Barbara Rossi

All-optical ultrasound system for integrated echography inside a needle

Tutor: prof. Antonello Cutolo

Cycle: XXXVIII

Year: Second

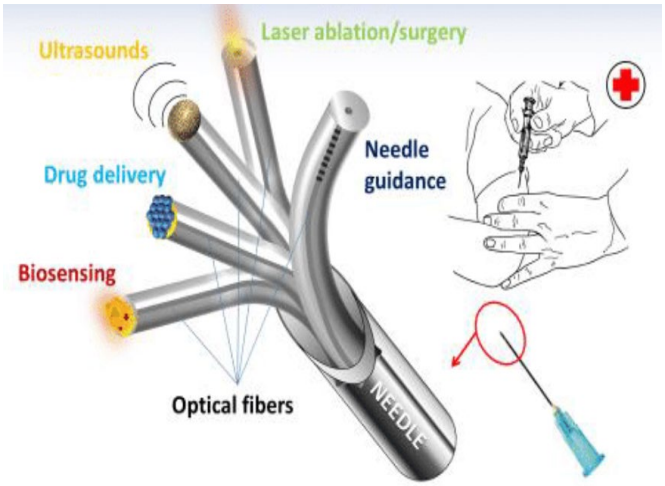
My background

- **M.Sc**. In Biomedical Engineering – 25th March 2022
- **OptoPower Lab** – DIETI
- **Tutor**: prof. Antonello Cutolo
- PhD started 1st Nov 2022 (**XXXVIII cycle**)
- Scholarship funded by **UNINA**

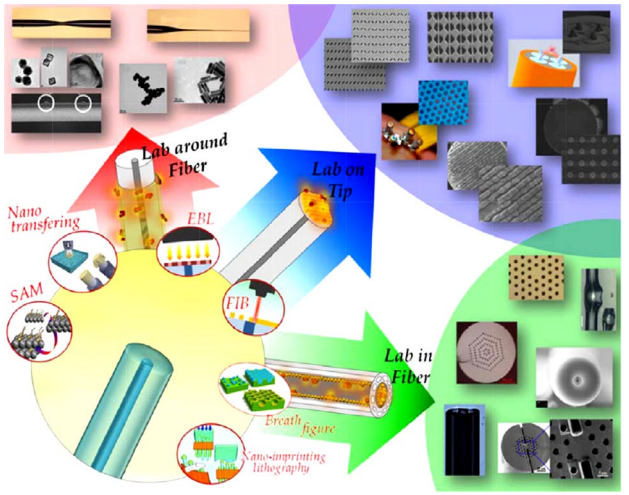
Research field of interest

Nowadays, there is a growing interest in **precision medicine** and the development of minimally invasive devices aimed at improving patient treatment.

