MICRON (Miniaturised aCceleRatOrs Network)

Giuseppe Torrisi (Nat. Resp.), Giorgio S. Mauro (Loc. Resp.)

Obiettivi generali

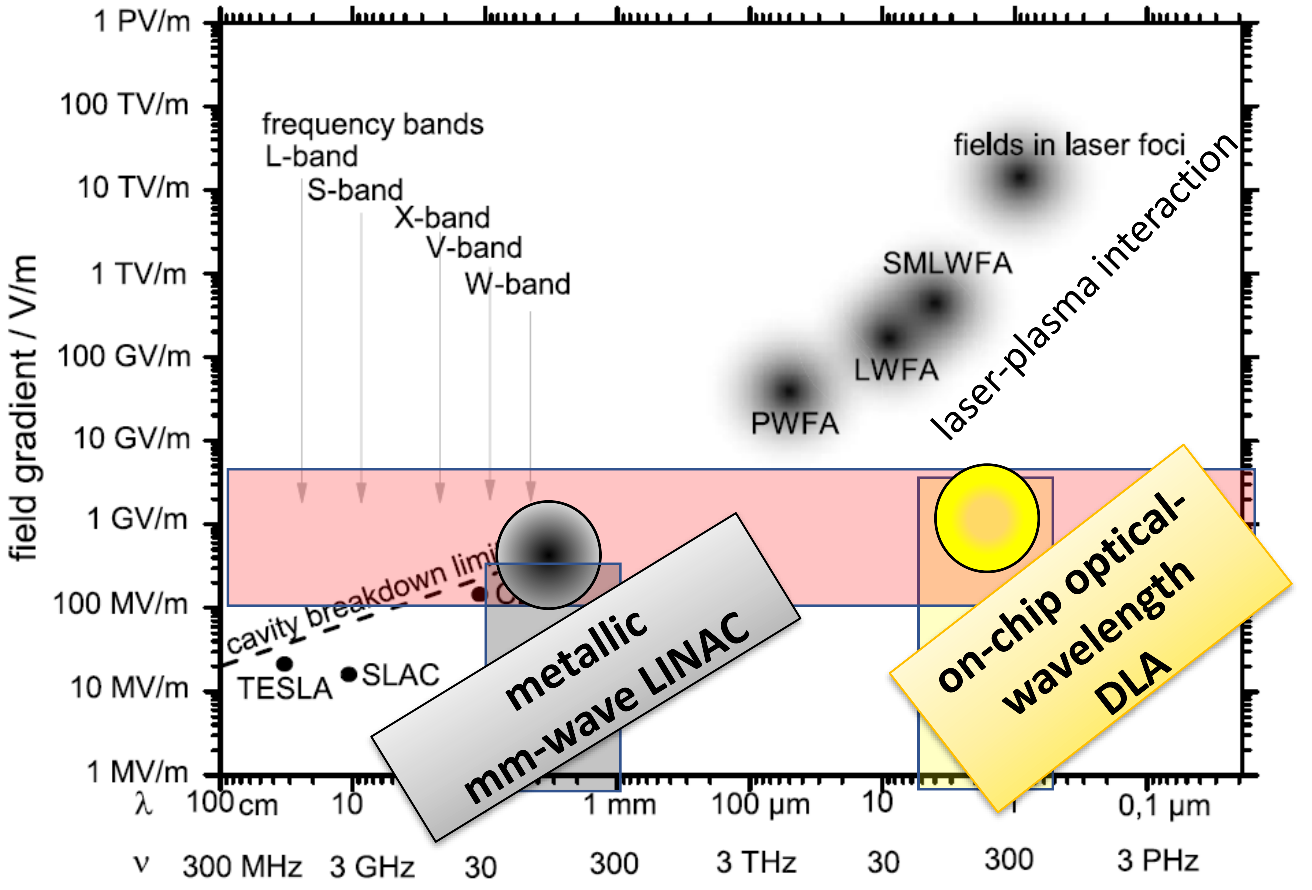
High accelerating gradients enable compact/miniaturized particle accelerators

MAIN GOAL of the PROPOSAL: Miniaturization of Accelerating Structures

1) **Feasibility studies supported/driven by fabricability proofs for optical dielectric accelerating structures**. *(simpler power feeding network, achieving of MeV scale energy, beam quality) as valid alternative/solution with respect to the side-pumped dual pillar phase reset devices.*

- **2) Fabrication and "cold" RF test of Ka-band metallic structures**: *to investigate the processes, materials, technology and welding procedure used to manufacture accelerating components in order to achieve the maximum possible accelerating gradient*

schematic overview of the accelerating gradient for different types of accelerators



Attività 2024

MILESTONES for Dielectric structures

1) Sub-relativistic to relativistic PhC-based transition design **(80%)**
2) Fabrication and SEM characterization on the selected dielectric prototype **(80%)**

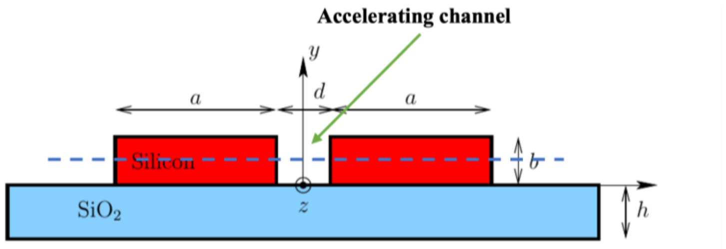
MILESTONES for Metallic structures

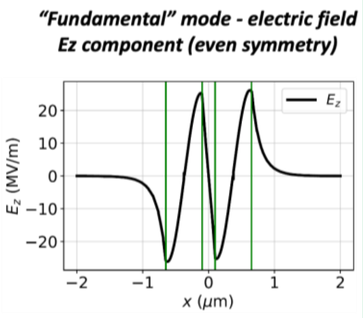
1) Procurement of the RF System components for measurement **(100%)**
2) Measurement @LATINO, LNF on the multi-cell cavity **(80%)**

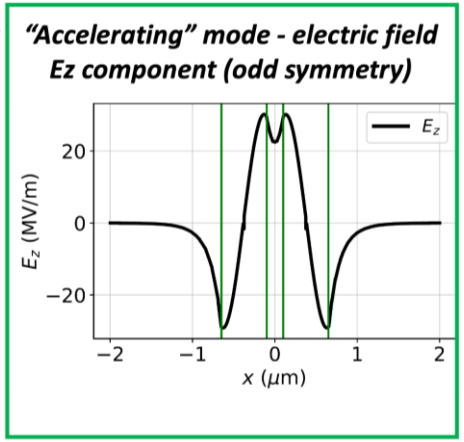
Attività 2024 – dielectric structures

1) Sub-relativistic to relativistic PhC-based transition design **(80%)**

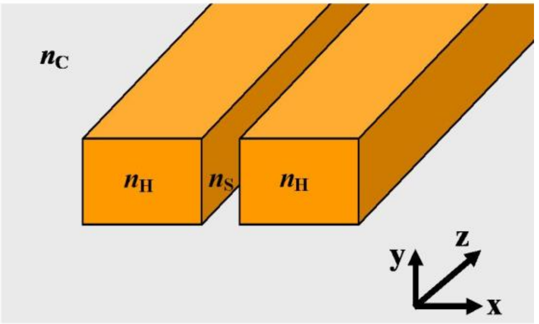
- High-index (silicon) strips separated by a small gap
- Fundamental (even) mode, accelerating (odd) mode
- Selective excitation of the accelerating mode
- Tuning of cross section to synchronize <u>sub-relativistic</u> particles

