μICRON
Mlniaturised aCceleRatOrs Network

MICRON (MIniaturised aCceleRatOrs Network)

«L'esperimento MICRON propone lo sviluppo di **strutture elettromagnetiche ad alto gradiente accelerante** sia di tipo **dielettrico** che di tipo **metallico**.

Più in dettaglio si parla di strutture dielettriche alimentate da laser infrarosso con gradienti al di sopra di **500 MV/m** e strutture metalliche da banda Ka (35 GHz) a banda W (100 GHz) con gradienti superiori a **100 MV/m**.

L'obiettivo finale per entrambe le strutture è la **costruzione e il test a freddo**.»
[Verbale Riunione dei Ref.]

MICRON (MIniaturised aCceleRatOrs Network)

Motivations

High <u>accelerating</u> gradients enable compact/miniaturized particle accelerators

<u>MAIN GOAL</u> of the PROPOSAL: <u>Miniaturization</u> of Accelerating Structures

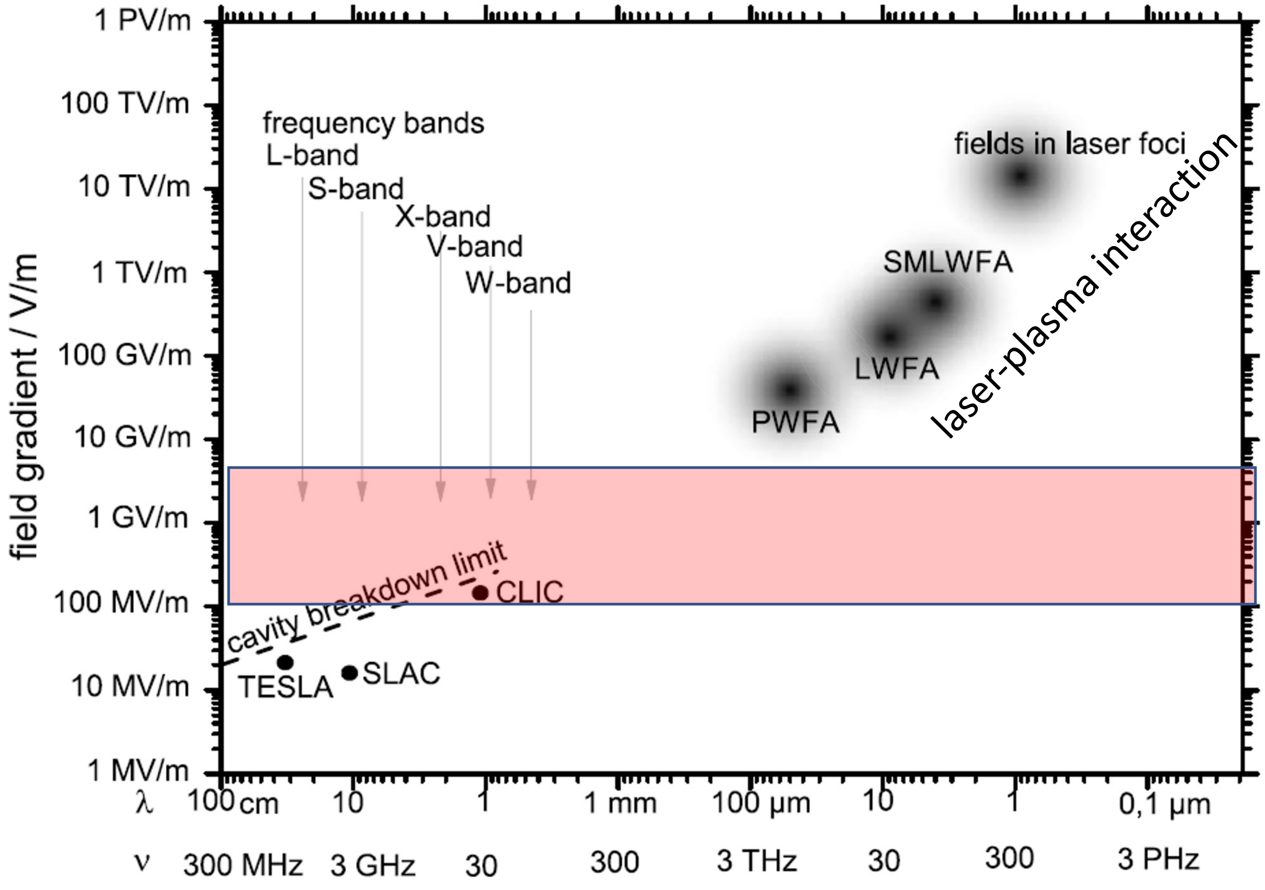
TARGET OF THE PROSAL

Accelerating Gradient: <u>~ 100 MV/m - 2 GV/m</u>

1) **<u>Metallic Structure</u> from <u>Ka to W-band</u> (35-200 GHz, mm-wavelength)**

2) **<u>Dielectric Laser Accelerator (DLA) structures operating at optical</u> wavelengths (~ 1- 5 μm)**

schematic overview of the accelerating gradient for different types of accelerators



MICRON (**MI**niaturised a**C**cele**R**at**O**rs **N**etwork)

