Dr. Adrià Grabulosa

Date of birth: 03/08/1996
Citizenship: Spanish
Phone: +33 6 05 75 24 17
Mail: a.grabulosa15@gmail.com

JOB EXPERIENCE

PhD in Optics and Photonics – Femto-ST Institute
2020-2023, Besançon, France
Design, fabrication and testing of 3D printed photonic circuits towards scalable and CMOS compatible integration of photonic neural networks.
Technology skills: direct-laser writing (DLW) based on two-photon polymerization (TPP), scanning electron microscopy (SEM), critical point drying and reactive ion etching (RIO).

Internship (DAAD scholarship) – Technische Universität of Berlin (TUB)
2022-2023, Berlin, Germany
The aim of the internship was to merge 3D printed photonic waveguides and semiconductor (GaAs) quantum dot micropillars in one single integrated device.
Technology skills: micro-photoluminescence (µPL) spectroscopy at cryogenic temperatures and metal-organic chemical vapor deposition (MOCVD).

MSc final project – The Institute of Photonic Sciences (ICFO)
2018-2019, Castelldefels, Spain
Design and testing of novel platforms for THz and mid-IR photodetection based on graphene.
Technology skills: design and construction of free-space optical set up.

BSc final project - Microelectronics Institute of Barcelona (IMB-CNM-CSIC)
2017-2018, Bellaterra, Spain
Design and fabrication of superconducting coplanar waveguide resonators.
Technology skills: electron-beam lithography (EBL), direct-laser writing (DLW) and general lithography processes, i.e. spin coating, mask alignment, thermal evaporation and lift-off.

Project member – Quantic BSC (Barcelona Supercomputing Center)
2017-2018, Barcelona, Spain
Research assistant for the development of a superconducting qubit platform, the first of its kind fully fabricated in Spain. Later developed into the startup *Qilimanjaro Quantum Tech*.
Technology skills: atomic force microscopy (AFM), transmission electron microscopy (TEM) and simulations via Sonnet Software.

EDUCATION

2020-2023 PhD in Optics and Photonics – Université Bourgogne Franche-Compté (UBFC).

2019-2020 MSc in Photonics – Universitat Politècnica de Barcelona (UPC), The Institute of Photonic Sciences (ICFO), Universitat Autònoma de Barcelona (UAB) and Universitat de Barcelona (UB).

2014-2019 BSc in Nanoscience & Nanotechnology – Universitat Autònoma de Barcelona (UAB).

GRANTS/AWARDS

2021-2022 SPIE Optics + Photonics Student Conference Support, San Diego (USA).

2022-2023 German Academic Exchange Service (DAAD) – Short-term grant at TU Berlin.

PUBLICATIONS

Grabulosa, A., Porte, X., Moughames, J., Brunner, D., "Combining one and two photon polymerization for accelerated high performance (3+1)D photonic integration", *Nanophotonics* 11, 1591 (2022).

Grabulosa, A., Porte, X., Jung, E., Moughames, J., Kadic, M., Brunner, D., "(3+1)D printed adiabatic 1-to-M broadband couplers and fractal splitter networks", *Optics Express* 31, 20256-20264 (2023).

Grabulosa, A., Moughames, J., Porte, X., Kadic, M., Brunner, D., "Additive 3D photonic integrations that is CMOS compatible", *Nanotechnology* 34, 322002 (2023).

Grabulosa, A., Porte, X., Moughames, J., Brunner, D., "3D printing towards scalability for photonic neural network integration", *2nd workshop on neuromorphic computing*, University of West Attica, Athens (2023). Invited talk.

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/

REPORT FOR DOCTORAL THESIS (ADRIÀ GRABULOSA)

30 November 2023

The Ph.D. thesis of Mr. Adrià Grabulosa is based on three published peer-reviewed articles and contains sufficient high-level content to warrant application for the doctorate. The thesis comprises six chapters, encompassing the research background and original publications. The PhD thesis is well-organized, written in a clear and concise manner, and includes an appropriate number of sources in the bibliography.

Strengths of his work and original contribution to its field

Undoubtedly, the 3D printing photonic technologies addressed by Adrià Grabulosa are promising for the next-generation 3D photonic circuits with high scalability and high-density integrability. One of the most unique strong points of his dissertation is that he established a printing technique for the basic optical components, such as 3D waveguides and optical splitters, required for 3D optical interconnections. The unique printing technologies merge the two polymerization processes, one-photon (OPP) and two-photon-polymerization (TPP), and significantly reduce printing time, compared to the conventional process using only TPP. This enabled the creation of very long 3D optical waveguides. Moreover, he designed and printed a unique 1-to-M optical splitter with low coupling loss and a broadband splitting ratio, which is highly promising for 3D optical network topologies. Interestingly, he successfully coupled a 3D optical waveguide with quantum dot microlaser arrays, introducing several innovations. The unique 3D printing photonic technology established by Adrià Grabulosa has a strong impact on the field of neuromorphic computing and optical integrated circuits.

