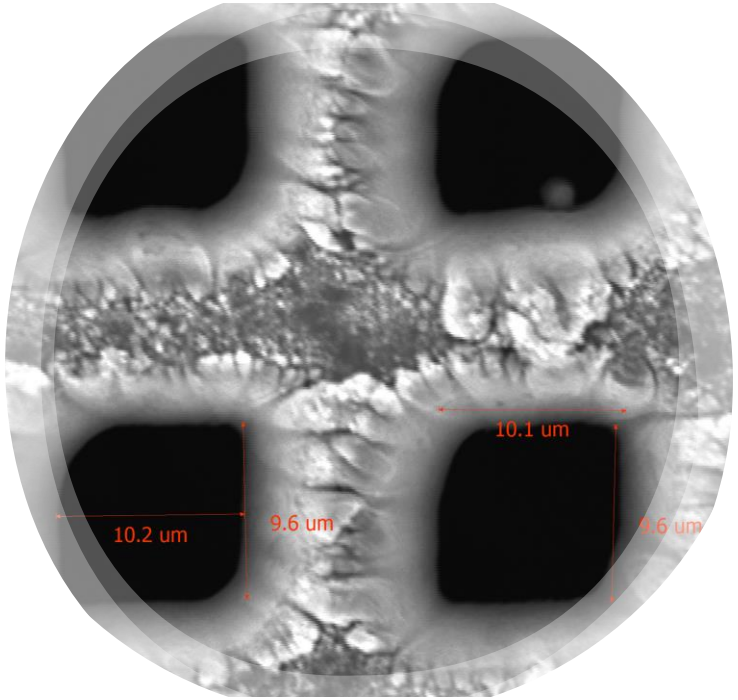



«Phonon traps fabrication»

COLD meeting Milano Bicocca 20/11/2023

Mourad El Idrissi, Dr. Oscar Azzolini, Dr. Giorgio Keppel

Outline:

I. **Introduction:**
- Brief overview of the work objective: Phonon trap coating.

II. **Deposition Techniques**
- HiPIMS (High Impulse Magnetron Sputtering) as a deposition technique.

III. **Phonon Traps Fabrication**
- Physical Mask Approach
- Conventional Photolithography

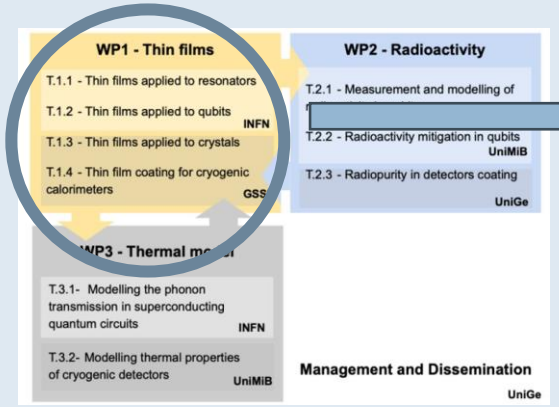
IV. **Physical Mask Processing Using LASER**

V. **Deposition Results from LASER-Processed Physical Masks**

VI. **Photolithography Process for Phonon Mask Fabrication**

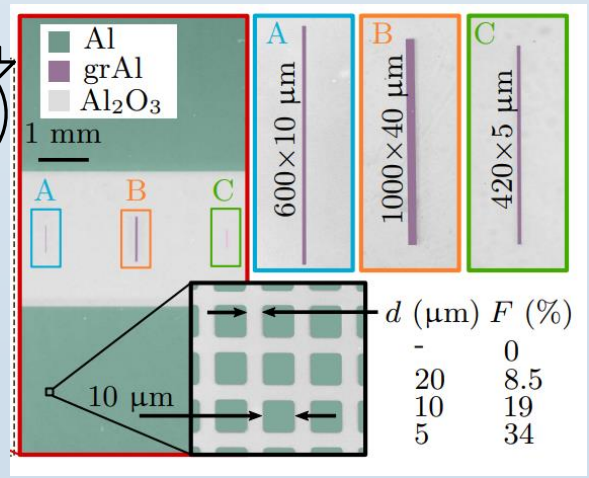
VII. **Results from Deposition Using Photolithography Phonon Masks.**

