



# RESEARCH BROCHURE



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# Victor Vassiliev

## Aston University

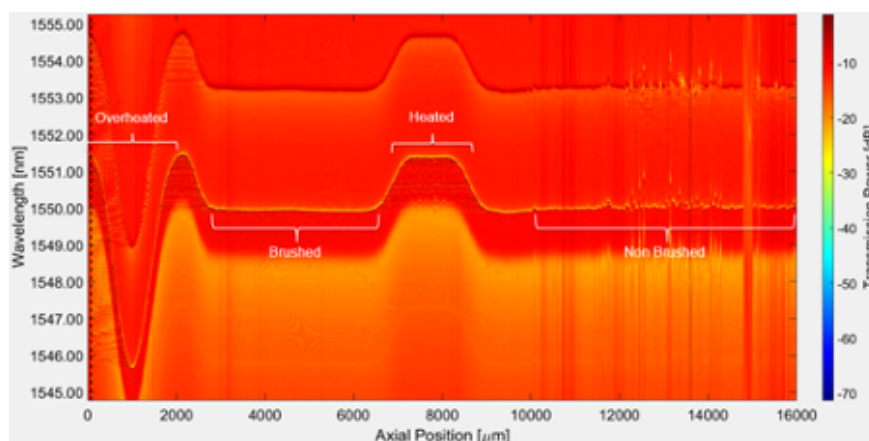
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## Heat induced SNAP resonators

We seek to create a more precise and accessible method to produce bottle micro resonators using the framework of the SNAP platform that allows for a high precision fabrication and characterisation of micro resonators. We use a heat source that can be a simple butane torch to introduce a nanoscale effective radius variation to the atomically smooth surface of a drawn fibre. Controlling this radius variation allows us to engineer the cut-off wavelengths to create the desired device.

## Relevance and impact

The value of increasing fabrication precision cannot be understated as it is currently what stands in the way of microscopic photonic devices reaching their full potential in optical processing, quantum computing, microwave photonics, optical metrology, and advanced sensing. In a SNAP resonator, the small nanoscale variation of the fibre radius necessary to steer the whispering gallery modes is quite simple to introduce and doesn't require a laser, which adds another benefit to our method: accessibility, as the setup for the fabrication is simple.



**Spectrogram: The different stages of heat exposure of an optical fibre**

# Summary of the progress

Several variations of fabrication method have been considered, a simple butane torch as heat source to modify an optical fibre either by directly putting it in proximity of the flame or by heating up an intermediary material like metal or sapphire to be placed in proximity of the fibre, modifying the later by transferring some of its heat to it.

The setup has been fully automated.

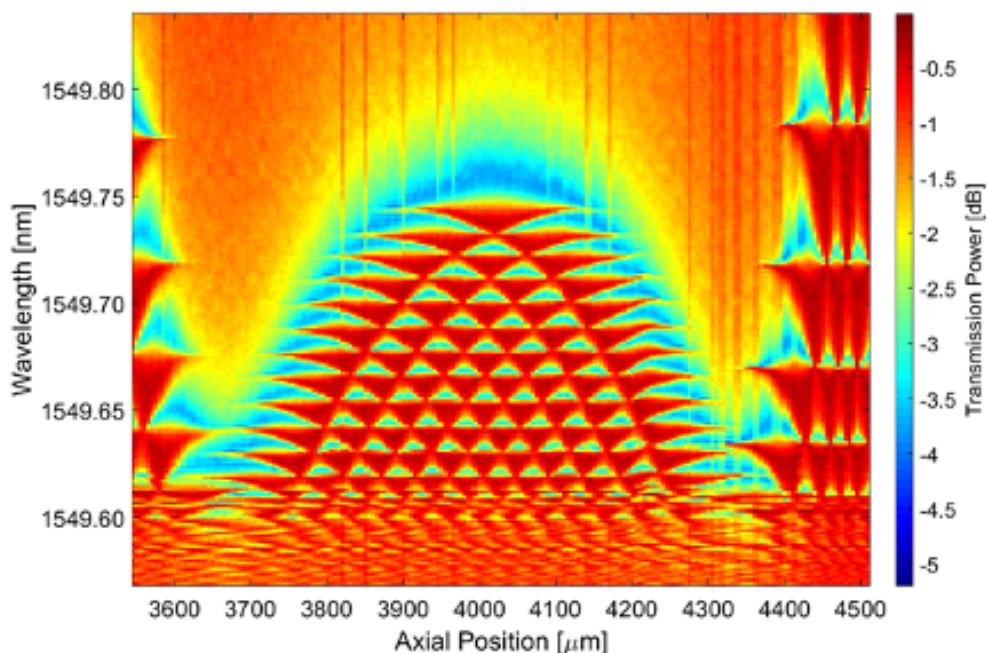
The developed method enables robust fabrication of SNAP devices with sub-angstrom precision.

