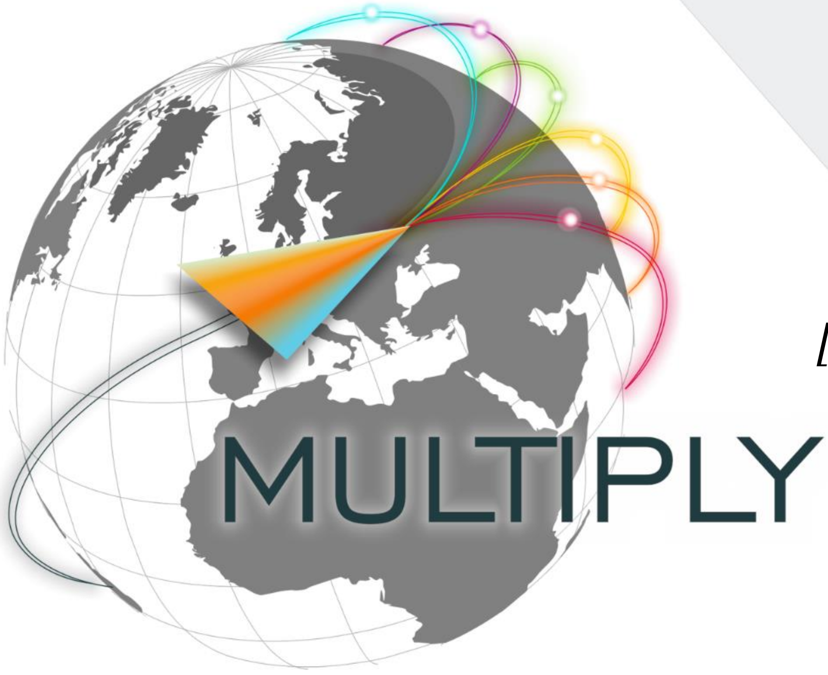
AiPT
Aston Institute of Photonic Technologies

PICASSO

Dr Nikita Toropov

Aston University, United Kingdom



Final report
Project duration – 2 Years

Project period -

[04-12-2017] – [03-12-2019]

PART A

Aston University

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 713694.

Project Full Title	Ultra low-loss photonic circuits: fabrication with picometre precision, applications for sensing and for ‘slow light’ devices
Host institution	Aston University
Scientist in charge	Professor Misha Sumetsky
Start date of the project	04-12-2017
Duration of the project	2 years
Periodic report no.	2
Period covered by the report	04-12-2017 – 03-12-2019
Project website address (if any)	Lab website http://snap-photonics.org/

Declaration

I, Dr Nikita Toropov, hereby declare that

- Both Part A and Part B of this Report and its related appendices have been approved by the Scientist in-charge, Professor Misha Sumetsky and any other relevant party (for e.g. secondment academic/non-academic organisation).

- The contents of the publishable summary (Section 1 of Part A) do not contain any confidential data, and have been approved by the Scientist in Charge and any other relevant party ((for e.g. secondment academic/non-academic organisation) involved in the generation of the Results.

Signed,

____

Nikita Toropov

Birmingham, UK

31 March 2020

1. Summary for publication

1.1 Summary of the context and overall objectives of the project

The main purpose of the Project is developing the SNAP (Surface Nanoscale Axial Photonics) technological platform for a number of diverse applications like integrated photonic circuits, optical buffers, slow light devices, frequency combs, sensors, etc. This platform is based on a controllable modification of optical fibre surfaces and their refractive indexes to obtain high-Q microresonators. Fabrication precision of such photonic elements is a crucial moment for applications and is the main advantage of this platform; it potentially can be unprecedented, less than 1 angstrom. For the development of SNAP, it was proposed to investigate the processes of laser annealing of optical fibres as well as modification of the fibres under mechanical tension and investigation of their photonic properties. The idea was extended on using chemical etching and femtosecond laser inscription of microdevices based on optical microresonators.

1.2 Work performed from the beginning of the project to the end of the project covered by the report and main results achieved so far

In the Lab, we have developed the technology allowing to introduce nanometre-scale inhomogeneities at the surface of optical fibres using CO2-laser annealing with high precision. The **world record** precision for microresonators fabrication was achieved. We demonstrated two coupled bottle microresonators fabricated at the fibre surface with resonances that are matched with a better than 0.16 GHz precision. This corresponds to a better than 0.17 angstrom that is an order of magnitude better than we proposed in the Project.