VIII. **Future Work**



WP1 T.1.1 → **Thin film applied to resonators and qubits**

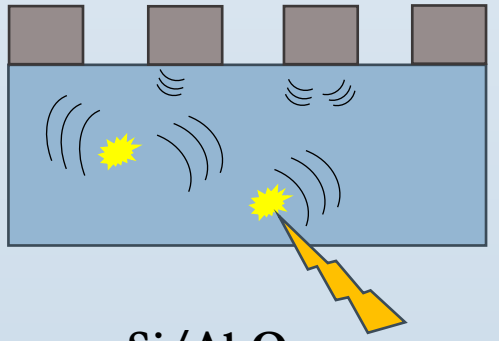
The **performance** of future quantum processors is **limited by radioactive interactions** These interactions deposit energy in the form of phonon waves, traveling through the chip and ultimately compromising the qubit's coherence time



Henriques, Fabio, et al. "*Applied physics letters* 115.21 (2019): 212601.

Preventing CP breaking: reducing high energy substrate phonons.
surrounding the chip with a **lower gapped superconducting** islands acting as a phonon traps
Thin-film coating that acts as a " Phonon traps"
Both *back side* and front *side using* low gap superconductor and innovative **PVD** techniques like **HiPIMS**

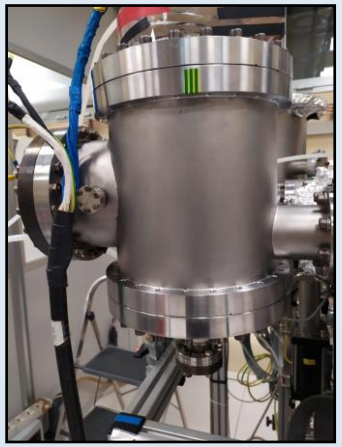
Pads in low gap superconductors Tc (Ti, Zr, W..)



Si/Al_2O_3

LNL coating facility

Chamber 3



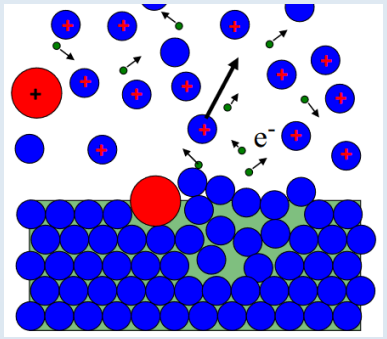
Vacuum chamber in stainless steel and has a cylindrical form with dimensions of 20 cm diameter and 30 cm of length. Magnetron source with 2-inch **Ti** target (99,99 %)

