Barbara Rossi

Optoacoustic sensors for integrated echography inside a needle

Tutor: prof. Antonello Cutolo

Cycle: XXXVIII

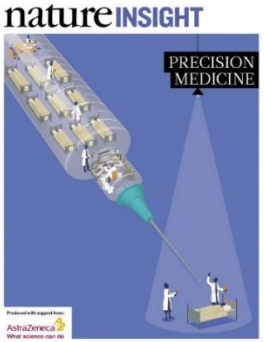
Year: First

My background

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

Research field of interest

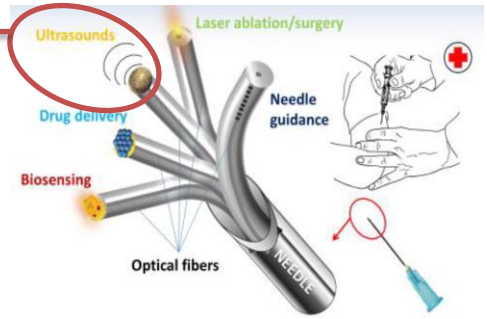
PRECISION MEDICINE AND NEED OF LOCALIZED APPROACHES



To this aim, the 'precision medicine' is following two main strategies:

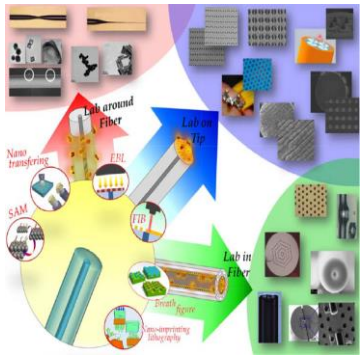
- Definition of specific treatments for each patient;
- Development of new compact devices for localized diagnosis and therapy.

HOSPITAL IN A NEEDLE VISION



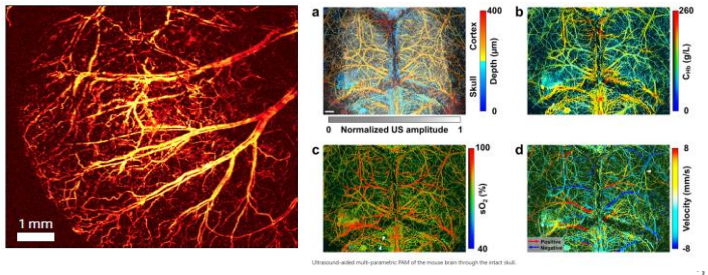
A multifunctional device for in vivo medical applications

LAB ON FIBER TECHNOLOGY



Integration of resonant nanostructures and functional materials on the surface of an optical fiber in order to control the light-matter interaction, adding to fibers new functionalities.

Whitin the Hospital in the Needle project, this study is focused on the localized echography



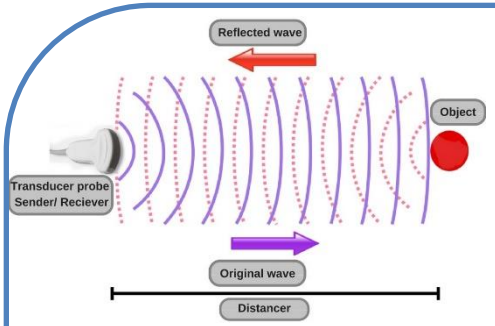
Research activity: Overview

- Problem
  - *Optimization of minimally invasive high-resolution in-vivo imaging system.*
- Objective
  - *Analysis of high-sensitivity optical fiber-based ultrasound detectors for photoacoustic imaging.*
- Methodology
  - *Matlab simulations*
  - *Comsol Multiphysics simulations*

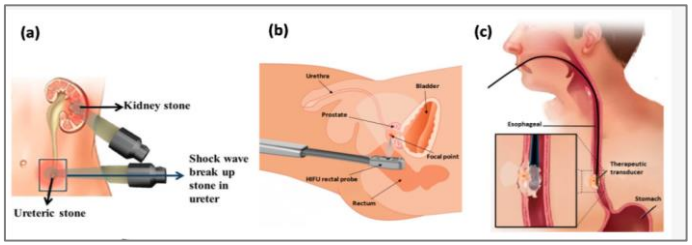
Problem

Ultrasound is usually used in medicine for imaging technique (***echography***) and it is based on the generation and detection of ultrasound waves.