HOSPITAL IN THE NEEDLE VISION



LAB ON FIBER TECHNOLOGY



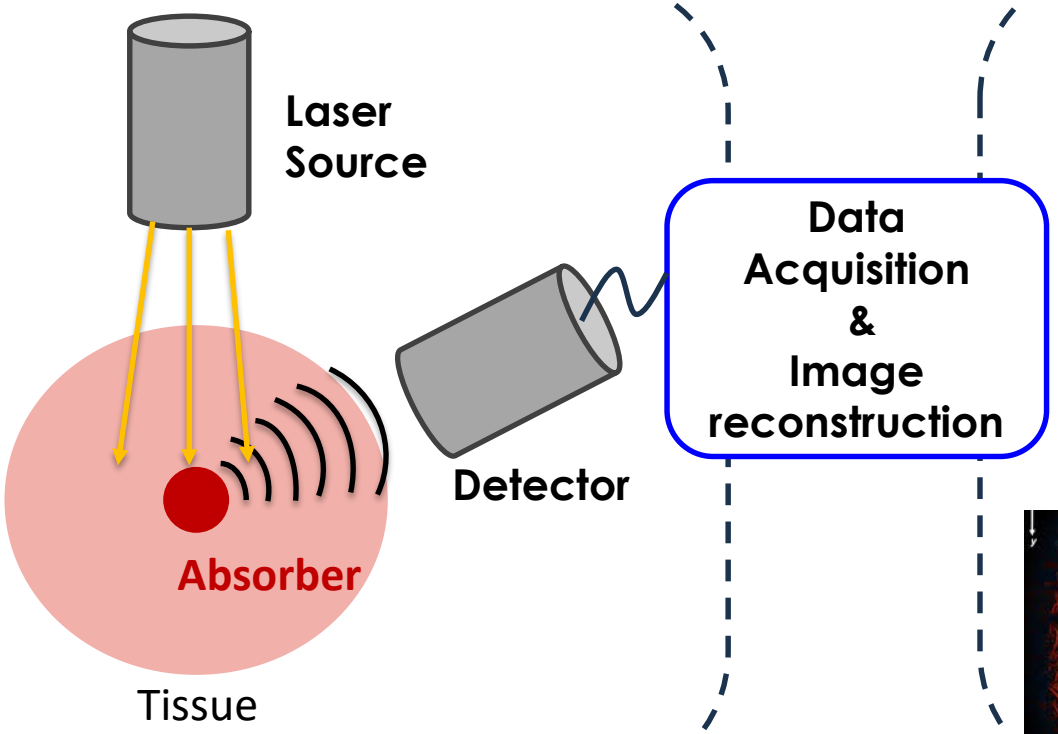
Vaiano.Patrizio, et al. Laser & Photonics Reviews, 2016, 10.6: 922-961.

Within the Hospital in the Needle project, this study is focused on minimally invasive photoacoustic imaging technique

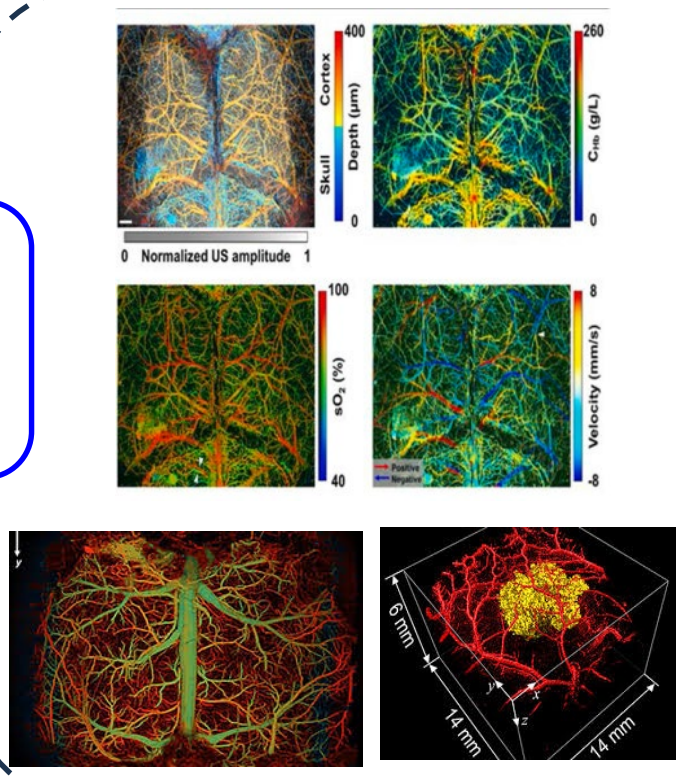
Research field of interest

Photoacoustic imaging is a hybrid imaging technique that combines optical and ultrasound methods.