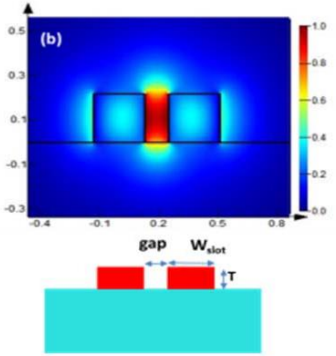






Schematic of a slot waveguide





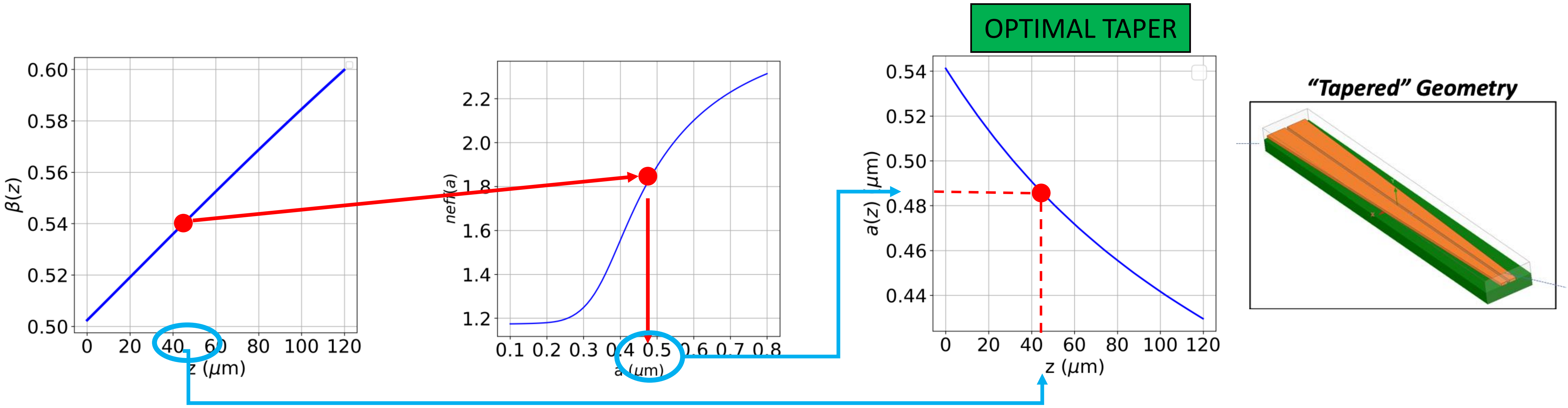
Zhao et al., "Design of a tapered slot waveguide dielectric laser accelerator for sub-relativistic electrons"; 2018

Attività 2024 – dielectric structures

[Palmeri, R., et al. "Optimization of sub-relativistic co-propagating accelerating structures." *Optics Express* 31.23, 2023.]

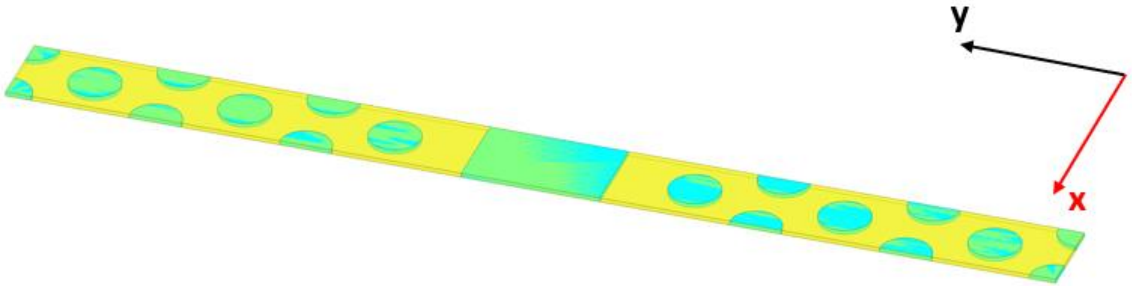
$$E_z(z,t) = E_0 \cos\left[\omega t - \int_0^z k_z(z')dz'\right]$$ Accelerating field

$$\Delta W = q\int_0^L E_z(z,t)dz = q\int_0^L E_0 \cos\left\{ \omega\left[\int_0^z \frac{1}{v_{\text{part}}(z')}dz' - \int_0^z \frac{1}{v_{\text{ph}}(z')}dz'\right]\right\} dz$$ Energy gain

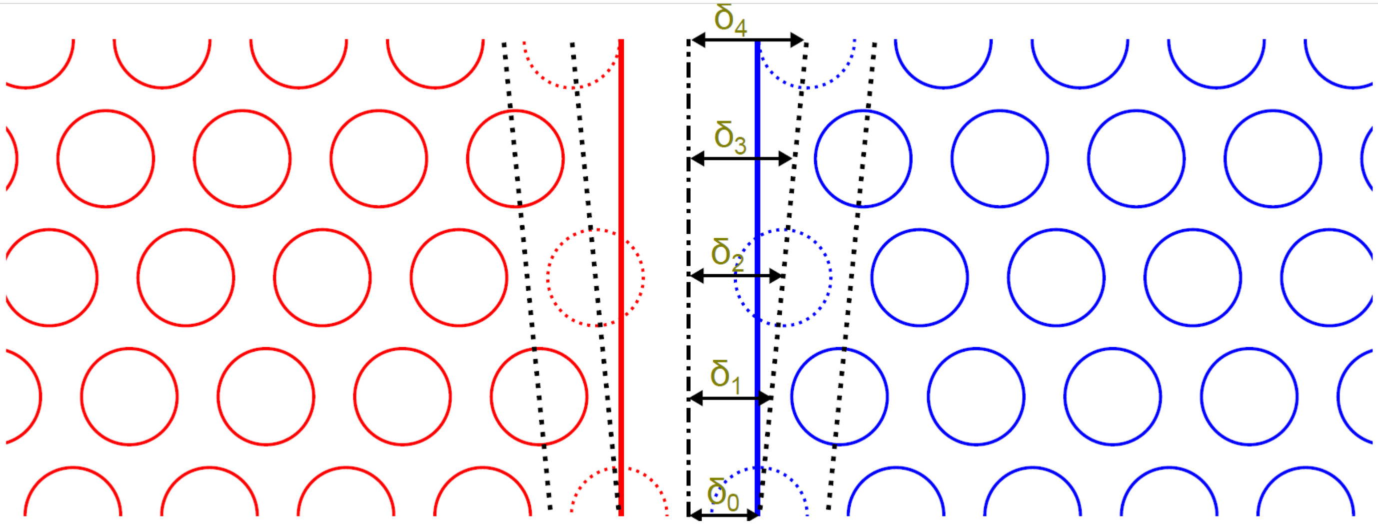


Attività 2024 – dielectric structures

Tapered 2D PhC waveguide



- By modifying the waveguide width, it is possible to decrease the normalized wave phase velocity of the guided mode.
- For the triangular lattice waveguide, we obtain a normalized wave phase velocity in the interval **0.7 < β < 1**.
- ➢ The decrease in waveguide width necessary to obtain a lower β is accomplished by a shift of the air rods along the transversal direction.