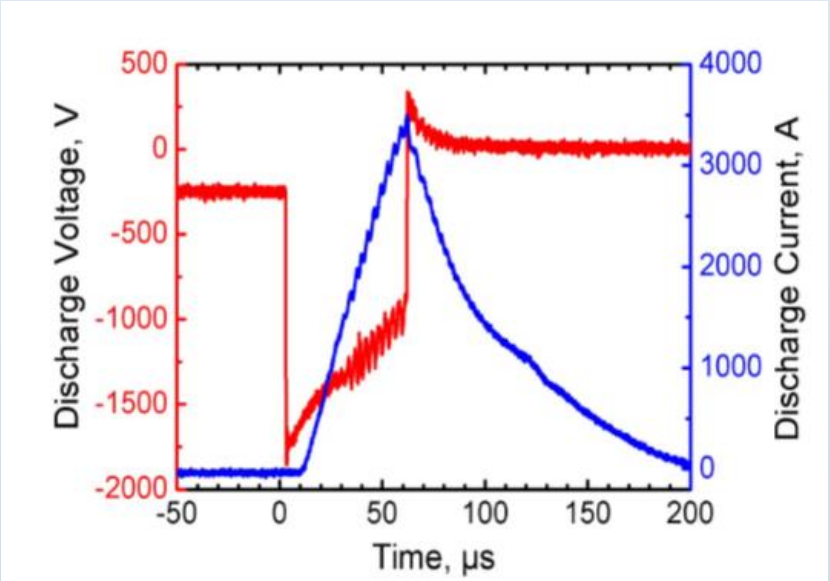
PVD machine

Multi-chamber system

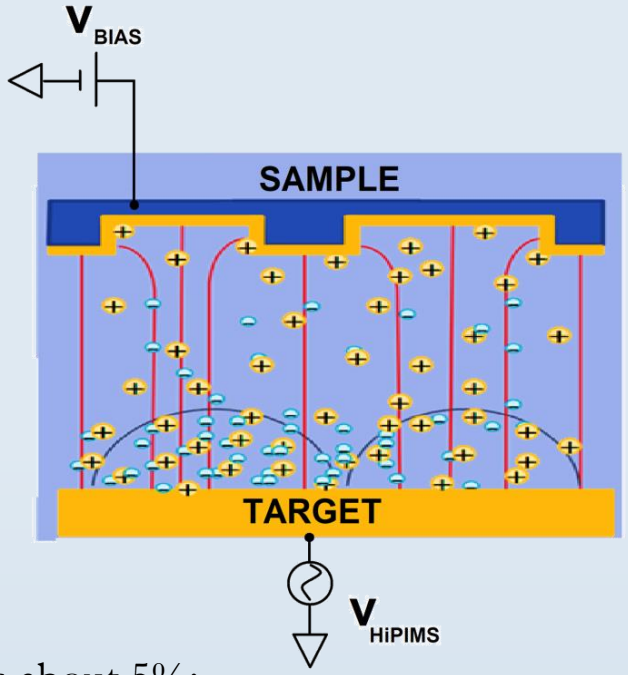
HiPIMS Power Supply

HiPIMS (High Impulse Magnetron Sputtering)





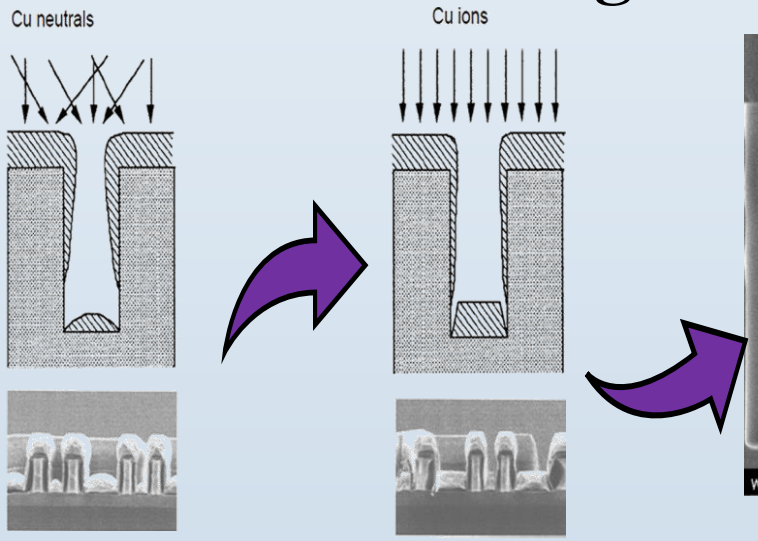
[*Ehiasarian et al.* https://doi.org/10.1351/PAC-CON-09-10-43]



- Degree of metal ionization in standard MS is about 5%; instead HiPIMS can reach 90%.
- Possible guiding the ions towards the substrate applying an electric field i.e. **Bias Voltage**
- Ion bombardment will also increase the **coating density**
- Improved film quality: **better adhesion, higher density, decreased roughness, good conformity**
- Applicable to non-flat surfaces
- **High aspect-ratio**

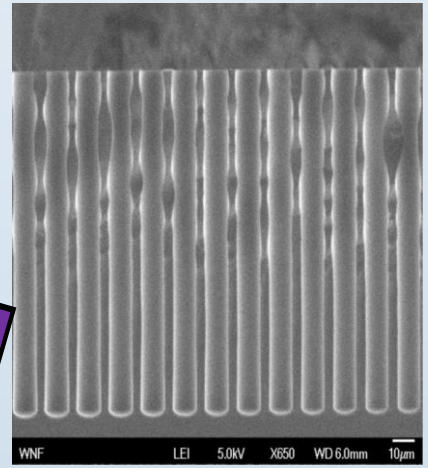
Uniformity on complex morphologies substrate

Conformal Coating

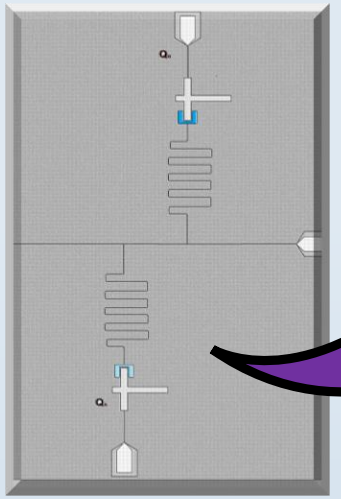


https://www.lesker.com/newweb/process_instruments/kjlc-impulse-hipims-powersupply.cfm