Review report

The thesis comprises six chapters. It presents 3D printed photonic components essential for 3D photonic integrated circuits in upcoming neuromorphic computing. Leveraging CMOS-compatible materials and processes using OPP and TPP, it is demonstrated how the 3D photonic components facilitate extensive interconnections, addressing challenges in current 2D/2.5D integration technologies.

Chapter 2 presents a groundbreaking printing approach, flash-TPP, which merges TPP and OPP, reducing printing time by approximately 90%. This approach employs distinct strategies

for various sections of photonic integrated circuits, ensuring high-resolution printing of waveguide cores and uniform cladding layers. This results in low-loss and stable optical performance over extended periods.

Chapter 3 showcases the accomplishment of broadband and low-loss adiabatic 1-to-M splitters using flash-TPP. The 3D splitters enable efficient splitting/combining of optical signals and will be essential for building 3D optical network topologies.

Chapter 4 demonstrates the development of air-cladding waveguides, offering the potential for higher integration density with increased optical confinement. Compared to polymer-cladding waveguides, these waveguides enable smaller bending radii and compact footprints, emphasizing their potential for high-density photonic integrations.

Chapter 5 introduces an innovative integration of quantum dot micro-lasers and 3D photonic waveguides in a hybrid platform, which is important for future all-optical neural networks. This unique approach demonstrates efficient emission collection using flash-TPP lithography.

Chapter 6 provides the summary and perspectives.

In summary, the Ph.D. thesis represents original and high-level technological work, generating significant new knowledge and technologies in the field of 3D photonic integration. The unique methodology has been scientifically described. The conducted experiments are well-organized, and the results are effectively presented. The explanations provided are both reasonable and appropriately focused on relevant topics. The thesis demonstrates his excellent skills and the high quality of his work, as evidenced by three first-authored peer-reviewed publications in reputable journals.

Therefore, I recommend the Ph.D. thesis of Mr. Adrià Grabulosa for defense.

Professor Satoshi Sunada, Ph.D.
Kanazawa University, Kakuma-machi, Kanazawa, Ishikawa, 920-1192, Japan
E-mail: sunada@se.kanazawa-u.ac.jp

Satoshi Sunada 30/11/2023

DEPARTEMENT OPTIQUE
Maxime JACQUOT
Directeur
Tél. +33 (0)3 63 08 24 16
maxime.jacquot@univ-fcomte.fr

Subject: recommendation letter

February 27, 2024

Dear committee,

I am writing to wholeheartedly recommend Dr. Adrià Grabulosa for consideration in the thesis prize competition conducted by the *Société Française de Physique*. Dr. Grabulosa has recently completed his doctoral studies in Optics and Photonics, and his thesis, entitled "3D Printed Photonic Circuits Towards Efficient and Scalable Integration of Hybrid Photonic Platforms" stands as a testament to his outstanding abilities and contributions to the field.

Dr. Grabulosa's research focuses on the innovative and groundbreaking application of 3D printing technology in the realm of photonic circuits. His work is particularly noteworthy for its emphasis on achieving efficient and scalable integration of hybrid photonic platforms, with a specific focus on applications in photonic neural networks. This innovative approach not only demonstrates its in-depth knowledge of emerging physical concepts for designing the machine learning architectures of the future, but also underlines its commitment to tackling challenges in a rich multidisciplinary field combining physics, technology and information processing through creative and effective solutions.

One of Dr. Grabulosa's most commendable qualities is his ability to bring clarity and precision to many complex scientific concepts. The manuscript accompanying his thesis reflects not only the depth of his fundamental and technical expertise, but also his ability to present highly complex experimental results in a clear and accessible way. His commitment to excellence is evident in the meticulous organization of his work, demonstrating a keen understanding of the importance of effective communication in advancing scientific discourse.

In addition to his academic accomplishments, Dr. Grabulosa is a dedicated and collaborative researcher who has consistently demonstrated a passion for advancing the boundaries of knowledge, particularly in 3D photonic integration. His work has the potential to significantly impact the field, and I am confident that his contributions will continue to garner recognition and acclaim.