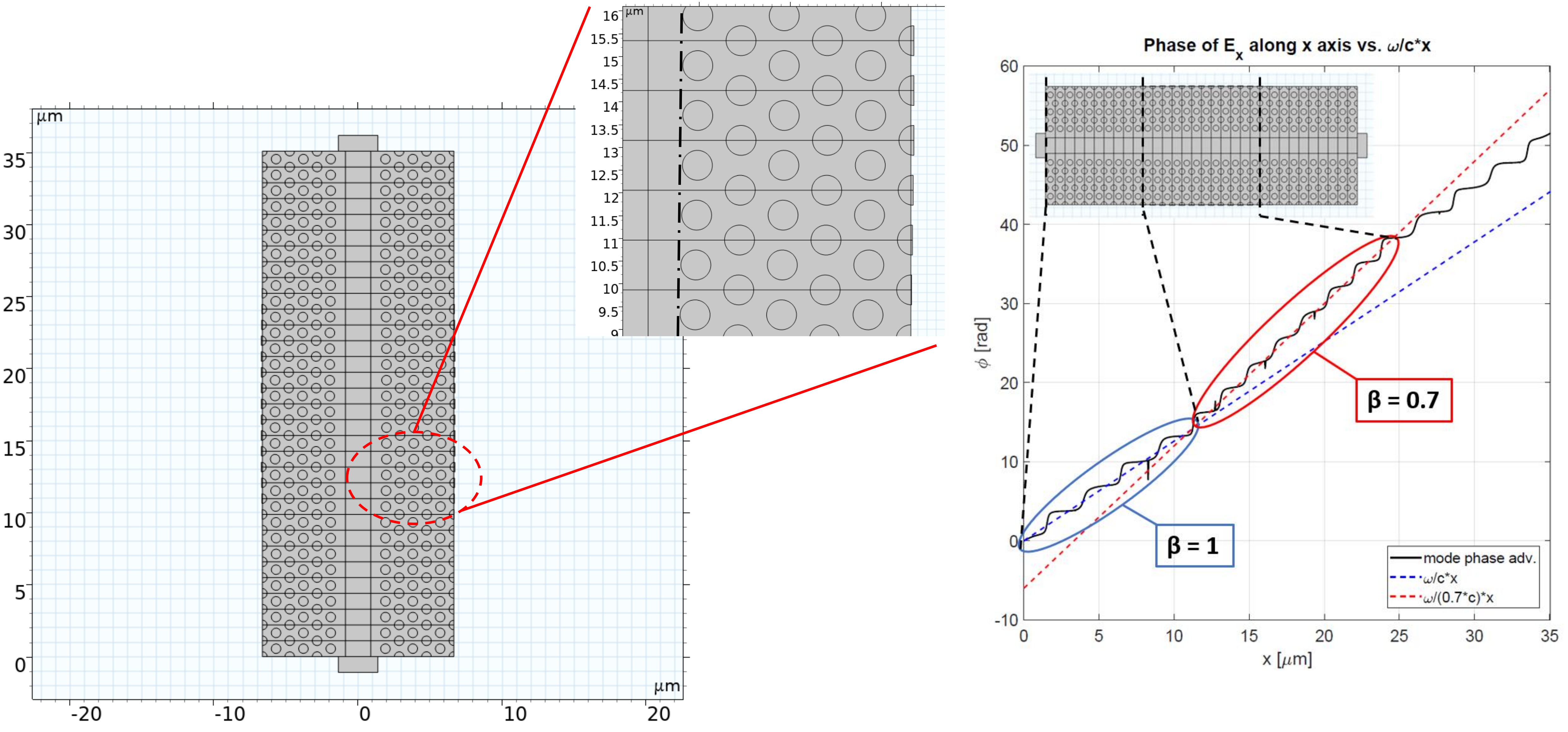


$$\delta_i = \frac{i}{N}\frac{w_p}{2}$$

Where:

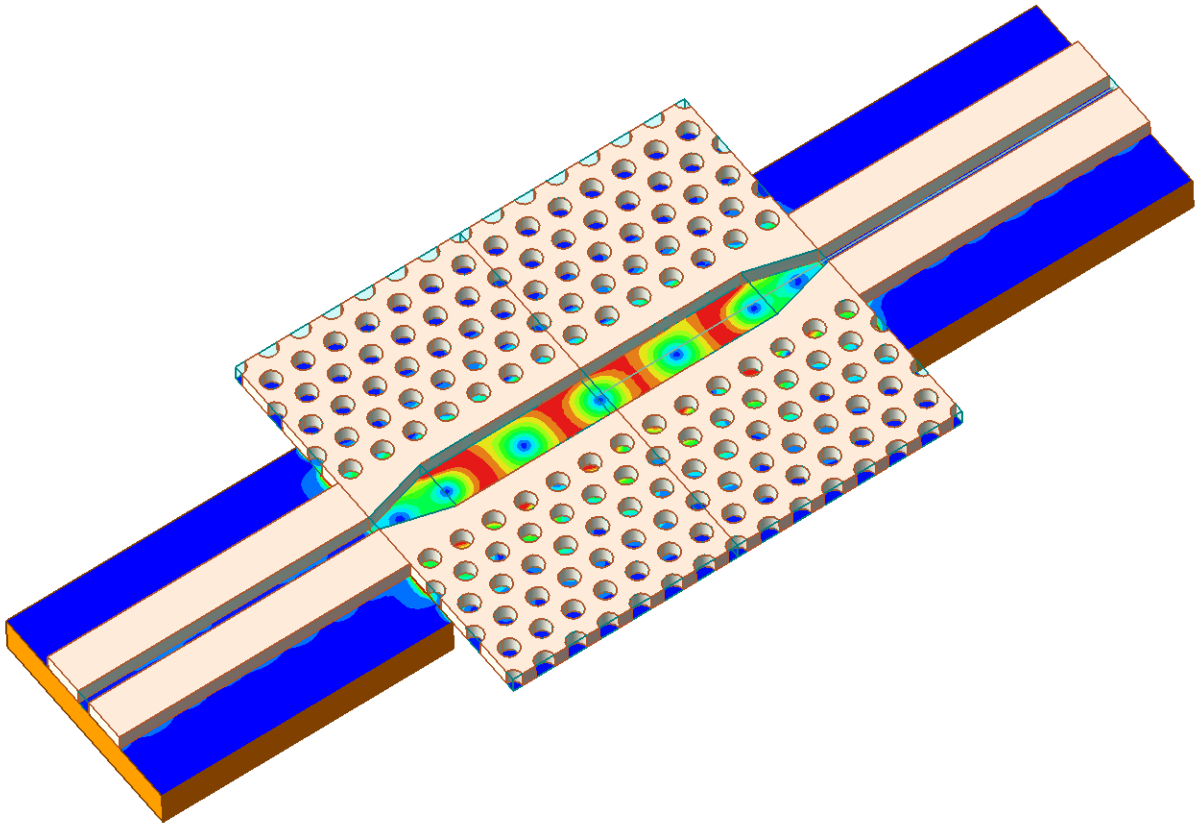
- N is fixed by the taper length
- w_p is the padding width to obtain a specific β