To better understand the heat source, characterization of different intensities of shooting butane jet flames was done.

Experimentation with different fabrication setups led to the observation that while the different methods impact important parameters like the quality of the surface of the fibre, fabrication repeatability, precision along the fibre axis and even whether the induced changes affect different frequencies in the same way or not, the fibre goes through the same stages, independent of the method used, as the temperature it is exposed to increases from room temperature to hundreds of degrees.

We established and documented the different stages of heat exposure of an optical fibre.

A potentially interesting and not yet fully understood effect was also noted, where the different modes were asymmetrically affected by the effective radius variation.



**Figure: SNAP Spectrogram, it allows us to see resonant frequencies inside the resonators.**



# Loredana Massaro

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## Nonlinear nanophotonic III-V semiconductor on Si platform for frequency comb generation

The goal of my thesis project is to design, fabricate and characterize experimentally a III-V semiconductor photonic crystal cavity on silicon on insulator for frequency comb generation.

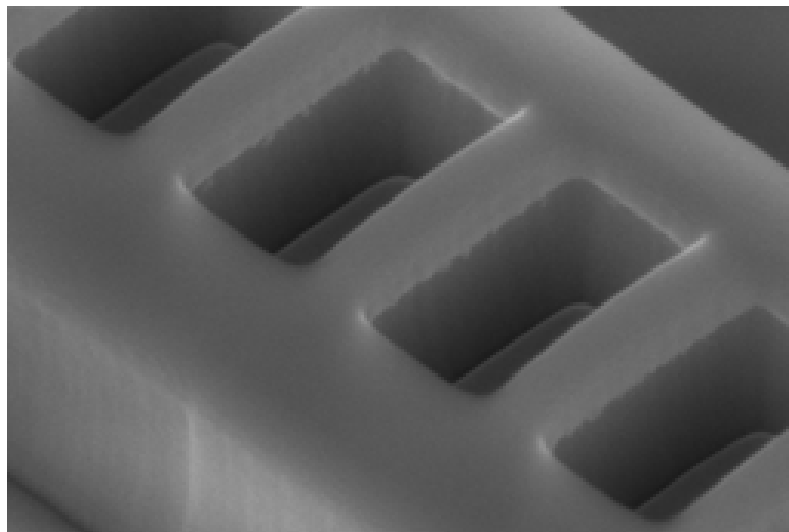


Figure 1: SEM image, Loredana Maria Massaro @ C2N.

## Relevance and impact

On-chip Frequency Comb (FC) are meant to be applied across various fields of science and engineering and amongst all nanostructures, photonic crystal cavities bring the advantages of strong light-matter interaction, small footprint, and high Q factors. Thanks to their large and tailorable band gap preventing two photons absorption, III-V materials platforms integrated on silicon on insulator seem the best candidates to achieve low modal volumes, opening the avenue to scalable and integrated, both quantum and classical, sources of light.