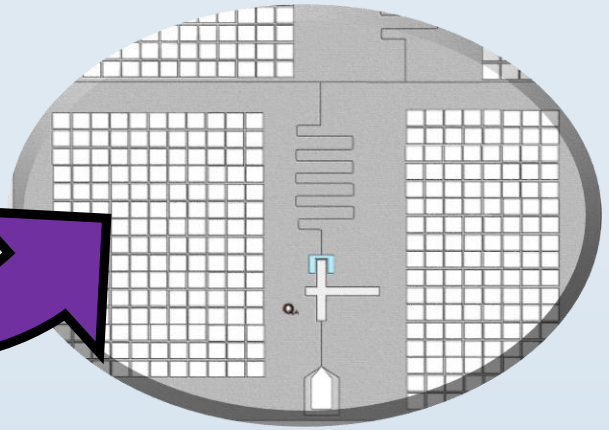
Aspect Ratio



Qbits chip before



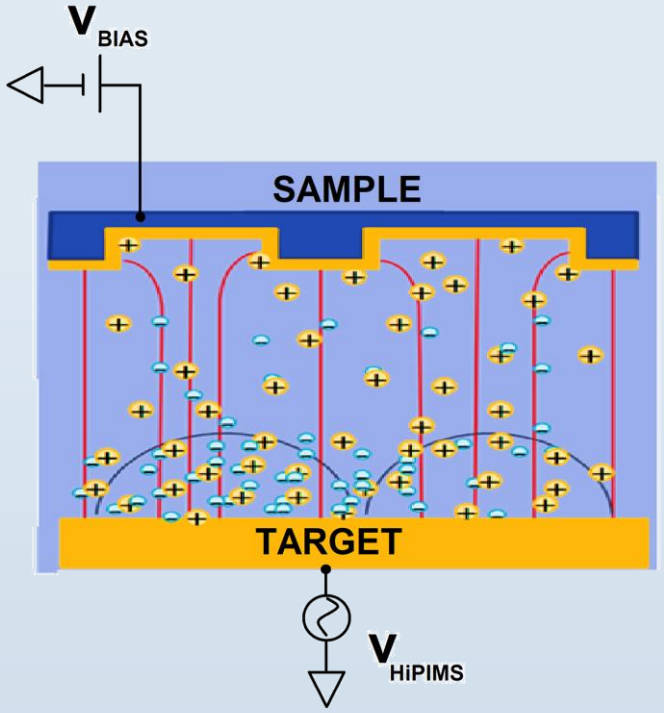
New design with phonon traps coating



Highly ionized deposition fluxes can be used, since the trajectories of charged species can be manipulated by electric and magnetic fields.

HiPIMS provides an alternative approach to successfully deposit films on complex-shaped substrates.