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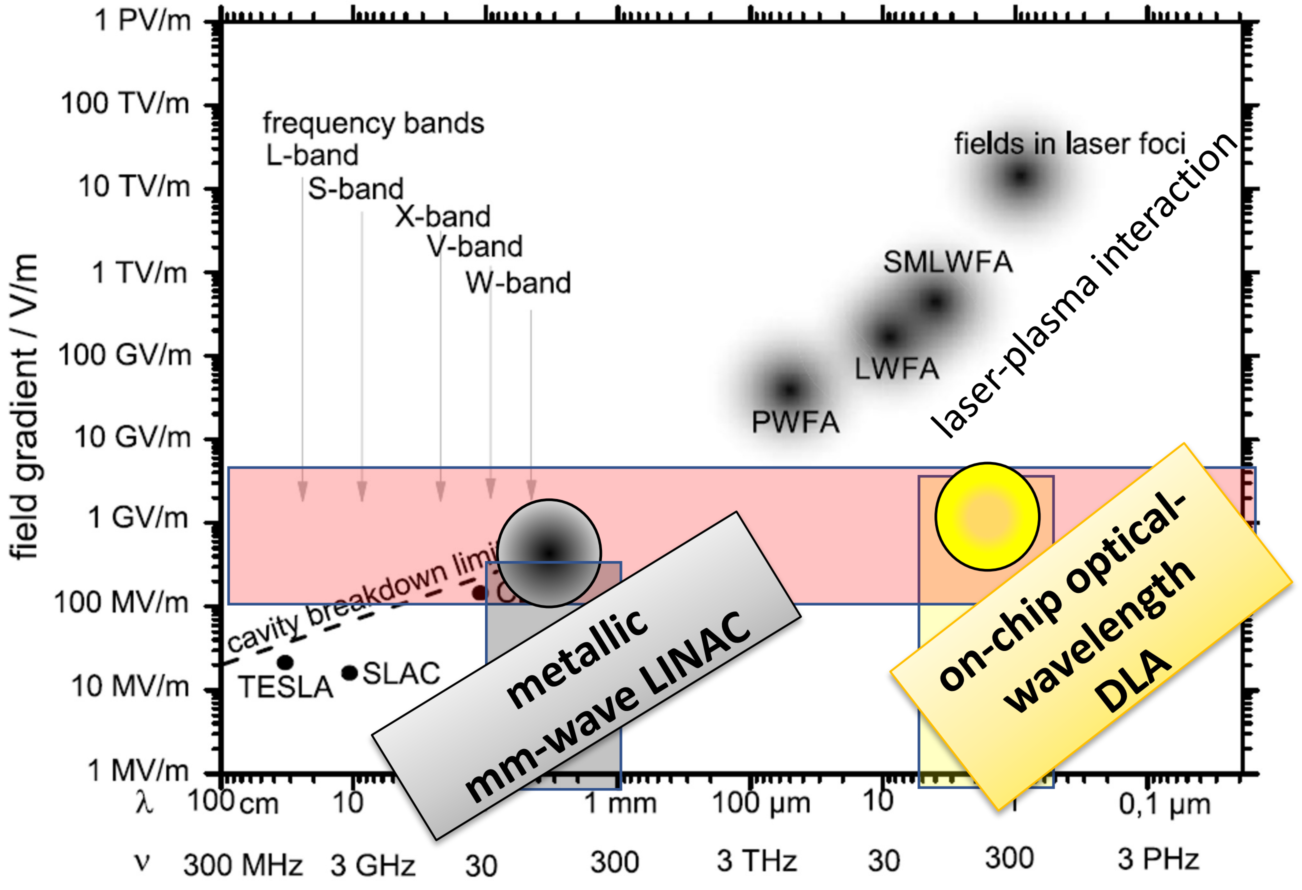
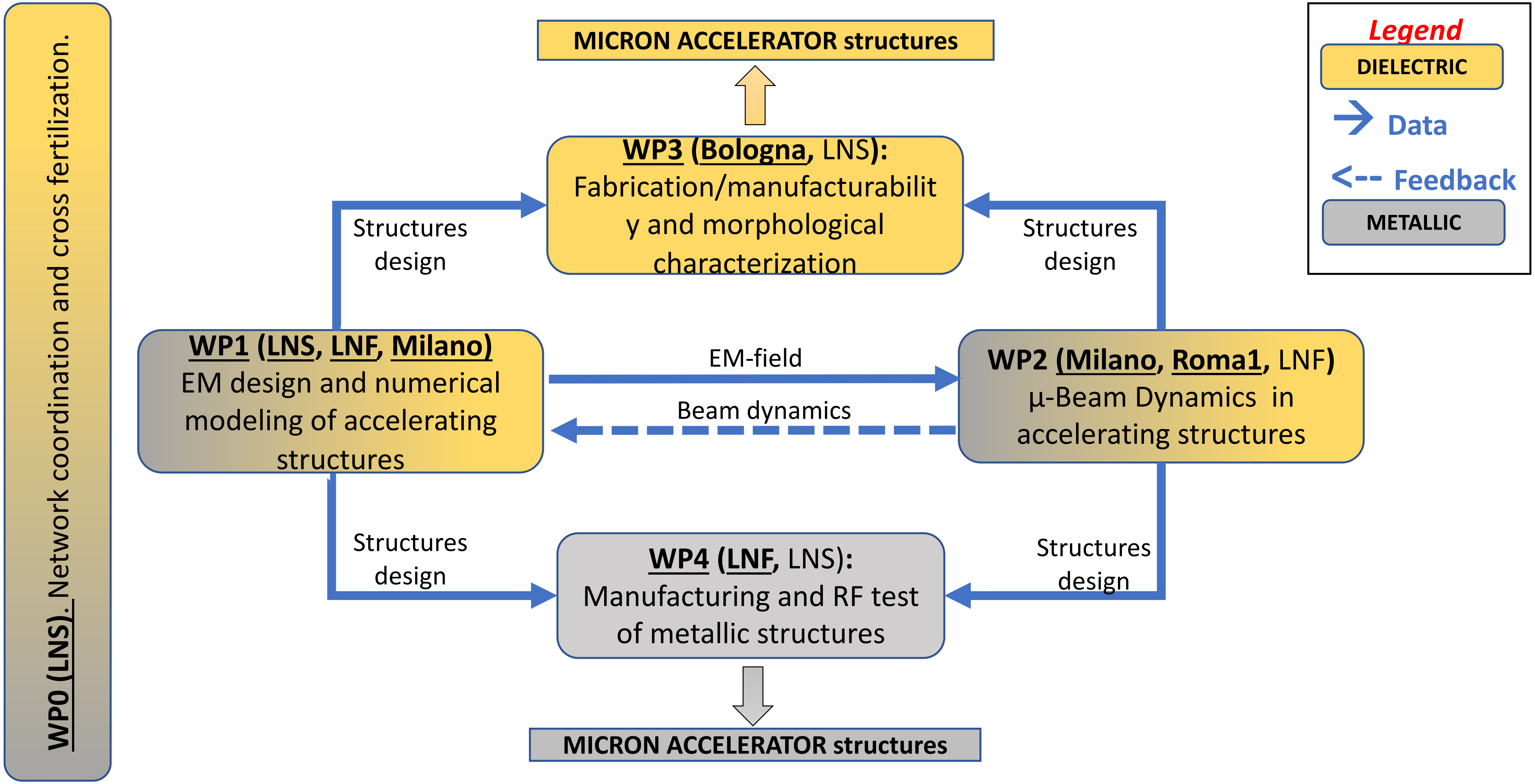


MICRON (**MI**niaturised a**C**cele**R**at**O**rs **N**etwork)

Struttura del progetto



Planning

Scala dei tempi (piano di svolgimento)	
PERIODO	ATTIVITA' PREVISTA
1-15	RF design of metallic Ka and W-band cells and mode launcher
1-24	Beam dynamics (GPT) and wakefield in metallic structures (CST, ASTRA)
1-27	Electromagnetic design of optical low- and high-ß dielectric structures
1-36	Networking, Management, Dissemination
22-33	RF cold test of metallic prototype
25-36	Fabrication and morphological characterization of dielectric structures
4-24	Welding/Fabricability, Fabrication, Optimization of metallic prototype
4-30	Beam dynamics in dielectric structures (ASTRA)
4-30	Manufacturability of dielectric structures

Legend

DIELECTRIC

METALLIC

WP3: Manufacturing/manufacturability

INFN-BOLOGNA [33.5 k€], LNS

- 2 k€ (resist, developer, materia)l
- 1 k€ (missioni)

+ Anticipo Budget 2021 30.5 k€

WP1 : EM Design

LNS [7 k€], LNF

- 6 k€ (licenza software)
- 1 k€ (missioni)

1st year BUDGET per unit

WP2: BD, Wakefield

INFN-MI [7 k€]