I wholeheartedly endorse Dr. Adrià Grabulosa for the thesis prize competition, confident that his work represents a significant and valuable contribution to the Optics and Photonics community. If you require any further information, please do not hesitate to contact me.

Sincerely,

Maxime JACQUOT
Directeur
Département Optique
Institut FEMTO-ST

Prof. Maxime JACQUOT
Université de Franche-Comté

Research Institute FEMTO-ST
UMR 6174 UFC & CNRS
Head of optics department

UBFC
UNIVERSITÉ BOURGOGNE FRANCHE-COMTÉ

PROCES VERBAL DE SOUTENANCE du 15 décembre 2023 à 14h00

Année universitaire 2022-2023

Doctorant :	Monsieur ADRIÀ GRABULOSA
Né le 3 août 1996	
Diplôme :	Doctorat de Optique et photonique
Titre des travaux :	Circuits photoniques imprimés en 3D pour une intégration efficace et évolutive des plates-formes photoniques hybrides
Ecole doctorale :	SPIM - Sciences Physiques pour l'Ingénieur et Microtechniques
Unité de recherche :	UMR 6174 - FEMTO-ST Franche Comté Electronique Mécanique Thermique et Optique - Sciences et Technologies
Directeur de thèse :	Daniel BRUNNER
Codirecteur de thèse :	☐ HDR ☐ Non HDR
Lieu de soutenance :	Amphithéâtre Jean-Jacques Gagnepain - Institut FEMTO-ST 15B Avenue des Montboucons 25000 BESANCON
Soutenance :	☑ Publique ☐ A huis clos
Résultat :	☒ Admission ☐ Ajournement
Confidentialité :	☐ Oui ☑ Non
Corrections mineures demandées par le jury[1] :	☐ Oui ☒ Non
Corrections majeures demandées par le jury[1] :	☐ Oui ☒ Non
Le doctorant a prêté serment à l'issue de la soutenance :	☒ Oui ☐ Non

Membres du jury [2]:

Nom	Qualité	Etablissement	Rôle	Signature
M. Satoshi SUNADA	Professor	Kanazawa Universit, Faculty of Mechanical Engineering	Rapporteur	Satoshi Sunada
M. Christophe MOSER	Professor	École polytechnique fédérale de Lausanne (EPFL)	Rapporteur	
M. François COURVOISIER	Directeur de recherche	Université Bourgogne Franche-Comté	Examinateur	

Nom et Signature du président du jury : François COURVOISIER

1. L'intéressé(e) dispose d'un délai de trois mois à compter de cette date pour déposer la version électronique corrigée de son manuscrit sur ADUM. Ce délai expiré, la thèse sera transmise à la Bibliothèque Universitaire, EN L'ÉTAT, et ne sera pas reproduite, ni diffusée, mais uniquement archivée.

2. Conformément à l'arrêté du 25 mai 2016, le directeur de thèse (et les codirecteurs le cas échéant) n'est pas autorisé à signer le PV de soutenance.

RAPPORT DE SOUTENANCE DE DOCTORAT DE Optique et photonique

Nom et prénom du candidat : ADRIÀ GRABULOSA

Date et lieu de naissance : 3 août 1996 à Girona Espagne

Lieu, Date et heure de soutenance : Amphithéâtre Jean-Jacques Gagnepain - Institut FEMTO-ST 15B Avenue des Montboucons 25000 BESANCON , le 15 décembre 2023 à 14h00

Mr. Adria Grabulosa I Vallmajo has defended his PhD thesis entitled "3D printed photonic circuits towards efficient and scalable integration of hybrid photonic platforms".

His presentation was very clear, didactic, and well-illustrated. He provided insight into a promising cutting-edge scientific topic that is currently very active. He has experimentally demonstrated several important contributions to the field of 3D waveguide engineering by additive manufacturing, which is highly relevant to optoelectronic chip interconnects, particularly for novel neural network architectures.

His work triggered numerous interesting questions from the jury, which he answered very satisfactorily. The discussion demonstrated his excellent command of the field and scientific maturity. He has become a real expert, well aware of the international state of the art in optical computing and two-photon laser writing.

Therefore, the jury unanimously awards Mr. Adria Grabulosa I Vallmajo the degree of PhD in Optics and Photonics of the University Bourgogne Franche-Comté.

Fait à Besançon le 15 décembre 2023

Nom, prénom et signature du président du jury COURVOISIER Francois

Membres du jury :

Nom, prénom	Signature	Nom	Signature
Daniel BRUNNER		Satoshi SUNADA	Satoshi Sunada
Christophe MOSER		François COURVOISIER	