Working principle



Applications

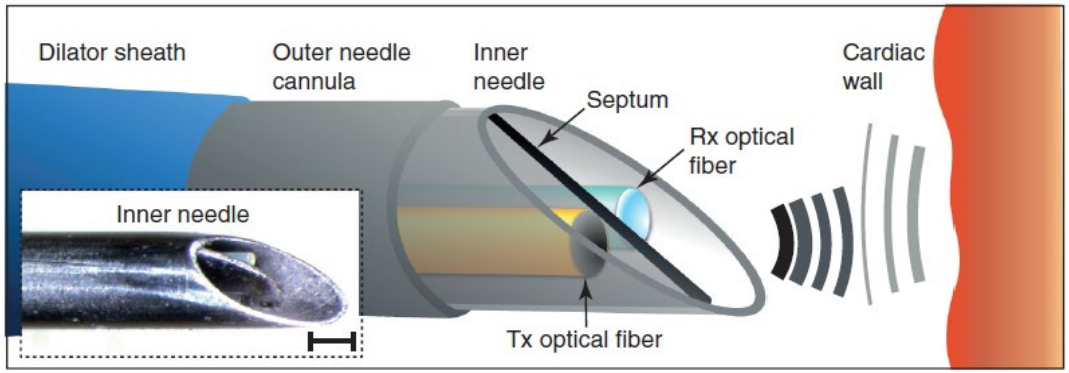


Research activity: Overview

- Problem
  - Lack of a rigorous and comprehensive engineering method for photoacoustic imaging probe optimization.
- Objective
  - *Find a rigorous method and exploit modern technology to engineer and optimize the device's performance.*
- Methodology
  - *Matlab simulations*
  - *Comsol Multiphysics simulations*

Problem

All-optical ultrasound transducer



System:

- Generation Fiber
- Detection Fiber

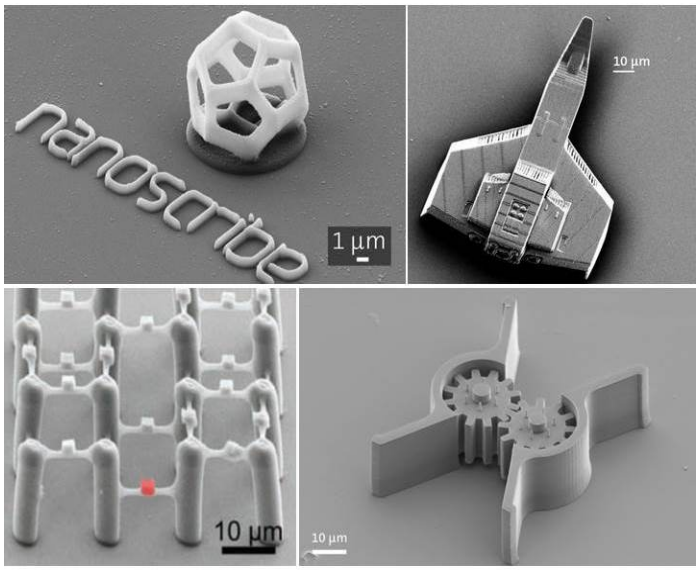
Advantages

- **Compact size:** Typically only a few millimeters in dimension.
- **High resolution**: Capable of producing detailed and precise images.
- **Use of non-ionizing signals**: Safe and non-invasive, reducing risk for the subject.

Main limitation: Lack of a rigorous and comprehensive engineering method for device optimization, which is crucial for enhancing performance.