- 6 k€ (Workstation)
- 1 k€ (missioni)

INFN-ROMA1 [1 k€]

1 k€+ 2 k€ SJ (missioni)

WP4: Manufacturing and test

LNF [23 k€], LNS

- 19 k€ (fabbricazioni)
- 3 k€ (workstation)
- 1 k€ (missioni)

MILESTONES 2022 (1^{st} YEAR)

DIELECTRIC

METALLIC

○ **1.** Evaluation of Figure of Merits on the numerical model
(R_{Sh} > 150 MΩ/m, Q> 5000)
(Z_c > 500 Ω , G > 0.5 GV/m)

○ **2.** Repeatable process for polymeric master fabrication
(Adhesion, Consistency 10%, Seamless)
FESEM Characterization

○ **3.** Manufacturability test
(tol < +- 3µm, Ra< +- 50 nm)

MILESTONES 2022 (1st YEAR)

DIELECTRIC

METALLIC

- **1.** Evaluation of Figure of Merits on the numerical model
  (R_{Sh} > 150 MΩ/m, Q> 5000)
  (Z_c > 500 Ω , G > 0.5 GV/m)

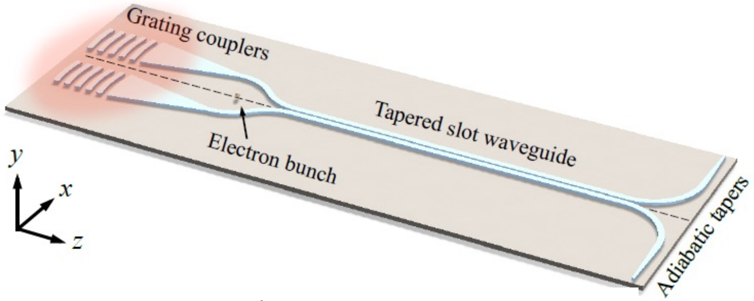
Attività 2022 LNS, LASA

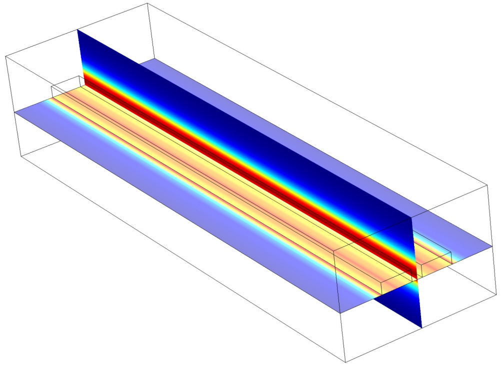
Milestone N. 1

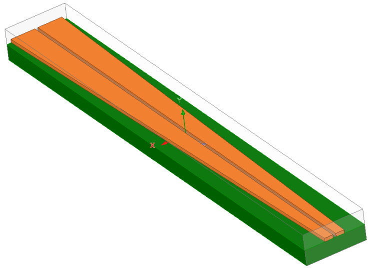
1. Evaluation of Figure of Merits on the numerical model

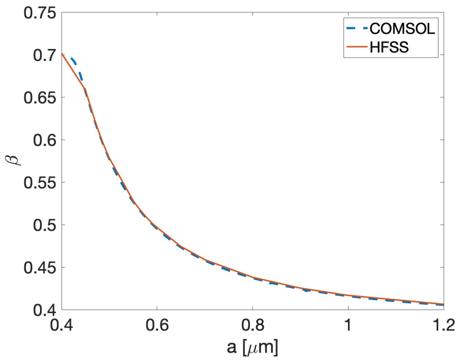
DIELECTRIC

Slotted waveguide @ 5 μm
$[0.4 < \beta < 0.75,\ Zc$=1.5 kΩ$]$

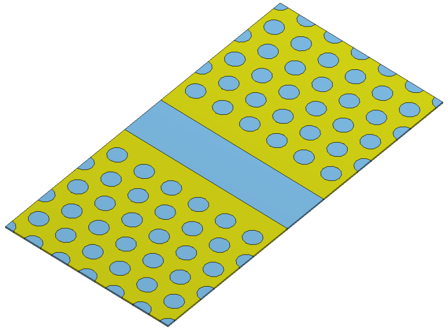


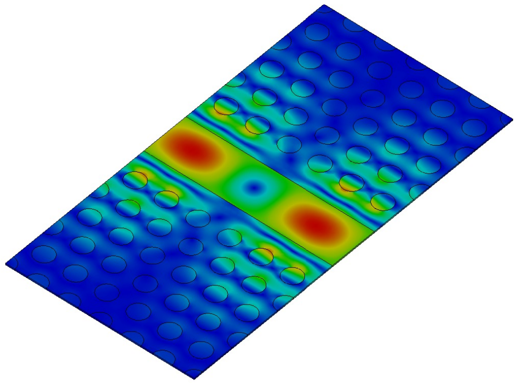


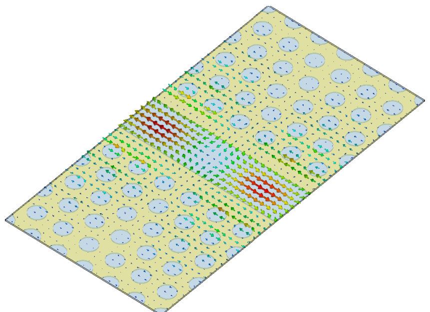




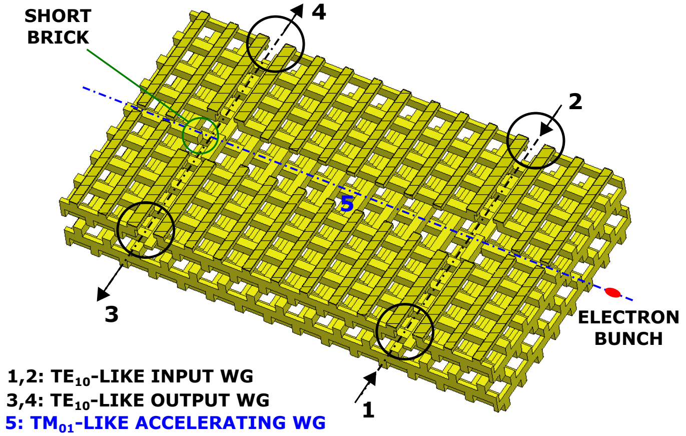
2D photonic crystal waveguide
$[0.75 < \beta < 1]$