In partnership with Wuhan Nat'l Lab for Optoelectronics & Huazhong University, we have developed the technique of femtosecond laser inscription of optical microresonators based on optical fibres allowing to reach a large contrast α at the introduction of nanoscale effective fibre radius variation. The contrast is defined as the maximum shift of the fibre cut-off wavelength introduced per unit length of the fiber axis. The previously developed fabrication methods achieved $\alpha \sim 0.02$ nm/μm. We developed a new method of SNAP microresonators with a femtosecond laser which demonstrates a **50-fold improvement** of previous results and achieve $\alpha \sim 1$ nm/μm.

In collaboration with Novosibirsk University, we have developed the technique allowing to demonstrate **tunable** SNAP resonators which are very wide and have parabolic potential. This is of crucial importance for the creation of tunable SNAP devices for applications in optical classical and quantum signal processing and ultraprecise sensing.

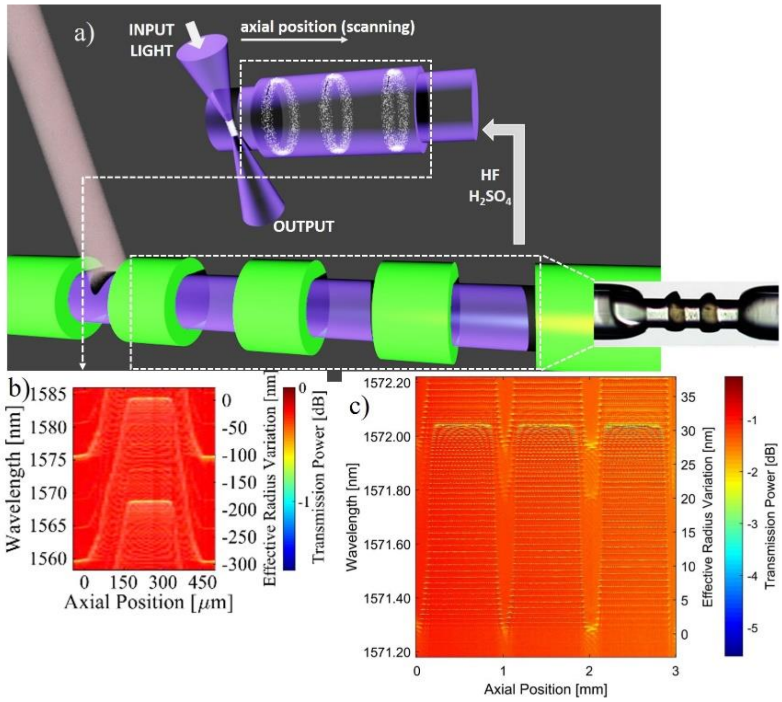


Fig. 1. Examples of SNAP resonators. a) Scheme of a mask recording with a laser beam and resonators fabrication with chemical etching, b) and c) spectrograms of optical resonators

In partnership with ITMO University and Ioffe Institute, we have developed the technique allowing to reach **any** desirable SNAP resonators profiles with multi-resonant profiles and wide range of radius changes, demonstrated for the first time, for broadband optical delay lines and buffers and high-span frequency combs.

1.3 Progress beyond the state of the art and potential impacts (including the socio-economic impact and the wider societal implications of the project so far)

We suggested several useful tools and techniques as well as performed a number of illustrative experiments contributing to the development of all-optical integrated circuits, slow light devices and ultraprecise sensors. Modern telecommunications and computing devices are substantially based on photonic technologies. Nevertheless, many problems arise when developing optical signal processing devices related to controlling their propagation speed, phase, frequency, etc. Up to now, these tasks are solved with the help of electronic devices which require optoelectronic conversion and vice versa that reduces the speed of data processing, and comes up with high dispersion and attenuation of signals while this approach, in general, is energy non-efficient and eventually reduced cost efficiency. The SNAP resonators developed open opportunity to build photonic integrated circuits without additional steps of converting signals from optical to electrical and back. They will positively contribute to the increase in the speed of data transmission and processing. That, in turn, will lead to socio-economic impact like a more rapid solution of the problems of forecasting, calculating complex engineering systems, analyzing large amounts of data and others.

For the fabrication of all-optical devices based on microresonators, sub-angstrom precision of the resonators intrinsic for the SNAP platform makes it as the technology with the highest precision in the world to date. Since the SNAP platform exploits industrial-grade optical fibres it can be rapidly introduced in the industry.

High Q-factor and high polarizability of the resonators supporting whispering gallery waves make them very relevant for single-molecule sensing. Distributed optical resonators developed in the project allow to sufficiently extend the technique for single-molecule detection to study proteins, enzymes and DNA that is a great of interest for medicine.