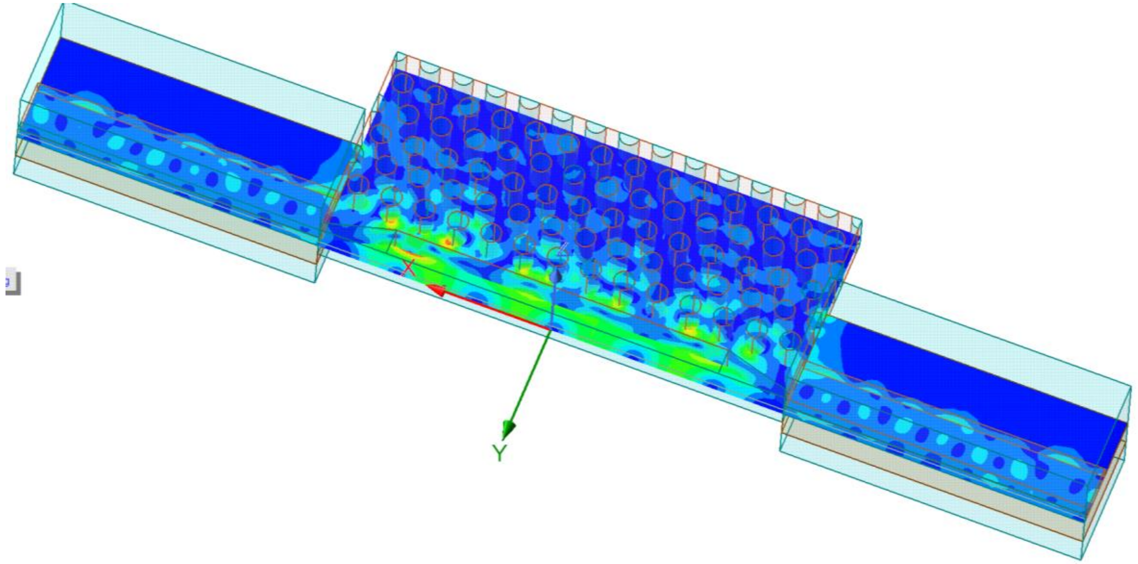
Attività 2024 – dielectric structures



Attività seconda metà 2024 – dielectric structures

- Sub-relativistic to relativistic ($0.4 < \beta < 1$) slot waveguide to silicon triangular lattice PhC accelerating waveguide.
- Study of particles transverse focusing by employing suitable field components or separate TE modes: **possible Deutsches Elektronen-Synchrotron (DESY) collaboration for this work**.

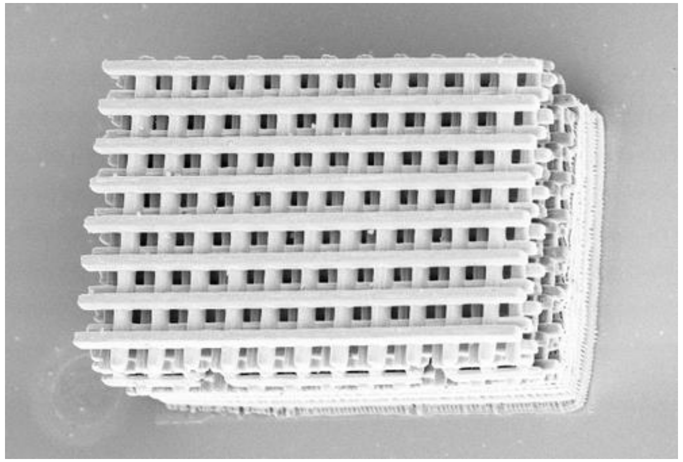
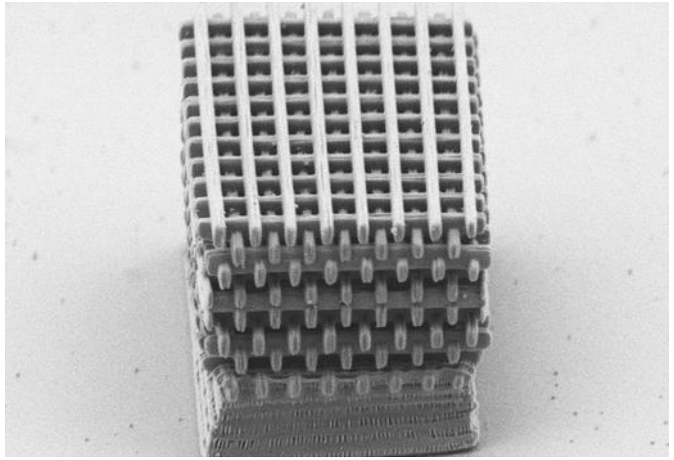
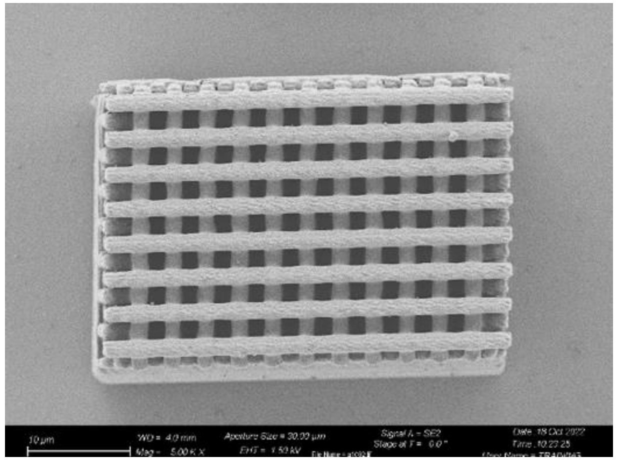




Attività 2024 – dielectric structures

2) Fabrication and SEM characterization on the selected dielectric prototype **(80%)**

- **March 2024: latest results <u>(woodpile @ λ = 5 um)</u>**
- Employed material: FemtoBond resin.
- Direct polymerization of the "final" positive structure followed by a pyrolysis to obtain a dielectric material with the final desired properties.