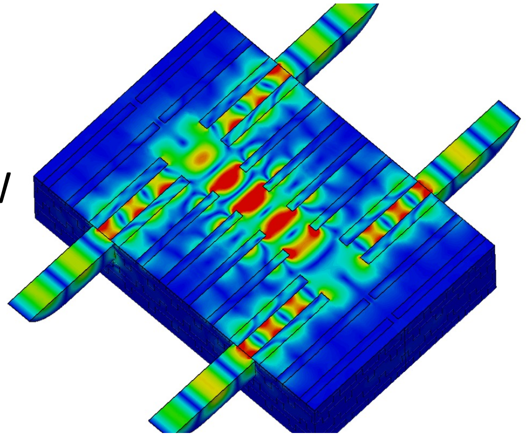


Woodpile @ 5 μm
$[\beta = 1, Zc$ = 11.4 kΩ$]$



~ 1 GV/m

@ P_inj=1 kW



<u>Attività 2022 LNS</u>, LASA

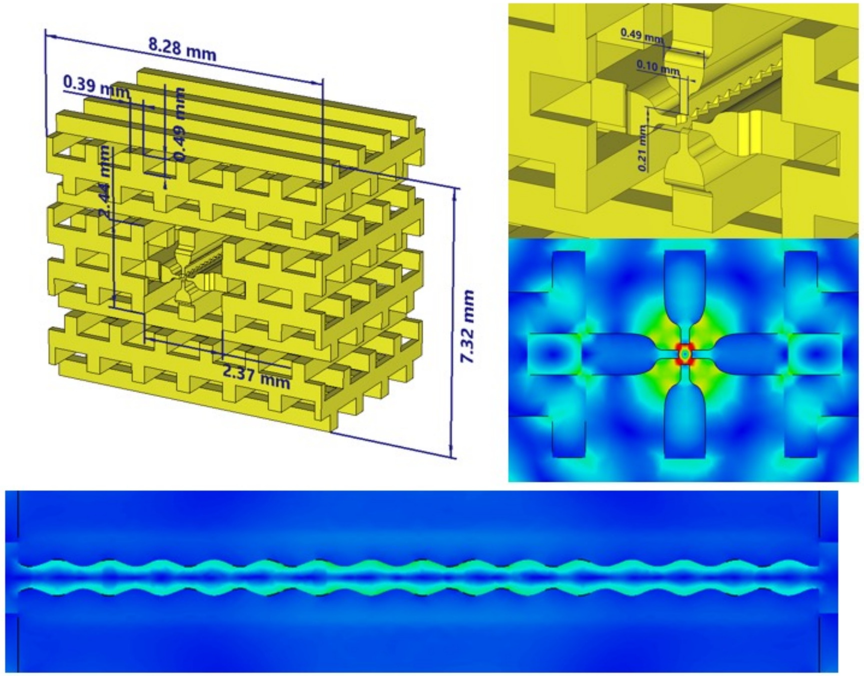
Milestone N. 1

1. Evaluation of Figure of Merits on the numerical model

DIELECTRIC

Dielectric Photonic Crystal woodpile-based RFQ

[*from β 0.05 to 0.2*]



Brevetto INFN

Metodo per progettare una struttura accelerante dielettrica che supporta un modo TE_{210}-like perturbato (Ita. Patent pending n. 102021000021158)

By: G. S. Mauro, G. Torrisi, D. Mascali, G. Sorbello, S. Gammino (INFN-LNS), G. Della Valle (PoliMi)

[G. S. Mauro et al., *Numerical Simulation of a Hollow-Core Woodpile Based Mode Launcher for Dielectric Laser Accelerators*, Applied Sciences 2022]

Attività 2022 LNS, LASA

Milestone N. 1

1. Evaluation of Figure of Merits on the numerical model

DIELECTRIC

ongoing

- Beam Dynamics setup…towards An “Adiabatic Phase-Matching Accelerator [1]
- 2D PhC waveguide needs third-dimension confinement

[1] Proceedings of IPAC2017, Copenhagen, Denmark WEPAB123 A PHASE MATCHING, ADIABATIC ACCELERATOR ∗ F. Lemery et al.,

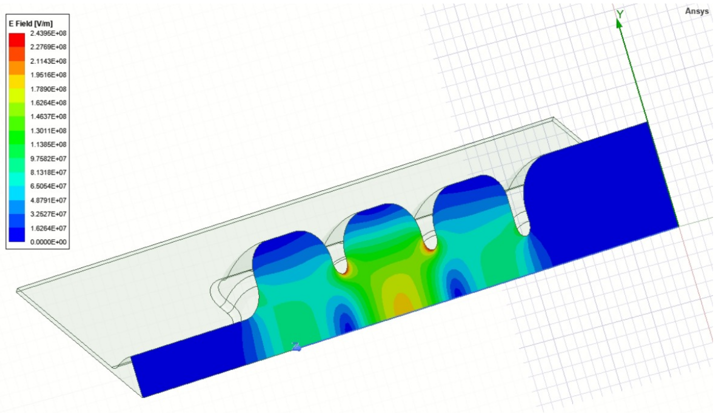
Attività 2022 LNF, Roma 1, LNS

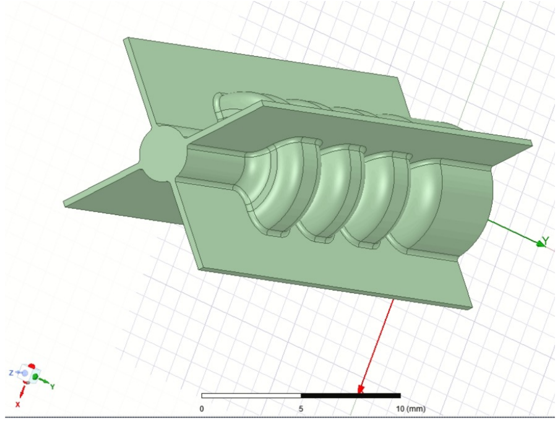
Milestone 1

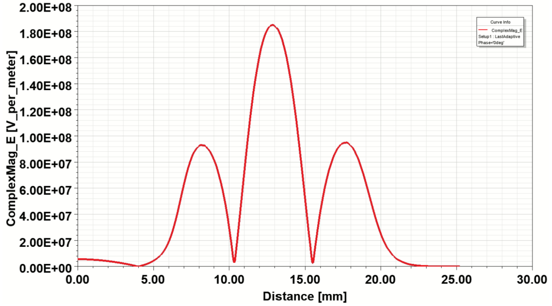
1. Evaluation of Figure of Merits on the numerical model

METALLIC

Cavity Design and Prototyping – Multiple parts open structures







The electric field in the middle cell is two times higher in the middle cell in order to localize and analyze the RF breakdown events.

Quadrants vs. Closed structure

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

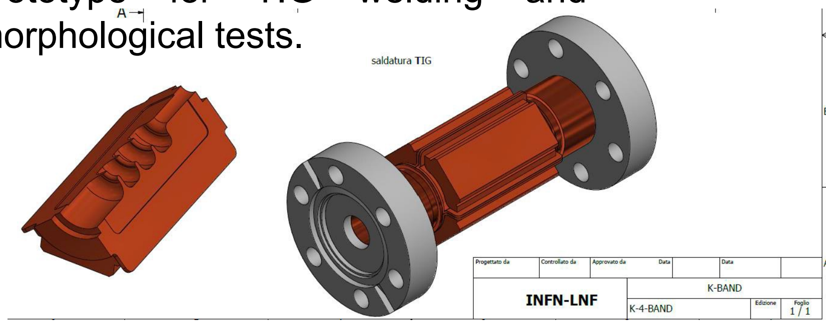
TIG welding on the outer slots → avoiding high temperature brazing and/or diffusion bonding processes (the typical assembly methods widely used to manufacture ultrahigh vacuum accelerating devices) which - occurring at about 800–1000 °C - significantly change the cavity mechanical properties.