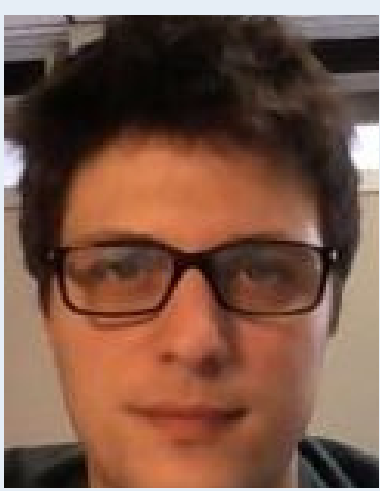
# Summary of the progress

Aiming at optical microcomb generation exploiting a hybrid technology, I modeled and analysed numerically structures consisting of a III-V semiconductor waveguide drilled with one periodic array of holes and surrounded by SiO<sub>2</sub>. Controlling the geometrical parameters of such structures, light has been confined in the desired range of frequencies exploiting the appearance of the Photonic Band Gap. In order to fabricate the III-V one dimensional photonic crystal cavity, clean-room fabrication procedures have been optimised, especially substrate removal techniques, and particular attention has been given to scanning electron microscope analysis of the fabricated samples.

A technique to have equidistant modes has been implemented. Numerical results concerning the alignment of the frequency comb modes of such engineered 1 dimensional photonic crystal structures have been presented as form of oral presentation at the conference Optique Dijon, organised in July 2021.



**Figure 2: Fabrication process, Loredana Maria Massaro @ C2N.**



# Francesco Talenti

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## **Theoretical modelling the build-up and evolution of the fields in microresonators and active cavities**

The very first demonstration of frequency comb (FC) in passive nonlinear resonators, was observed around 15 years ago. From that moment researchers put an huge effort in developing the FC technology for different platforms and practical situations, to find the best solutions for the different applications of these incredible optical sources. This implies from one side a deep theoretical investigation of nonlinear interactions in resonators, from the other the exploration of novel platforms suitable for on-chip integration.

## **Relevance and impact**

The theoretical description of the dynamical field evolution in passive resonators, is extensively studied in literature. Nonetheless researchers always faced several problems which often become a cumbersome in practical situations. In this context we proposed novel schemes for FC generation to excite single or multisolitons states [1], and to control the repetition rate of the comb [2]. We plan to summarize these results in a journal paper. We are also currently working in designing optimal Photonic crystal (PhC) cavities with a flat dispersion. We have submitted a conference paper and we are planning to publish in a scientific journal these latter results.

# Summary of the progress

We showed how a passive resonator coupled by a chirped Gaussian pulse lead to an easily reachable single soliton states with a wide locking range in the frequency domain [1]. This is very interesting in the context of the FC as it solves, at least theoretically, the cumbersome problem of the difficulty to excite single soliton FC state. In the novel scheme we proposed, we can control the soliton formation dynamics by correctly tuning the chirp parameter. As results, very stable solitons states with a wide spectrum can be generated easily (figure 1). In the context of technology integration on-chip, we are working on topology optimization for PhC cavities.

These platforms are particularly promising because of the low power needed to trigger nonlinear interaction. The modal confinement is sketched in figure 1.