- **Second half of 2024 work: print a <u>λ = 3.3 mm structure</u>** (f_0 ~ 100 GHz) with a lab-made resin possessing alumina-like electrical characteristics (BO-To).

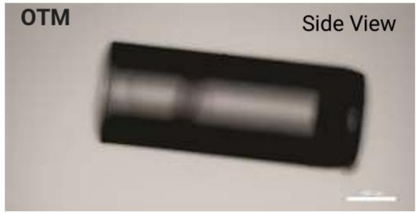
- **Characterization of the λ = 3.3 mm** structure with standard laboratory equipment:
  1. Measurement of S-parameters with W-band VNA;
  2. Measurement of the on-axis alectric field through the bead-pull technique.

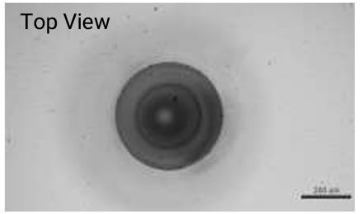
Attività seconda metà 2024 – dielectric structures

- Possible collaborations with other research institutes with the objective to print different prototypes at the wavelenghts of interest (λ = 2 μm or 5 μm).

- **CANDLE Synchrotron Research Institute (Yerevan, Armenia)**: two-photon polymerization technique.

Tube with patterned inner surface

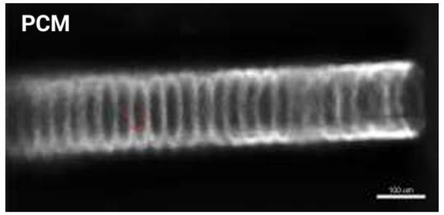


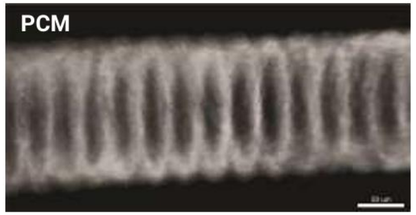


Fabrication parameters:
Wavelength: 800 nm
Pulse Duration: 80 fs
v = 300 um/s
P = 131.25 mW

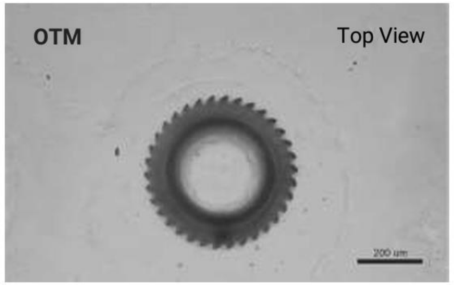
External Diameter: 415 um
Length of the tube: 1 mm
Fabrication Duration: about 40 min

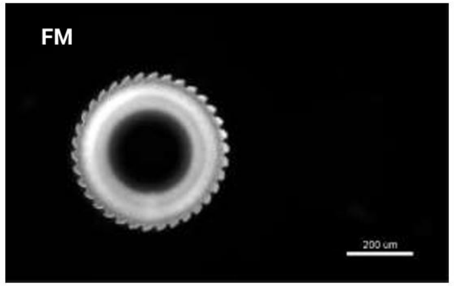
Patterned Helical Structure: period of the helix is 30 μm





Saw-like structures





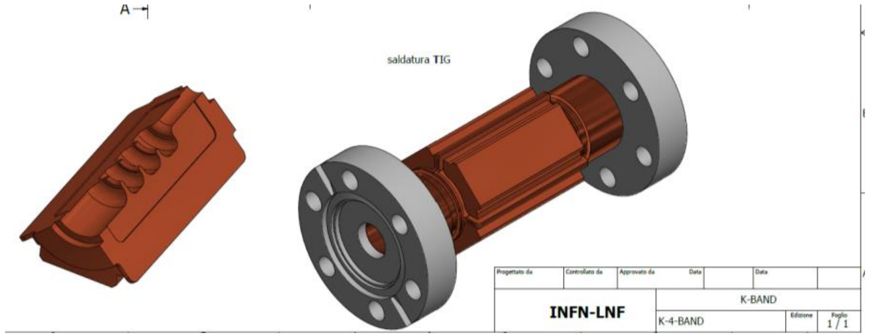
Fabrication parameters:
Wavelength: 800 nm
Pulse Duration: 80 fs
v = 600 um/s
P = 105 mW

Outside Diameter: 450 um
Height: 300 um

- **CNR-IMM (Catania).**

Attività 2024 – metallic structures

1) Procurement of the RF System components for measurement (100%)
2) Measurement @LATINO, LNF on the multi-cell cavity (80 %)



Quadrants (4 slots and sectors) vs. Closed structure (w/o slots)

- Similar longitudinal shunt impedances;
- Higher lower-modes separation;
- Higher vacuum pumping capacity through slots;
- The quality factor decreases by only 2%.

TIG welding on the outer slots → avoiding high temperature brazing which - occurring at about 800–1000 °C - significantly changes the cavity mechanical properties.

Attività 2024 – metallic structures

1) Procurement of the RF System components for measurement (100%)
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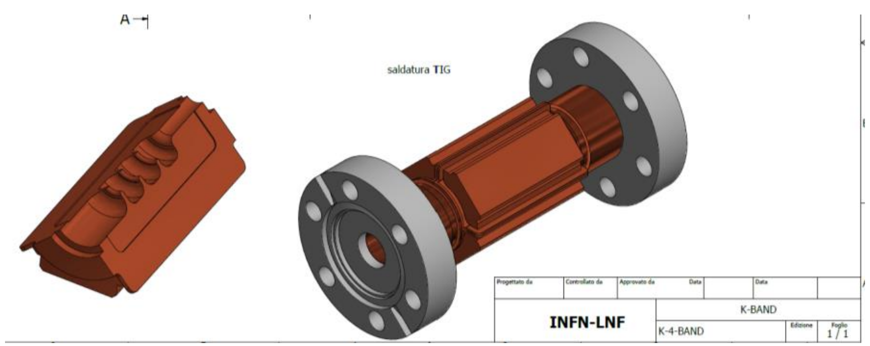
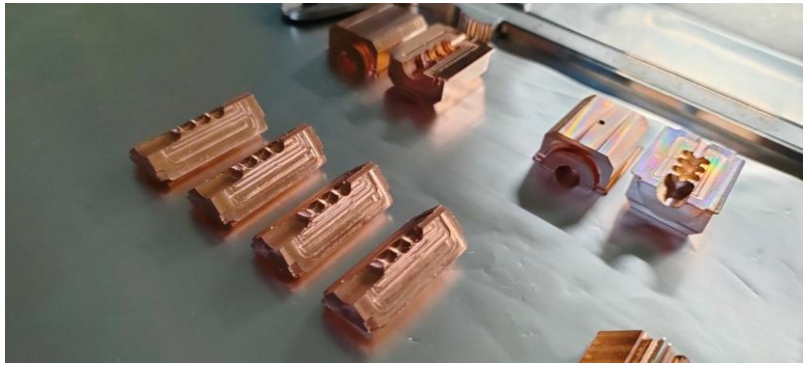