Main RF Parameters

Resonant Modes	Closed structure	4 quadrants
0 mode frequency (GHz)	33.897	33.838
Pi/2 mode frequency (GHz)	34.603	34.580
Pi mode frequency (GHz) Operating mode	35.982	35.982
0 mode Quality factor	5,980	5,883
Pi/2 mode Quality factor	5,806	5,711
Pi mode Quality factor	5,978	5,877
Operating mode (pi) Longitudinal Shunt Impedance (MΩ/m)	240	235

Ka- band cavity Prototyping

Drawing of the 4-quadrants structure prototype for TIG welding and morphological tests.

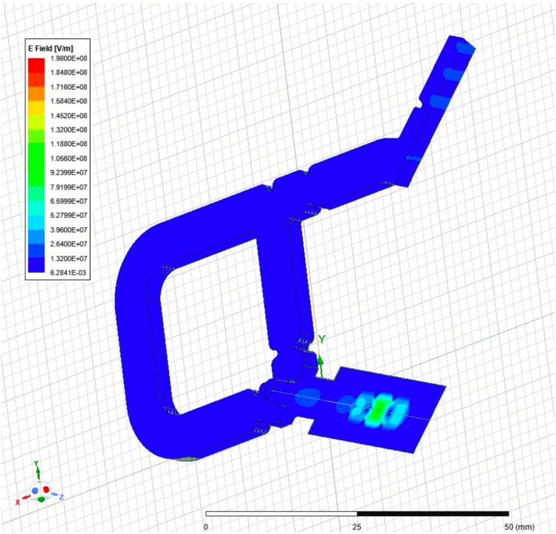


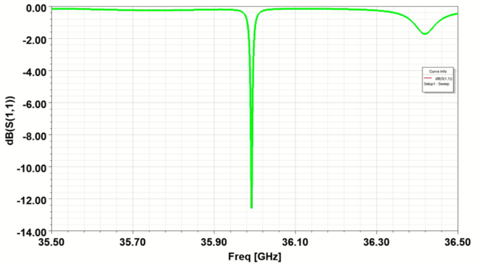
Attività 2022 LNF, Roma 1, **LNS**

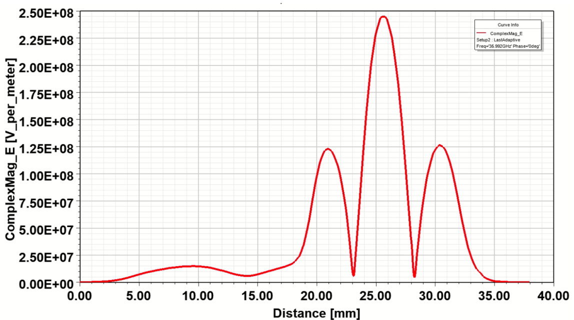
Milestone 1

1. Evaluation of Figure of Merits on the numerical model

METALLIC

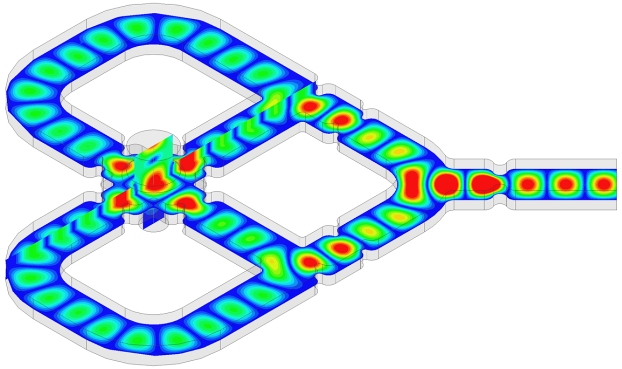




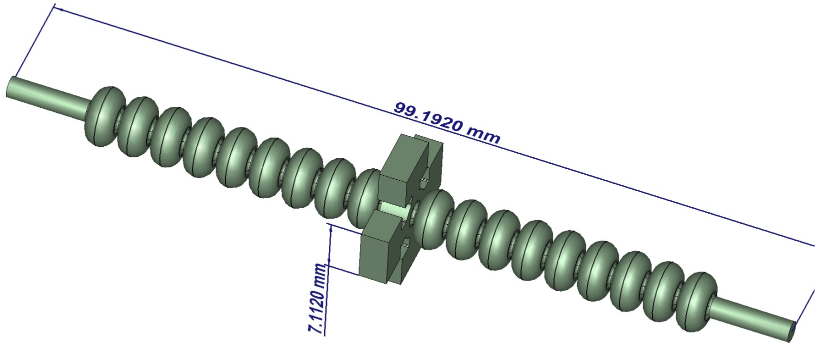


Ka-band Mode launcher

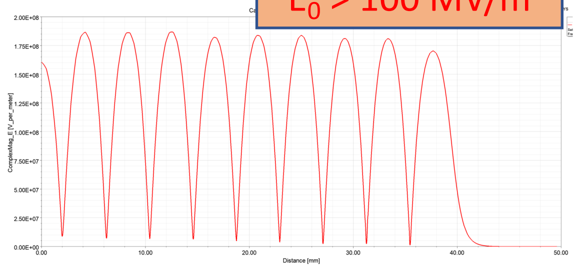
- Design numerico e caratterizzazione sperimentale di **lanciatori-convertitori di modo** a simmetria quadrupolare.



- Design numerico di **cavità acceleranti per elettroni** ad elevato gradiente, operanti in banda Ka.



$E_0 > 100$ MV/m



MILESTONES 2022 (1st YEAR)

DIELECTRIC

METALLIC

- **2.** Repeatable process for polymeric master fabrication
  (Adhesion, Consistency 10%, Seamless)
  FESEM Characterization

Milestone N. 2. Repeatable process for polymeric master fabrication

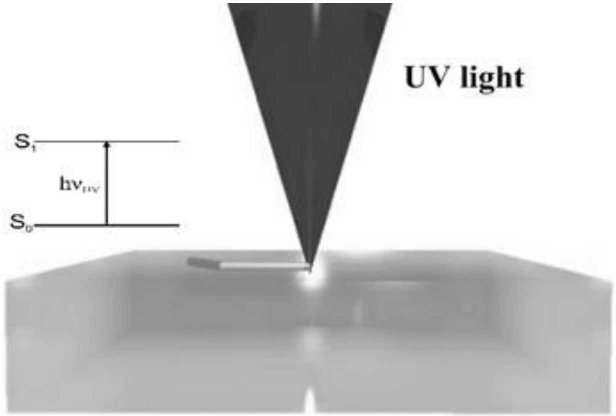
Attività 2022 INFN-BOLOGNA
(CNR IMM-Bologna e PoliTO - Chi-Lab)