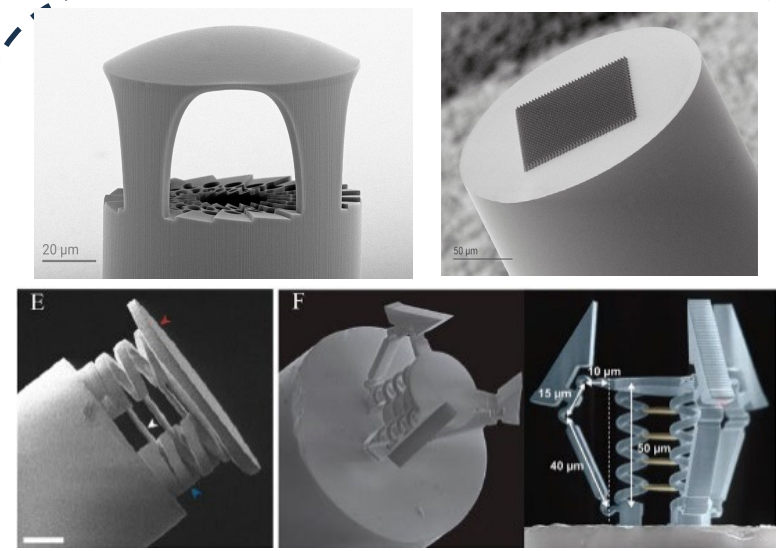
Objective

Potentialities offered by 3D micro-printing based on two photon lithography



Williams, Henry E., et al. "Fabrication of three-dimensional micro-photonic structures on the tip of optical fibers using SU-8." Optics express 19.23 (2011): 22910-22922.

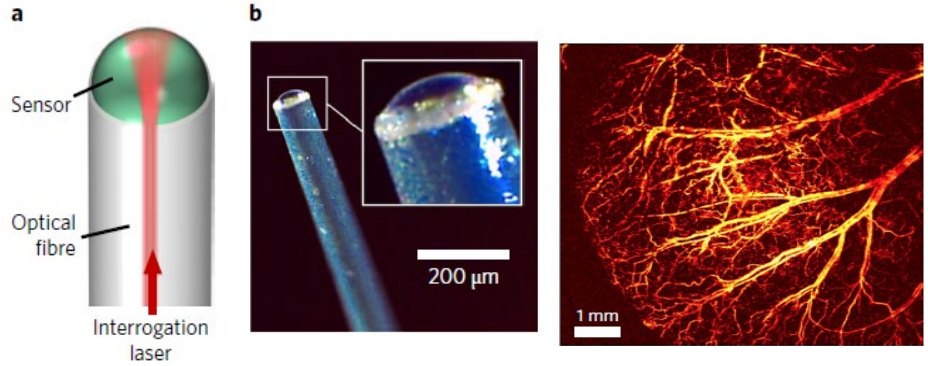
Example of applications on optical fibers tip



A. Asadollahbaik, S. Thiele, K. Weber, A. Kumar, J. Drozella, F. Sterl, et al., "Highly efficient dual-fiber optical trapping with 3D printed diffractive fresnel lenses," ACS photonics, vol. 7, pp. 88-97, 2019.

Find a rigorous methods and exploit modern technology to engineering and optimize the device's performance.

Detection System

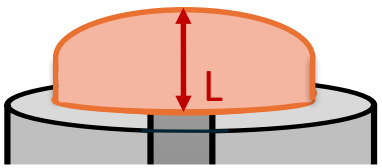


A polymeric curved structure with two reflective layers on the top and bottom realized on the fiber tip with two.

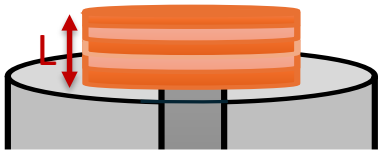
Guggenheim, James A., et al. "Ultrasensitive plano-concave optical microresonators for ultrasound sensing." *Nature Photonics* 11.11 (2017): 714-719.

The structure is realized using the dip coating technique, which results in poor dimensional control.