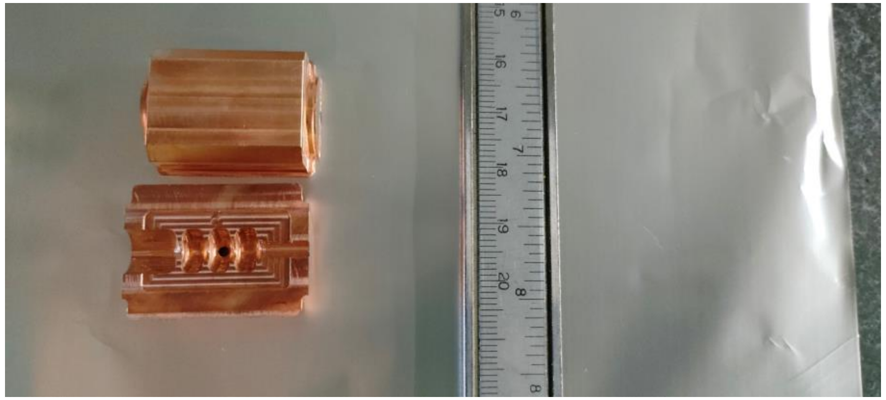


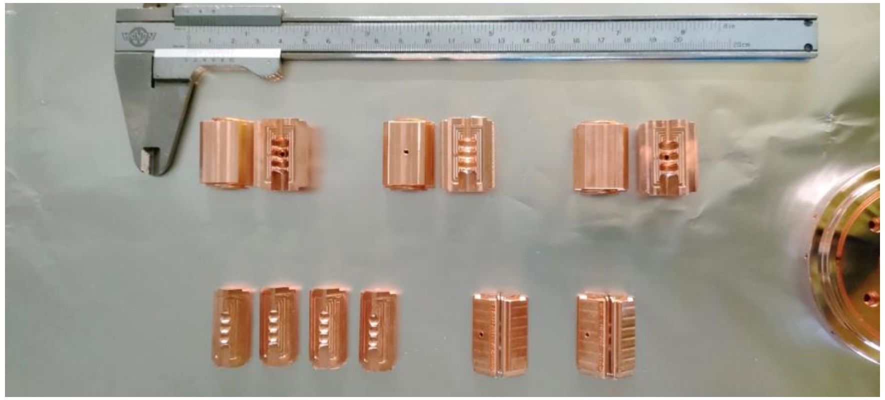
Parameter	Value
Resonant frequency, f [GHz]	35.982
Quality factor Q	6000
Shunt impedance [MΩ/m]	160
H_{max} [MA/m]	0.6
E_{max} [MV/m]	400
Power loss [MW]	0.75
a [mm]	2
a/λ	0.24
t [mm]	0.635
Iris ellipticity	1.38
Accelerating Gradient (MV/m)	150 MV/m
Phase advance per cell (deg)	180

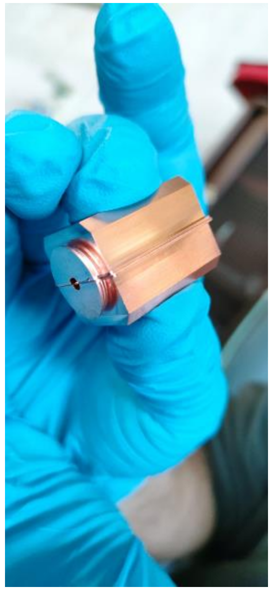
- ❑ All cavity sectors were manufactured by using a CNC 5-axis milling machine.
- ❑ Machining tool is crucial:
- ➢ Tungsten-carbide tool → Tolerance = +- 10 µm; Roughness with Ra = 1.6 µm.
- ➢ Diamond tool with spherical radius < 1 µm → Tolerance = +- 2 µm; Roughness with Ra < 80nm.

→ **multi-cell cavity with mode launcher (end of 2024)**

Machined sectors for the 2-halves Cavities

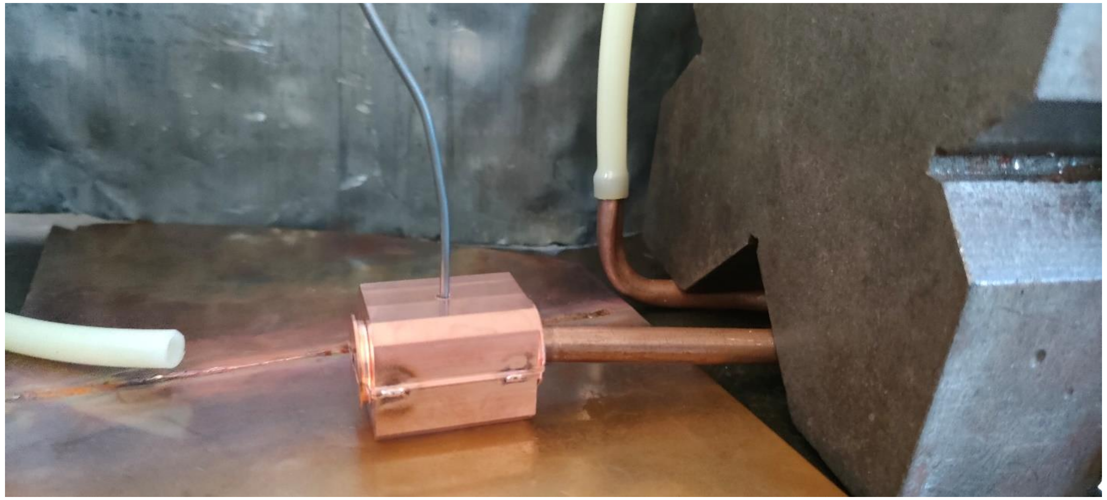




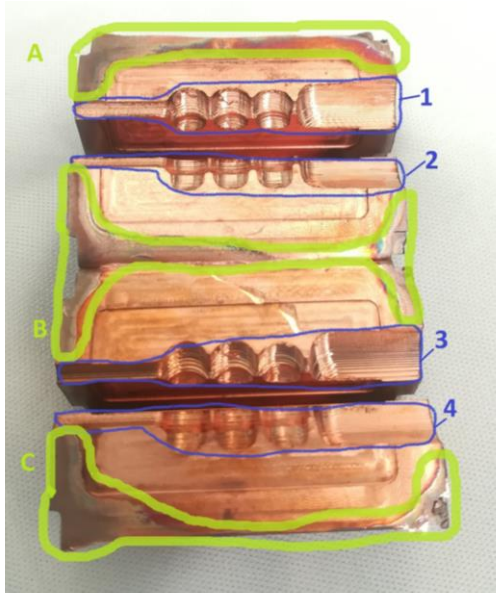


Attività 2024 – metallic structures

1. **Successful execution of each weld bead/seam in order to assure vacuum tightness of the cavity**.
2. **The cleanliness of the inside surfaces of the cavities**: visual inspection for absence of oxidation after cutting the cavity samples;
3. **The temperature of the cavity surfaces always below the annealing one** (mechanical properties significantly change after heating above 590 °C), **in order to keep the hardness of the copper**.