3D printing at the micro- / nano- scale

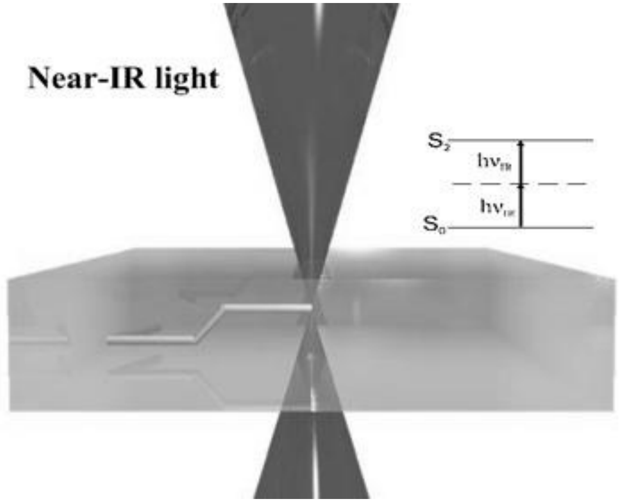
Two photon polymerization

Femtosecond pulsed laser to induce resist polymerization

100x objective

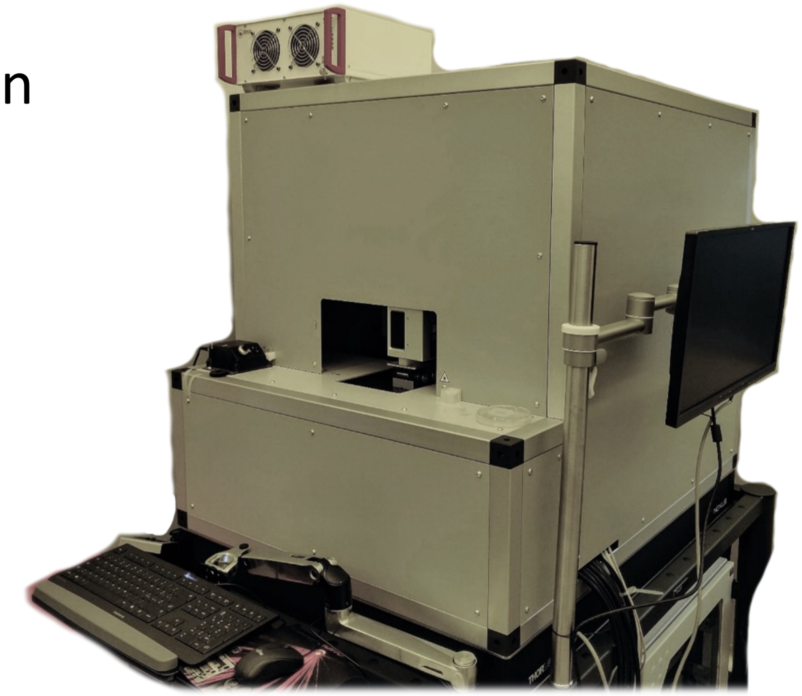


Single photon polymerization (standard): lower resolution, surface polymerization



Two photon polymerization: higher resolution, polymerization inside volume

Laser nanoFab



M4D System by Laser nanoFab
TPP setup

Milestone N. 2. Repeatable process for polymeric master fabrication

Attività 2022 INFN-BOLOGNA (CNR IMM-Bologna e PoliTO - Chi-Lab)

DIELECTRIC

Anticipo Budget 2021 30 k€

k850 critical point dryer (CPD) *from Quorum*

- represents a key instrument for the fabrication of dielectric waveguides fabricated at micro/nanometric
- By using CPD, the evaporation step is finely controlled, allowing the replacing of solvent with liquid CO_2, and then CO_2 is removed going beyond its critical point.
- liquid CO_2 changes to vapour without change of density and therefore without surface tension effects which could damage the structures.

CVD / PECVD deposition of Si

AIM: obtain the designed Dielectric PC structure starting from the TPP printed structure

Fabrication of the Si woodpile micrometric structure by covering the polymeric structure obtained by TPP with Si deposited by CVD techniques as

- PECVD (a-Si:H)
- LPCVD (a-Si:H or polySi)

PECVD

Milestone N. 2. Repeatable process for polymeric master fabrication

Attività 2022 INFN-BOLOGNA (CNR IMM-Bologna e PoliTO - Chi-Lab)

TPP test pattern: a matrix with many woodpile structures (5 μm) ORMOCOMP / glass

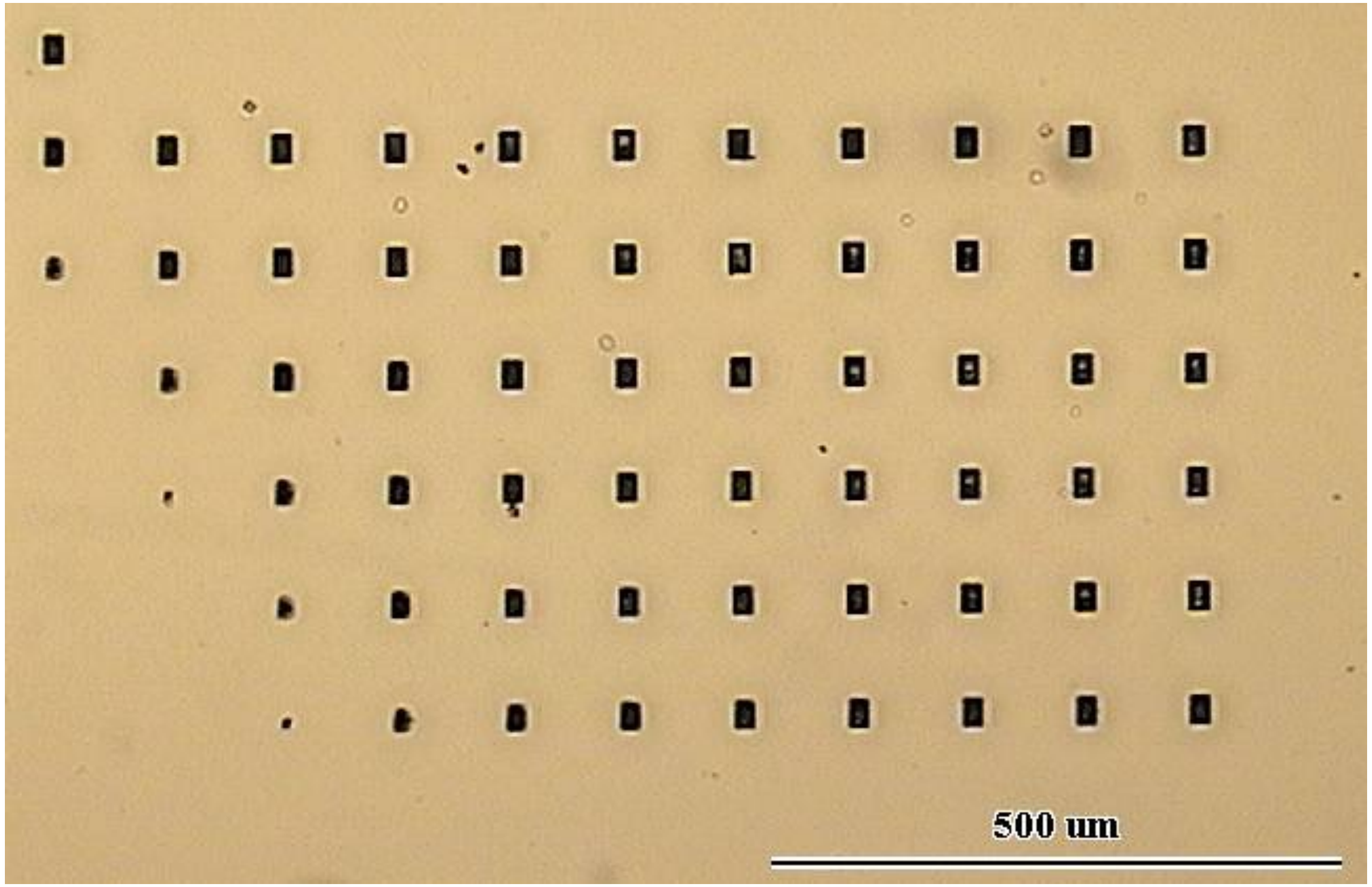
AIM: determine the best printing parameters by varying laser power and velocity