Classic approach based on PZT transducers

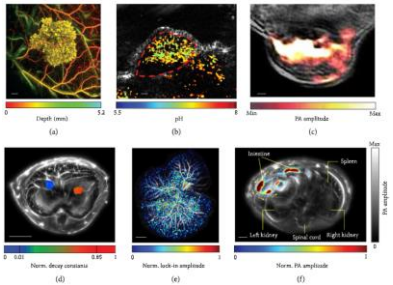


The penetration depth reduction as a function of the frequency increase limits the application for high-resolution imaging, making necessary the use of miniaturized probes inserted in the human body

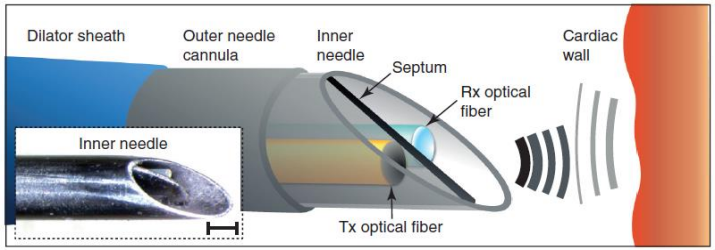


Zahra.Izadifar et al. Journal of clinical medicine, 2020, 9.2: 460

Optical fiber based approach



All optical ultrasound transducer are able to perform high frequency in-vivo imaging.



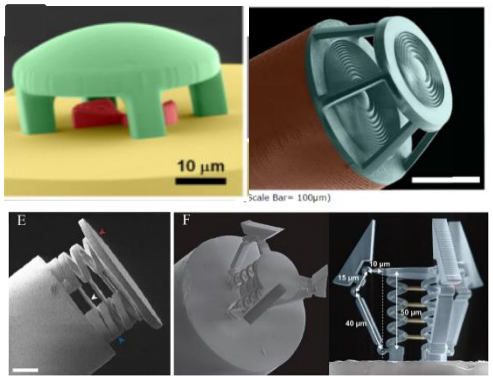
Zhao.Tianrui et al.Journal of healthcare engineering, 2018.

An all optical ultrasound transducer :

- a generation element;
- a detection element.

My focus

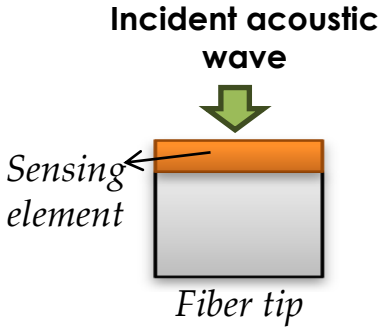
Objective

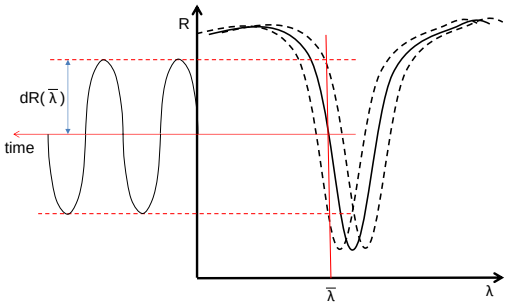


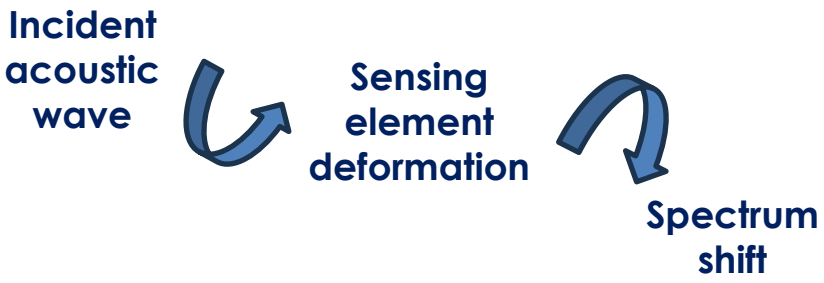
I numerically investigate the possibility of exploiting the degrees of freedom offered by the LOF technology and new fabrication technique (Two-photon lithography), for **the design of high-sensitivity optical fiber-based ultrasound detectors**

WORKING PRINCIPLE

The sensing element realized on the optical fiber tip essentially works as **an interferometer.**







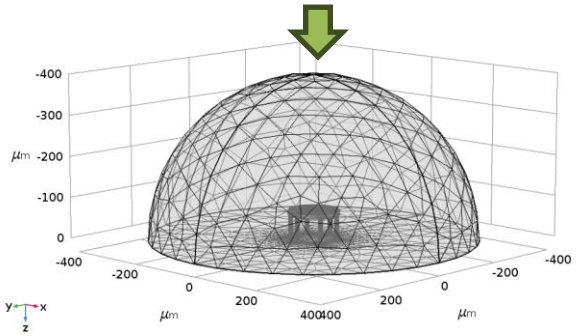
Our aim is to obtain a design of a compact structure, with high sensitivity realized on the tip of a standard single mode optical fiber.

Methodology

The analysis has been carried out by means of **Finite Element Method based numerical simulations**, implemented in the commercial software COMSOL Multiphysics.