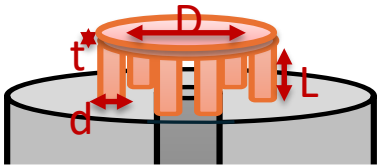
PROPOSED AND ANALYZED STRUCTURE



Curved FP structure



Multilayer structure



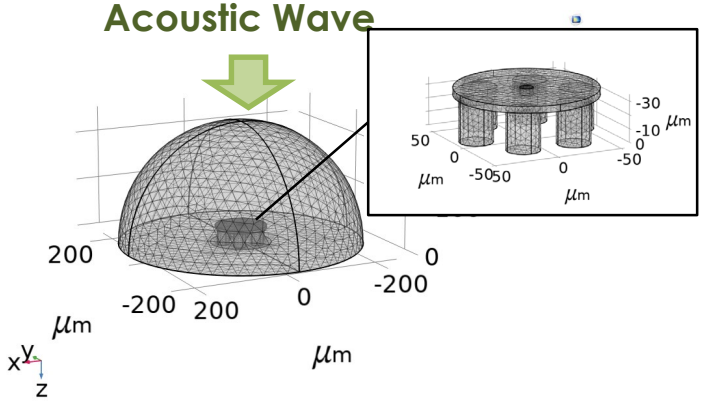
Membrane structure

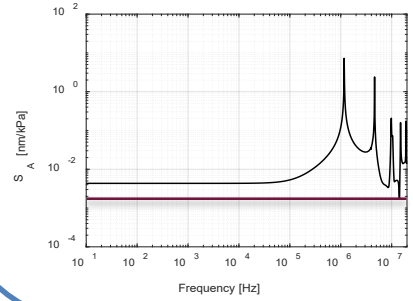
Methodology - Detection System

The analysis was conducted with a **Finite Element Method** approach using the commercial software Comsol Multiphysics.

Acoustic analysis

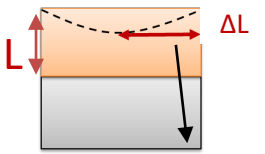
INPUT:
Acoustic Wave





OUTPUT
Displacement and bandwidth

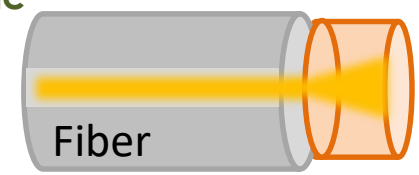
Intermediate Output:
Displacement



Sensing element

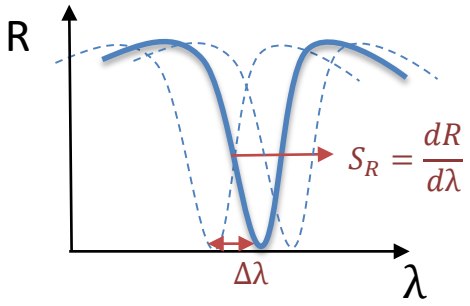
Optical analysis

INPUT:
Electromagnetic Wave



We analyze the interaction between the Gaussian beam and the structure under equilibrium and stimulated conditions.

OUTPUT
Reflectivity spectrum

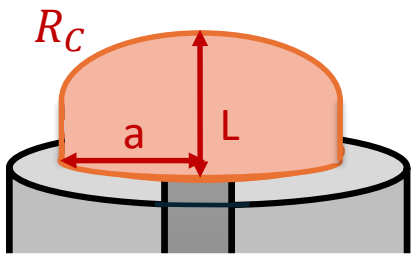


Sensitivity definition:

$$S = \left.\frac{dR}{dP}\right|_{\bar{\lambda}} = \left.\frac{dR}{d\lambda}\right|_{\bar{\lambda}} \cdot \frac{d\lambda}{dL} \cdot \frac{dL}{dP} = S_R \cdot S_\lambda \cdot S_A$$

RESULTS

Curved FP structure

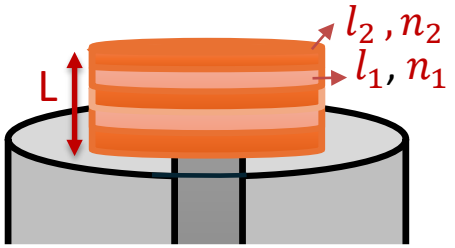


[P1,C1]

- Better Reflection spectrum
- High fabrication tolerance
- Improvement less than expected

The curvature effect is minimal up to 30 μm as the Gaussian beam remains focused within the polymer.