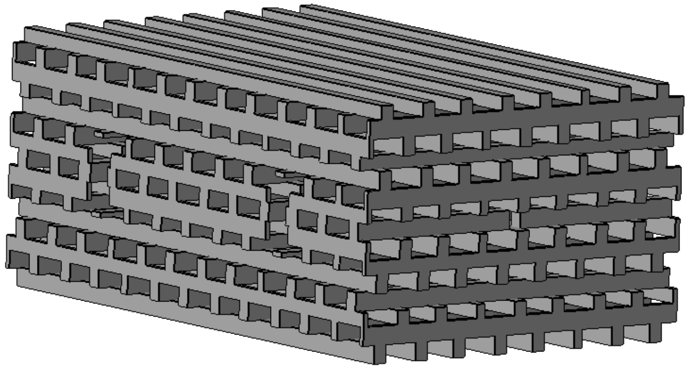
10 12 14 16 18 20 22 24 26 28 30

P(mW)

0.05
0.1
0.15
0.2
0.25
0.3

v(mm/s)





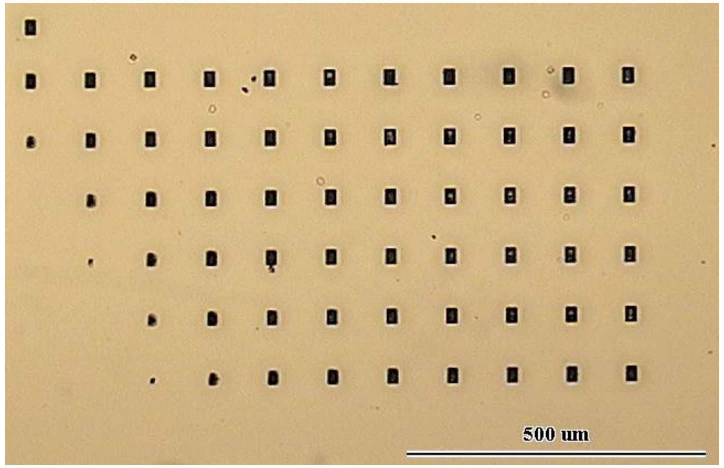
Milestone N. 2. Repeatable process for polymeric master fabrication

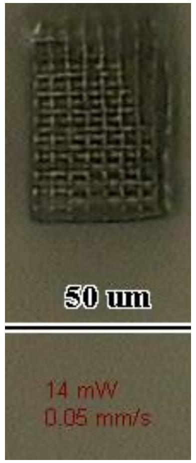
Test of adhesion and quality of the 3D printed structures

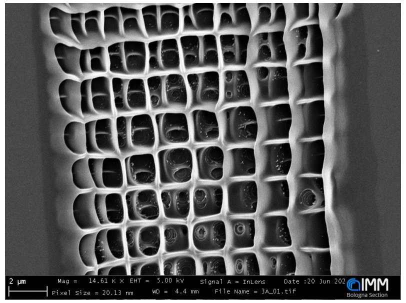
- Pyrolysis (graphitizaton) of the polymer @ 450°C and @ 690°C in Ar
- SEM observation to see **adhesion, quality of the 3D printing and to find the best printing parameters**

Good adhesion of the printed structure to the substrate

- **Printing to be optimized**
- **Results are promising,**
- **Best parameters (14mW, 0,05 mm/s)**







Milestone N. 2. Repeatable process for polymeric master fabrication

Attività 2022 INFN-BOLOGNA (CNR IMM-Bologna e PoliTO - Chi-Lab)

On going:

- Deposition of a-Si-H by PECVD and thermal CVD on the graphitized woodpile structures to test the % of coverage of the printed structures on the whole volume of the woodpile
- TPP fabrication of new woodpile structures on fused silica with optimized TPP optical setup

Towards 2023

- Optimization of Si deposition
- Etching tests of the skeleton after Si deposition

Towrads 2024:

- SEM characterization of the morphology and geometrical quality of the woodpile structure

Attività 2022 LNF, LNS

Milestone N.3 Manufacturability test
(tol < +- 3µm, Ra< +- 50 nm)

○ **3.** Manufacturability test
(tol < +- 3µm, Ra< +- 50 nm)

3.1 Fabbricazione Campioni
(quotazione OK, consegna prevista)

3.2 Misure metrologiche/test
campioni (fine anno)

3.3 Misure Temperatura vs
weling/brazing,
e feedback al modeling (fne anno ?)

- Metallic Samples have been commissioned to COMEB
- Manufacturing on ONGOING

MILESTONES 2023 (2nd year)

DIELECTRIC

- M2 Selection of one or more dielectric EM structure
- M3 Import EM field from HFSS to ASTRA

METALS

- **M3** Evaluation of the Beam dynamics pars
- **M4** Prototype Mechanical Draw
- **D2** Ka-band Metallic Prototype

MILESTONE 2nd year 2023

Struttura del progetto

Month		1	3	6	9	12	15	18	21	24	27	30	33	36	
WP1	T1.1					D1	M2								EM Design of optical low- and high-ß dielectric structures
	T1.2					M1	D1								RF design of metallic Ka and W-band cells and mode launcher
WP2	T2.1						M3					D2			Beam dynamics in dielectric structures (ASTRA)
	T2.2						M3								Beam dynamics (GPT) and wakefield in metallic structures (CST, ASTRA)
WP3	T3.1					M1									Dielectric Manufacturability
	T3.2										M4			D3	Dielectric Fabrication and morphological characterization
WP4	T4.1					M2		M4		D2					Welding/Fabricability, Fabrication, Optimization
	T4.2										M5		D3		RF cold test of metallic prototype
WP0	T0														Networking, Management, Dissemination