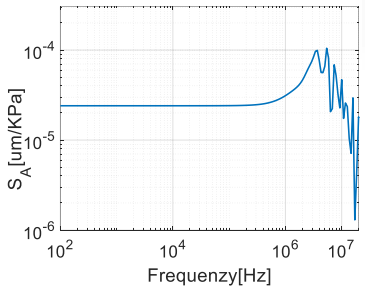
Acoustic analysis

Plane wave:1kPa

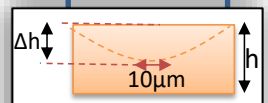


Output: Displacement

$$S_a = \frac{\Delta h}{\Delta P}$$



COMSOL MULTIPHYSICS®

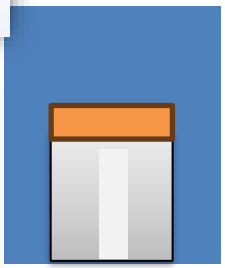


h = cavity length with no excitation

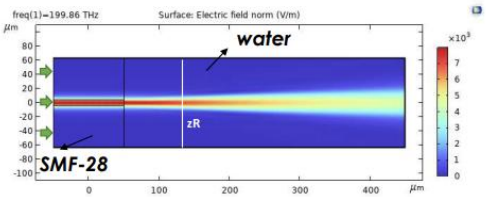
Δh = avarage longitudinal displacement in 10μm wide area

h - Δh = cavity length with excitation

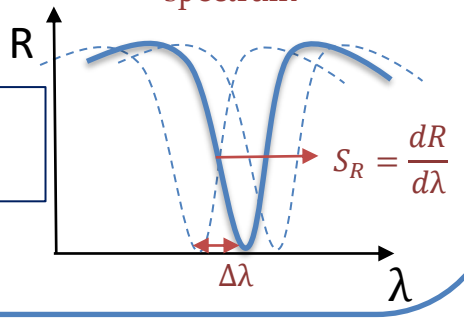
Optical analysis



Input: EM wave



Output: Reflectivity spectrum



$$S_o = \frac{\Delta R}{\Delta \lambda} \times \frac{\Delta \lambda}{\Delta h}$$

Sensitivity definition:

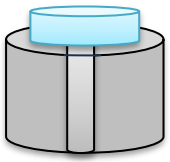
$$S = \frac{dR}{dP} = \frac{\Delta R}{\Delta P} = S_a \times S_o$$

Comparative study

Once the model was settled, we started to investigate various configurations conducting a comparative analysis.

REF

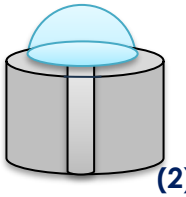
Flat Fabry-Perot



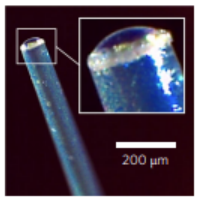
(1)

- ✓ High bandwidth
- ✗ It is possible to change only on the cavity thickness

Plano-concave Fabry-Perot

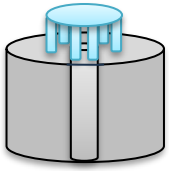


(2)



- ✓ High number of degree of Freedom
- ✓ Better Reflection spectrum
- ✗ Improvement short than expectations
- ✓ Directive Response

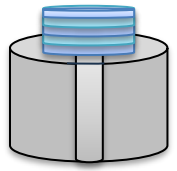
Membrana Structure



(3)

- ✓ High bandwidth
- ✓ High sensitivity at peak frequency
- ✓ Directivite Response
- ✗ Resonant structure

Multilayer Structure



(4)

- ✓ High optical sensitivity
- ! Ongoing studies

(1)DOI: 10.1109/58.808883, (2) Rossi, Barbara, MA Cutolo, and M. Giaquinto. "Advanced Lab-on-Tip ultrasound detectors: A numerical analysis." *Results in Optics* 9 (2022): 100312.

(3) https://doi.org/10.1038/s41566-017-0027-x (4) **DOI** 10.1088/1464-4258/2/5/301

Products

[P1]	B. Rossi, M. Giaquinto, M. A. Cutolo, A. Cusano, A. Cutolo, "*Advanced integrated optical devices for ultrasound diagnostics*", Springer Nature, Proceedings of SIE 2023 - 54th Annual Meeting of the Italian Electronics Society, A Springer book series Lecture Notes in Electrical Engineering

Summary of study activities

	Courses	Seminars	Research	Tutorship	Total
Bimonth 1	-	0.20	10	-	10.20
Bimonth 2	2	5	5	-	12
Bimonth 3	4	-	3	-	7
Bimonth 4	18	-	5	-	23
Bimonth 5	-	5.2	5	-	10.2
Bimonth 6	4	-	7	-	11
Total	28	10.40	35	--	73.40

Conference and Phd School

- China-Italy Joint Laboratory on Advanced Manufacturing (CI-LAM 2023), Napoli, Italy, 17-21 July 2023
- SIE PhD School**,** Messina, Italy, 4-6 September 2023
- SIE 2023-54th Annual Meeting of the Italian Electronics Society**,** Noto(SR), Italy, 6-8 September 2023**- Poster Presentation**

Thank you for your attention!