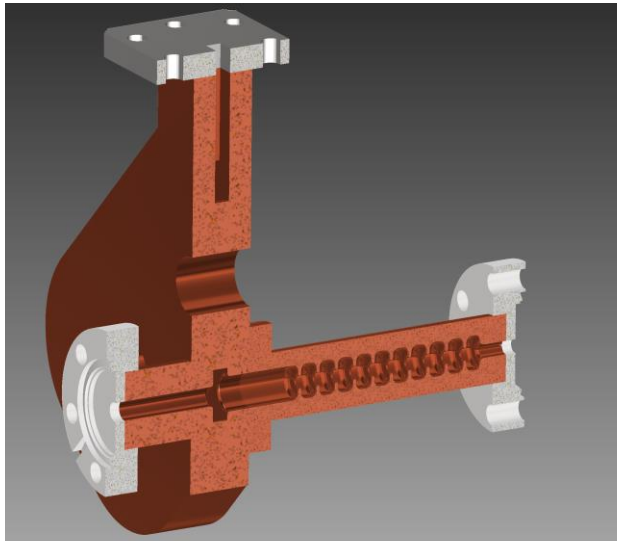


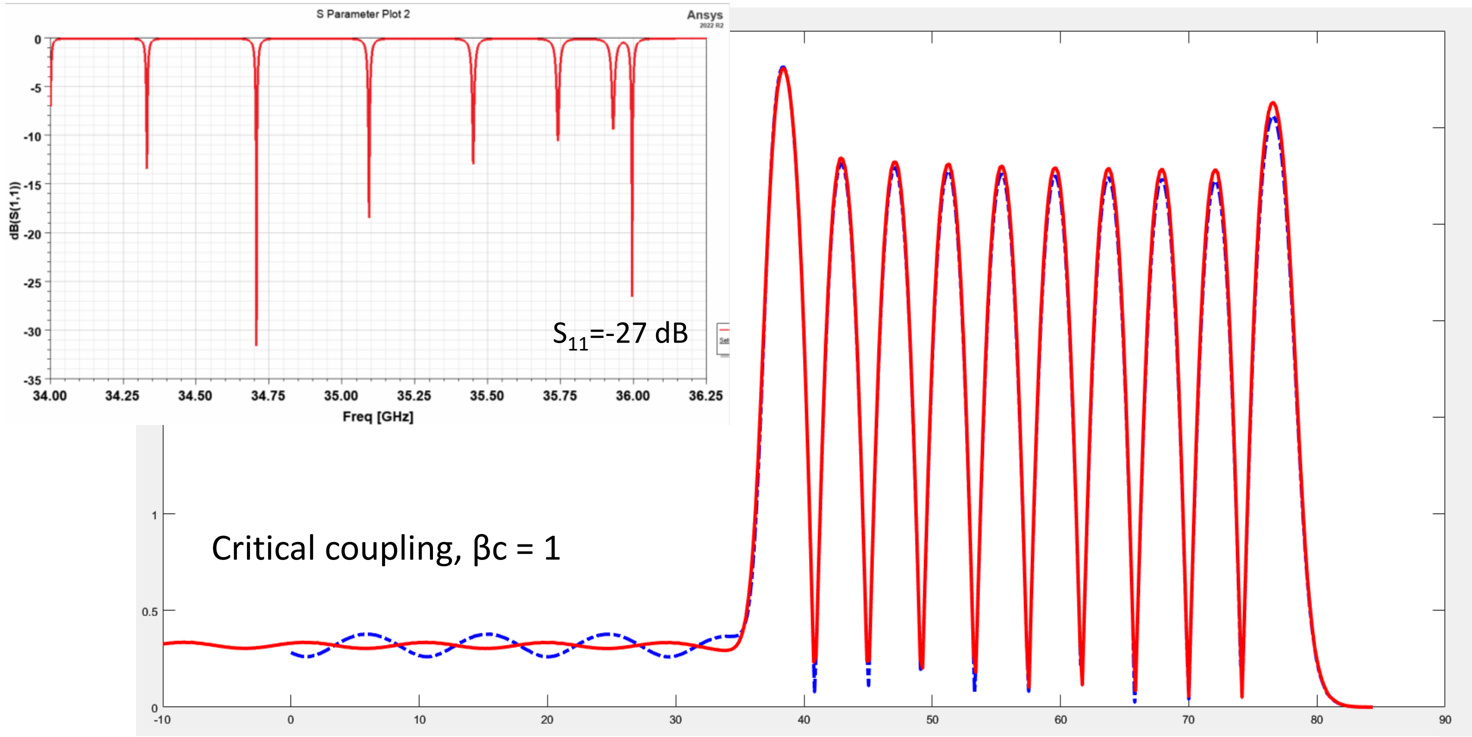
- The appearance of the cavity is shiny and there are **no traces of oxidation in the area where there was direct flushing of argon**.
- The central area where argon was flowing **(1, 2, 3 and 4)**, the appearance remains bright. At a visual analysis, there are no traces of oxidation.
- The areas closest to the weld seam **(A, B, C)** show instead the presence of oxide, but it is to be considered that in those areas due to the direct contact between the surfaces to be welded, the presence of inert gas was absent and therefore such result was expected.

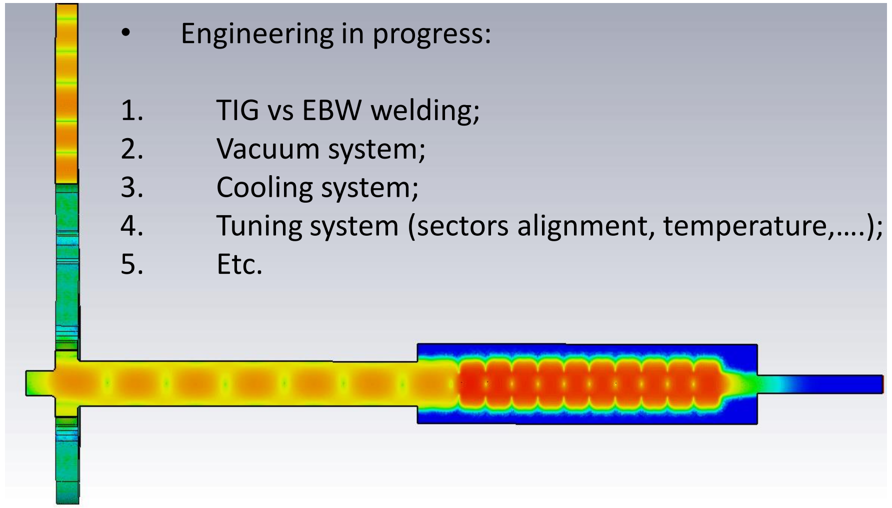


Attività seconda metà 2024 – metallic structures

- **4-port mode launcher with multi-cell 4-quadrant cavity** realization and characterization (S-parameters, bead-pull for E-field measurement, tuning, etc).