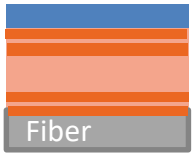
Multilayer structure



[C1]

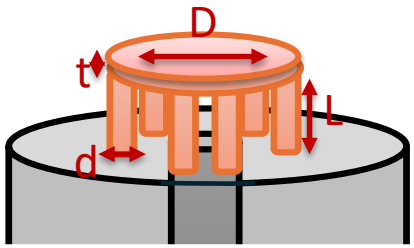
- Higher optical sensitivity
- High number of degree of freedom
- Reduced bandwidth

Ongoing Projects



We are currently evaluating multilayer with a central slab

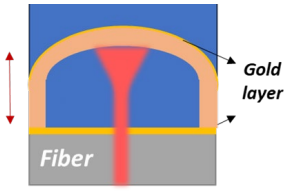
Membrane structure



[C1]

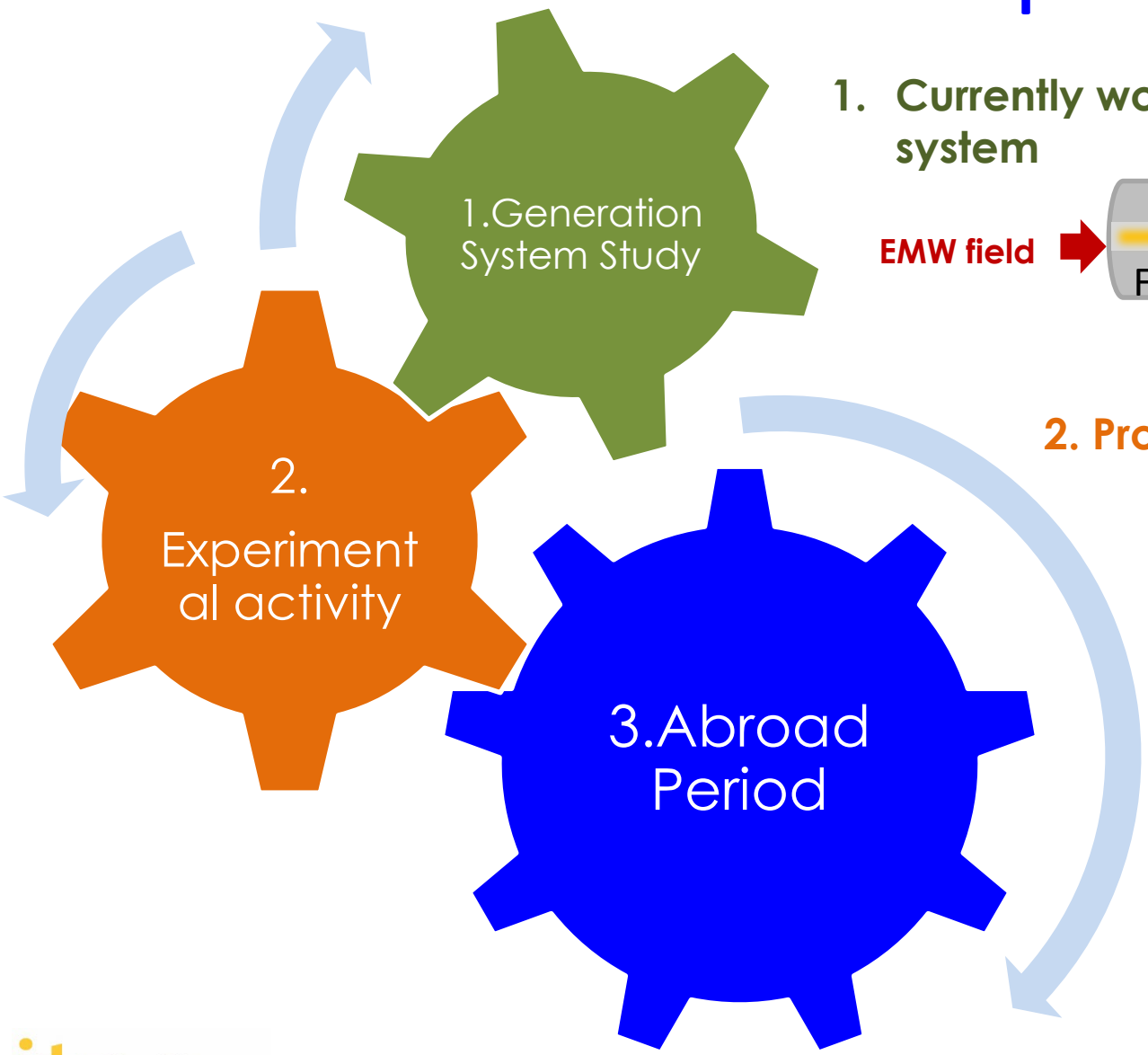
- Outperforms the plano-concave structure in terms of sensitivity
- Resonant structure

