - 1015 Lausanne

Phone : +4121 69 36110 / 35185
Fax : + 4121 69 33701
E-mail : christophe.moser@epfl.ch
Website : https://lapd.epfl.ch/