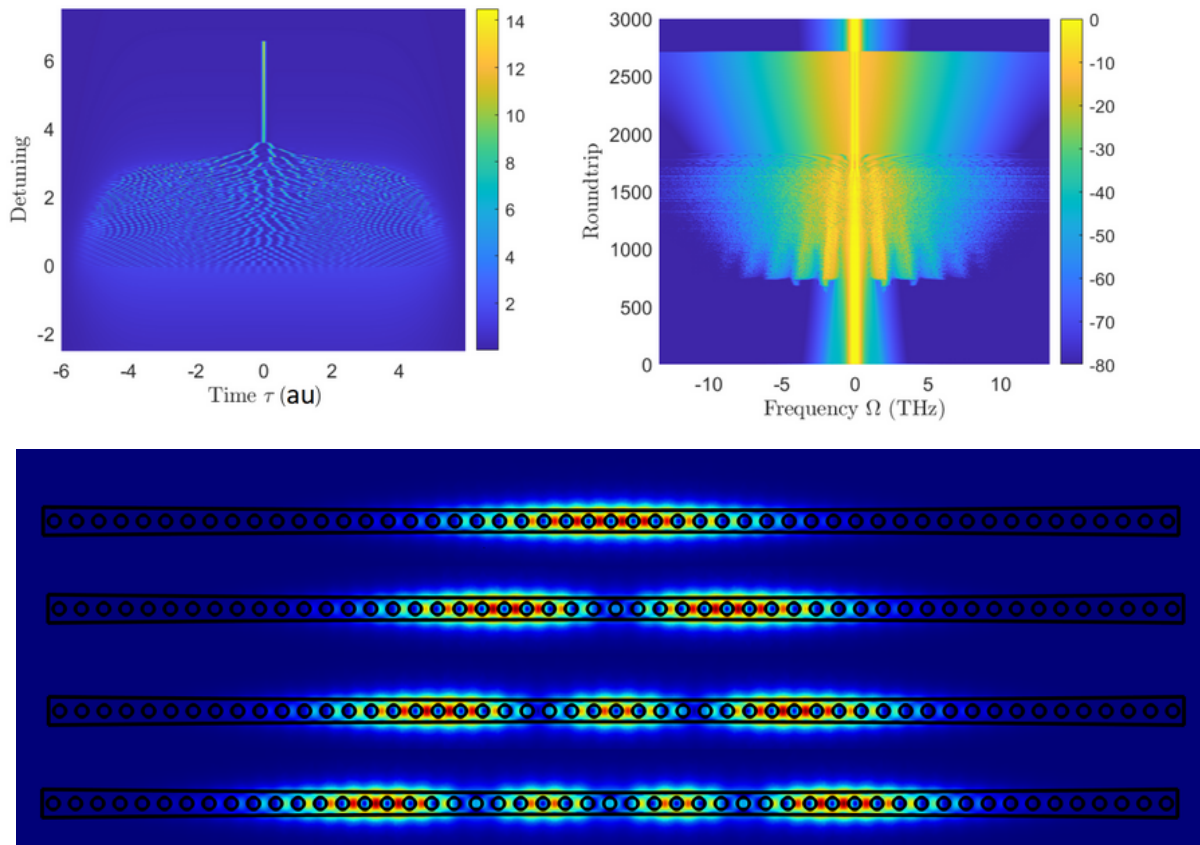
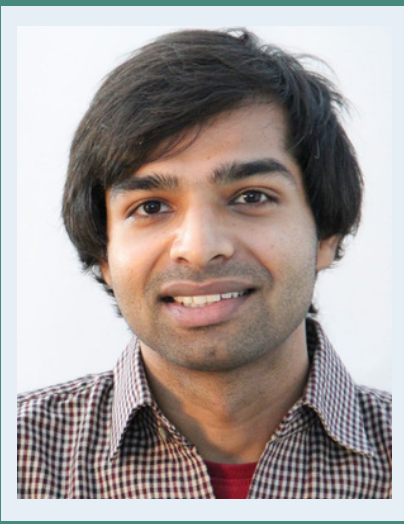


Figure 1.

## Bibliography

- [1] Francesco Rinaldo Talenti, Tobias Hansson, and Stefan Wabnitz. Control of kerr cavity soliton combs by chirped pumping. In OSA Advanced Photonics Congress (AP) 2020 (IPR, NP, NOMA, Networks, PVLED, PSC, SPPCom, SOF), page JTU2D.4. Optica Publishing Group, 2020.
- [2] J. M. Chavez-Boggio, D. Bodenmüller, A. Baig, S. Ahmed, T. Hansson, F. Talenti, S. Wabnitz, and D. Modotto. Frequency comb generation in silicon nitride resonators with amplitude modulated pump. In Vladimir S. Ilchenko, Andrea M. Armani, Julia V. Sheldakova, Alexis V. Kudryashov, and Alan H. Paxton, editors, Laser Resonators, Microresonators, and Beam Control XXIII, volume 11672, pages 8 –14. International Society for Optics and Photonics, SPIE, 2021.



# Avinash Kumar

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## Generating Higher Harmonics in Silicon Nitride (Si<sub>3</sub>N<sub>4</sub>)