Ongoing Projects

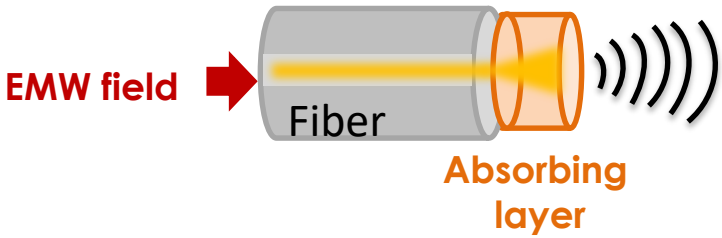


We are currently evaluating the effect curvature in the membrane structure.

Next Step



1. **Currently working on the generation system**



2. **Prototype of detection sensor**

CNOS Centro di Nanofotonica e Optoelettronica per la Salute dell'uomo.

iit ISTITUTO ITALIANO DI TECNOLOGIA

3. **Abroad Period**

DTU Technical University of Denmark

Products

[C1]	B. Rossi, P. M. Aiello, M. A. Cutolo, M. Giaquinto, A. Cusano, G.Breglio, A. Cutolo, "*Polymer-Based Lab-on-Tip Microstructures For Ultrasound Medical Diagnostics*," *2024 IEEE Sensors Applications Symposium (SAS)*, Naples, Italy, 2024, pp. 1-6, doi: 10.1109/SAS60918.2024.10636662.
[P1]	B.Rossi, M.A Cutolo, M. Giaquinto, G.Breglio, A.Cusano, *Curved Fabry-Perot Ultrasound Detectors: Optical and Mechanical Analysis,* Optics & Laser Technology Journal (submitted)

- Photonics and Electromagnetics Research Symposium PIERS, April 2024, Chengdu (China)– **Oral Presentation**.
- Italian Conference on Optics and Photonics (ICOP), June 2024, Florence Italy- **Oral Presentation.**
- *IEEE Sensors Applications Symposium SAS,* Napoli, Italy, 25 July2023**. Poster presentation.**

Summary of study activities

	Courses	Seminars	Research	Tutorship	Total
Bimonth 1	-	0.2	7	-	7.20
Bimonth 2	4	0.3	6	-	10.3
Bimonth 3	-	-	8	-	8
Bimonth 4	-	1.5	7	-	8.5
Bimonth 5	4	-	8	-	12
Bimonth 6	-	-	9	-	9
Total	8	2	45	--	55,3

Course Attended:

- *Numerical Methods for Thermal Analysis, Modeling and simulation: Application to Electronic Devices and system, Dott.A.P. Catalano, (Ad Hoc course)*
- *Innovation and Entrepreneurship, Prof. P. Rippa (Ad Hoc course)*

Thank you for your attention!