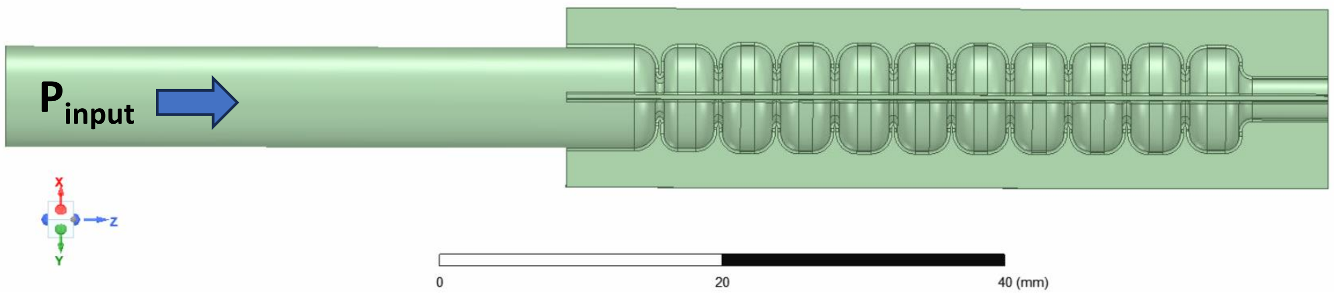






- Engineering in progress:

1. TIG vs EBW welding;
2. Vacuum system;
3. Cooling system;
4. Tuning system (sectors alignment, temperature,….);
5. Etc.



output scientifico - 2022

PAPER

- A low-perveance electron gun for a high-efficiency Ka-band klystron, Spataro, B. et al EUROPEAN PHYSICAL JOURNAL PLUS
- Ka-band linearizer structure studies for a compact light source, Castilla, A. et al., PHYSICAL REVIEW ACCELERATORS AND BEAMS
- Numerical Simulation of a Hollow-Core Woodpile-Based Mode Launcher for Dielectric Laser Accelerators Mauro, Giorgio Sebastiano et al., APPLIED SCIENCES

TESI

- Studio di dielectric laser accelerators (DLAs) per applicazioni medicali, Marta Maria Costanza Università Di Catania
- Study of Integrated-optics sub-relativistic Linear Dielectric Laser Accelerators, Atiya Usmani, Università' Di Catania

TALK

- COPROPAGATING SCHEMES FOR DIELECTRIC LASER ACCELERATORS (DLAS), Giuseppe Torrisi, High-Gradient Workshop 2022
- Copropagating schemes for Dielectric Laser Accelerators (DLAs), Giuseppe Torrisi, Los Angeles, California
- Copropagating schemes for Dielectric Laser Accelerators (DLAs), Giorgio Sebastiano Mauro, 13th International Particle Accelerator Conference (IPAC'22), Bangkok, Thailand
- Copropagating schemes for Dielectric Laser Accelerators , Giuseppe Torrisi, Ultrafast Beams and Applications (UBA) 2022, CANDLE, Armenia International Workshop, Yerevan, Armenia
- Copropagating schemes for Dielectric Laser Accelerators , Giorgio Sebastiano Mauro, Congresso Nazionale SIF, Milano, Italia
- Design and Prototyping of high gradient Ka-band accelerating structures, Luigi Faillace, International Workshop on Breakdown Science and High Gradient Technology (HG2022)
- Development of X-band high gradient structures and status on the Ka-band accelerating ones, Bruno Spataro, Catania, Italy

output scientifico - 2023

PAPER

- Design of Integrated Optics Accelerating Structures Torrisi G. et al. IEEE Conference on Antenna Measurements and Applications, CAMA
- RF design of a compact C-band RF pulse compressor for a VHEE linac for flash radiotherapy, Torrisi, Giuseppe et al JACoW
- MeV-Scale simulations and fabrication tests of woodpile-based waveguide for Dielectric Laser Accelerators, Giorgio S. Mauro et al., JACoW

TESI

- Modelling of Tapered Co-propagating Structures for Dielectric Laser-driven Accelerators (DLA), Andres Leiva Genre Università' Di Catania

TALK

- Co-propagating waveguides for Dielectric Laser Accelerators (DLAs): Design, Results and Perspectives, G. Torrisi, International School of Particle Accelerators , Erice, italia
- DESIGN OF INTEGRATED OPTICS ACCELERATING STRUCTURES, G. Sorbello, International Conference on Dielectric Photonic Devices and Systems Beyond Visible Merging Optics and Microwaves, Bari, italia
- Design of Integrated Optics Accelerating Structures , G. Torrisi, IEEE CAMA, Genova, Italia
- MeV-scale Simulations and Fabrication Tests of Woodpile-based Waveguide for Dielectric Laser Accelerators, G. Mauro, IPAC14, Venezia, Italia
- MeV-scale simulations and fabrication tests of silicon slot and woodpile-based waveguides for Dielectric Laser Accelerators, G. Torrisi, HG2023
- Opportunità e Applicazioni di strutture acceleranti miniaturizzate metalliche (banda Ka) e dielettriche (ottiche), G. Torrisi, Seconda Giornata INFN Acceleratori, Catania, Italia
- Simulation of tapered co-propagating structures for dielectric laser accelerator, Andrés Leiva Genre, 14th International Particle Accelerator Conference , Venezia, italia
- The INFN MICRON project at LNF: Development of high-gradient metallic mm-wave accelerating structures, Luigi Faillace, 15th Workshop on Breakdown Science and High Gradient Technology (HG2023, Frascati, italia

output scientifico - 2024

Optimization of sub-relativistic co-propagating accelerating structures, Palmeri, R. et al. OPTICS EXPRESS

TESI

Ongoing master degree Thesis

Modelling of Tapered Co-propagating Structures for Dielectric Laser-driven Accelerators (DLA), Sebastian Quevedo

TALK

- ACHIP workshop @Desy, Hamburg, **Invited talk,** Giuseppe Torrisi
- UBA workshop @CANDLE, Armenia, **Invited talk,** Giorgio S. Mauro

FTE @LNS

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