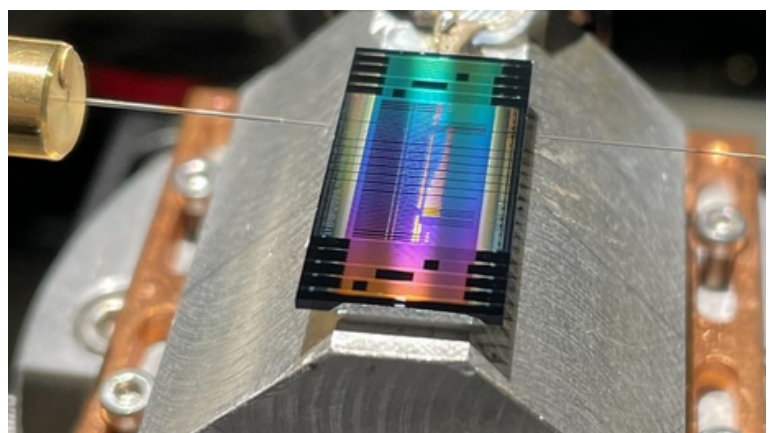
In project MOCCA, we are trying to efficiently generate second harmonic (SHG) and third harmonic (THG) wavelengths corresponding to telecom wavelength of 1550 nm with racetrack resonators on a Si<sub>3</sub>N<sub>4</sub> photonic platform. These higher harmonic components then will be utilized to generate frequency combs needed for self- referencing applications like dual comb spectroscopy.

## Relevance and impact

Silicon Nitride being extensively used in integrated electronics & photovoltaics due to its wide bandgap and high refractive index also possess optical properties, ideal for developing integrated photonics on CMOS platform. It is very important from scalability & from cost point of view to create photonic solutions which can be integrated on CMOS electronics. Developing self- referencing frequency combs in Si<sub>3</sub>N<sub>4</sub> integrated will be one of the photonic solutions for CMOS electronics for an efficient, faster and highly precise way for non-invasive measurements, high density data management etc.

## Summary of the progress

Relevant methodologies for Simulations, Fabrication, Measurements & Analysis are done. From initial data analysis, we learned different device parameters that are needed to be modified for producing desired results.



**Figure 1: Fabricated Silicon Nitride chip with racetrack resonators and other photonic components for MOCCA project at AMO. Figure shows the measurement method used for planar photonic-chip integration.**



# 1

## PAPERS

- J. M. Chavez-Boggio, D. Bodenmüller, A. Baig, S. Ahmed, T. Hansson, **F. Talenti**, S. Wabnitz, D. Modotto "Frequency comb generation in silicon nitride ring resonators with amplitude modulated pump". Proc. SPIE 11672, Laser Resonators, Microresonators, and Beam Control XXIII, 1167206 (5 March 2021);
- Misha Sumetsky and **Victor Vassiliev**. "Angstrom-precise fabrication of surface nanoscale axial photonics (SNAP) microresonators with a flame". Laser Physics Letters, Volume 19, published 7 April 2022;
- Sergey Sergeyev, Stanislav Kolpakov, and Yury Loika. "Vector harmonic mode-locking by acoustic resonance". Photonics Research, Volume 9, Issue 8, pp. 1432-1438 (2021);
- Gabriel Marty, Sylvain Combrié, Fabrice Raineri and Alfredo De Rossi. "Photonic crystal optical parametric oscillator". Nature Photonics, 15, January 2021, pp. 53-58.

# 2

## CONFERENCE TALKS & POSTERS

- MOCCA ESR4, **Avinash Kumar**, gave a talk on "Integration of Graphene with Mid-IR Optical Materials & Far-Field Excitation of Graphene Plasmons" at AMO (April 30, 2020);
- ESR3, **Francesco Rinaldo Talenti**, gave the paper "Control of Kerr Cavity Soliton Combs by Chirped Pumping" at the OSA "Non-Linear Photonics" meeting at "Advanced Photonics Congress 2020". This took place on July 13-14, 2020. Initially planned in Montreal, the conference was held remotely due to the Covid-19 outbreak.
- ESR2, **Loredana Maria Massaro**, presented her project at *ePIXfab*, within the *ePIXfab Silicon Photonics Summer School*. The summer school was held online, on 15-19 June 2020
- ESR2, **Loredana Maria Massaro**, participated as speaker at the *TONIQ* ("*Nanophotonique Non linéaire et Information Quantique*") Group Meeting held on the 15/02/2021
- ESR2, **Loredana Maria Massaro**, presented the paper "Design of III-V/ Silicon Platform for Optical Frequency Comb Generation" at the conference Optique Dijon 2021



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