Milestone primo anno (2022)

Milestone secondo anno (2023)

M1	Repeatable process and post-process steps for polymeric master fabrication
M2	selection of one (or more) EM structure
M3	import EM field from HFSS to ASTRA
M4	inversion of the master with oxide deposition/fabrication of masters for 3D printing
D1	preliminary report of the EM design
D2	full-wave model (EM+BD)
D3	Report of the dielectric study

M1	Evaluation of the RF Figure of merits on the optimized numerical model
M2	Manufacturability (tolerance, roughness) Test, welding, material handling
M3	Evaluation of the BD parameters (wakefield effects on the optimized numerical model)
M4	Mechanical engeneering and executive drawing
M5	Check/Procurements of RF components/system for the measurements
D1	full-wave model (EM+BD)
D2	Ka-band metallic protoype
D3	Report of the RF characterization on the metallic protoype

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Richieste finanziarie per l’anno 2023

STRUTTURA	MISSIONI [k€]	CONSUMO [ek]
BO	4 k€*	2 k€ - Fotopolimeri tipo ORMOCOMP ed SU8 per stampa 3D TPP - Wafer fused silica per realizzazione di strutture con stampa 3D TPP; - Gas di processo per deposizione di silicio mediante CVD.3k€ Missioni
LNF	4 k€ (including visit to SLAC)	21 k€ (prototipo 16 Acc. cells in «open»-technology @36 GHz+ mode Launcher)
LNS	4.6 k€ (misure @LNF e Bo)*	
MI	3 k€	
RM1	4 k€ (including visit to UCLA)	7 k€ (leghe CU/Ag)

MICRON (MIniaturised aCceleRatOrs Network)

Anagrafica 2023

					MICRON TEAM MEMBERS					
LNS		LNF			Milano		ROMA1		BOLOGNA	
NOME	FTE	NOME	FTE		NOME	FTE	NOME	FTE	NOME	FTE
Giuseppe Torrisi	50	Luigi Faillace	30		Alberto Bacci	25	Mauro Migliorati	40	Rita Rizzoli	15
David Mascali	10	Luca Piersanti	10		A. Rossi	20	F. Bosco (PhD)	50	Simona Marasso	10
Giorgio S. Mauro	50	Fabio Cardelli	10		M. Rossetti Conti	10	D. De Arcangelis	100	Valentina Bertana	0
Gino Sorbello	40	Alessandro Gallo	10		C. De Angelis	30			Caterina Summont	15
Loreto Di Donato	30	Marco Bellaveglia	10		G. Della Valle	5			Virginia Boldrini	10
Santi Pavone	25	Mostafa Behtouei	80		A. Locatelli	40			Fulvio Mancarella	10
Nunzio Salerno	60	Claudio Marcelli	10		L. Vincetti	40				
Tommaso Isernia	30	Antonio Falone	10		F. Broggi	20				
TOT	2,95	TOT	1,7		TOT	1,9	TOT	1,9	TOT	0,6
				FTE_TOT	9,05					

TALK, CONF., PUBL.

- **White paper** successfully submitted to **Snowmass AF6 (Advanced Accelerator Concepts):** "*Laser-Driven Structure Based Accelerators*", J. England, D. Filippetto, G. Torrisi, A. Bacci, G. Della Valle, D. Mascali, G. S. Mauro, G. Sorbello, P. Musumeci, J. Scheuer, B. Cowan, L Schachter, Y-C. Huang, U. Niedermayer, W. D. Kimura, R. Li, R. Ishebeck, E. I. Simakov, P. Hommelhoff, R. L. Byer , arXiv:2203.08981 https://arxiv.org/abs/2203.08981
- Mauro, G.S.; Torrisi, G.; Locatelli, A.; Bacci, A.; De Angelis, C.; Mascali, D.; Sorbello, G. Numerical Simulation of a Hollow-Core Woodpile-Based Mode Launcher for Dielectric Laser Accelerators. *Appl. Sci.* 2022, *12*, 2609. https://doi.org/10.3390/app12052609
- **Book** Project "*High Resolution Manufacturing From 2D To 3D/4D Printing: Applications in Engineering and Medicine* ***" Photonic applications Part II - Impact on "Dielectric laser accelerators" and other case studies***, C. De Angelis, Andrea Locatelli, Giorgio S. Mauro, R. Rizzoli, G. Sorbello and G. Torrisi, *submitted for publication*

- **Talk** Copropagating schemes for high gradient Dielectric Laser Accelerators (DLAs)" @The 3rd International Workshop on "Ultrafast Beams and Applications" 4-8 July 2022 at CANDLE Institute in Armenia, UBA22 Workshop, Yerevan, Armenia
- **Poster@** International Workshop on Breakdown Science and High Gradient Technology (HG2022) 16–19 May 2022 "COPROPAGATING SCHEMES FOR DIELECTRIC LASER ACCELERATORS (DLAS)" G. Torrisi, D. Mascali, G. S. Mauro, A. F., M. M. Costanza (DIEEI, Catania), A. Bacci, G. Sorbello, C. De Angelis, A. Locatelli
- **Poster@** HIGH GRADIENT 2022 workshop, L. Faillace, B. Spataro, M. Behtouei, M. Carillo, V. Dolgashev, G. Mauro, M. Migliorati, G. Torrisi, "Design and Prototyping of high gradient Ka-band accelerating structures, poster at HIGH GRADIENT 2022 workshop."
- **Poster@** IPAC'22, B. Mostafa et al, Studies of a Ka-Band High Power Klystron Amplifier at INFN-LNF, Proceedings of IPAC'22, Bangkok, Thailand.
- "Copropagating schemes for high gradient Dielectric Laser Accelerators (DLAs)" submitted to SIF, 108° Congresso Nazionale 12 -16 settembre 2022, Milano
- G. Torrisi, G. Mauro, G. Sorbello, A. Usmani, C. De Angelis, A. Locatelli and A. Bacci, "Copropagating Schemes for Dielectric Laser Accelerators (DLAs)" XIV Riunione Nazionale di Elettromagnetismo Catania, 18-21 settembre 2022

- "**deposited patent** n. 102021000021158 "*Metodo per progettare una struttura accelerante dielettrica che supporta un modo TE210-like perturbato*" G. S. Mauro, D. Mascali G. Torrisi, S. Gammino, INFN, G. Sorbello UniCT, G. Della Valle, PoliMI

- Master degree **Thesis**, M. M. Costanza 31/03/2022, UniCT, DIEEI, CDL Ing. Delle Telecomunicazioni
- ERASMUS Master degree **Thesis**, A. Usmani , *UniCT, DIEEI, CDL Ing. Delle Telecomunicazioni*
- N. 2 **lessons** on DLA and RFQ @ Corso Fisica degli Accleleratori (Dr. David Mascali) anno Accademinco 2022-2023
- Seminario B. Spataro, "Development of X-band and Ka band high gradient structures", 9/5/2022
- N. 2 lessons on "Beam Dynamics", A. Bacci, 28/4/2022 e 11/5/2022