Ti thin film as phonon trap material

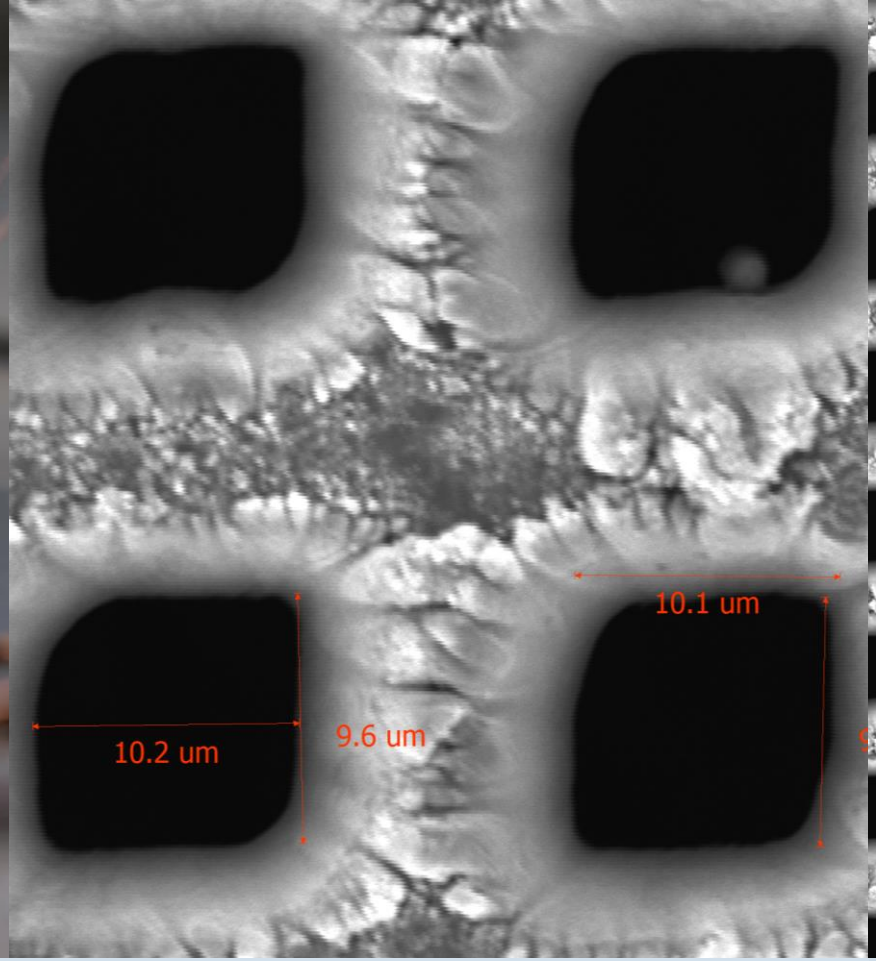


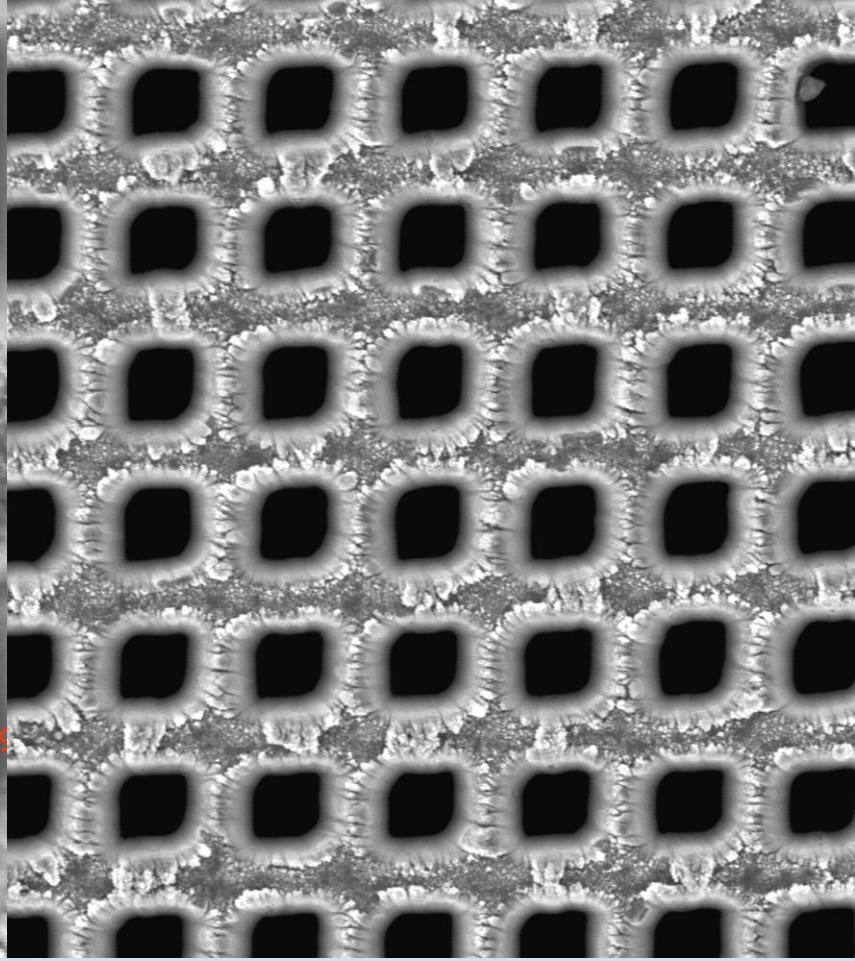
- Which has been choose for his relative low **Tc (0,39 K)** and his **good phonon transmission rate** to Al_2O_3 substrate and *Si* substrate.
- After a testing phase we found the best parameters in terms of adhesion and coating quality for Ti.

How to build pads for phonon trap and which techniques can be applied?

Physical Mask for phonon trap fabrication

Phonon trap Lithography fabrication process

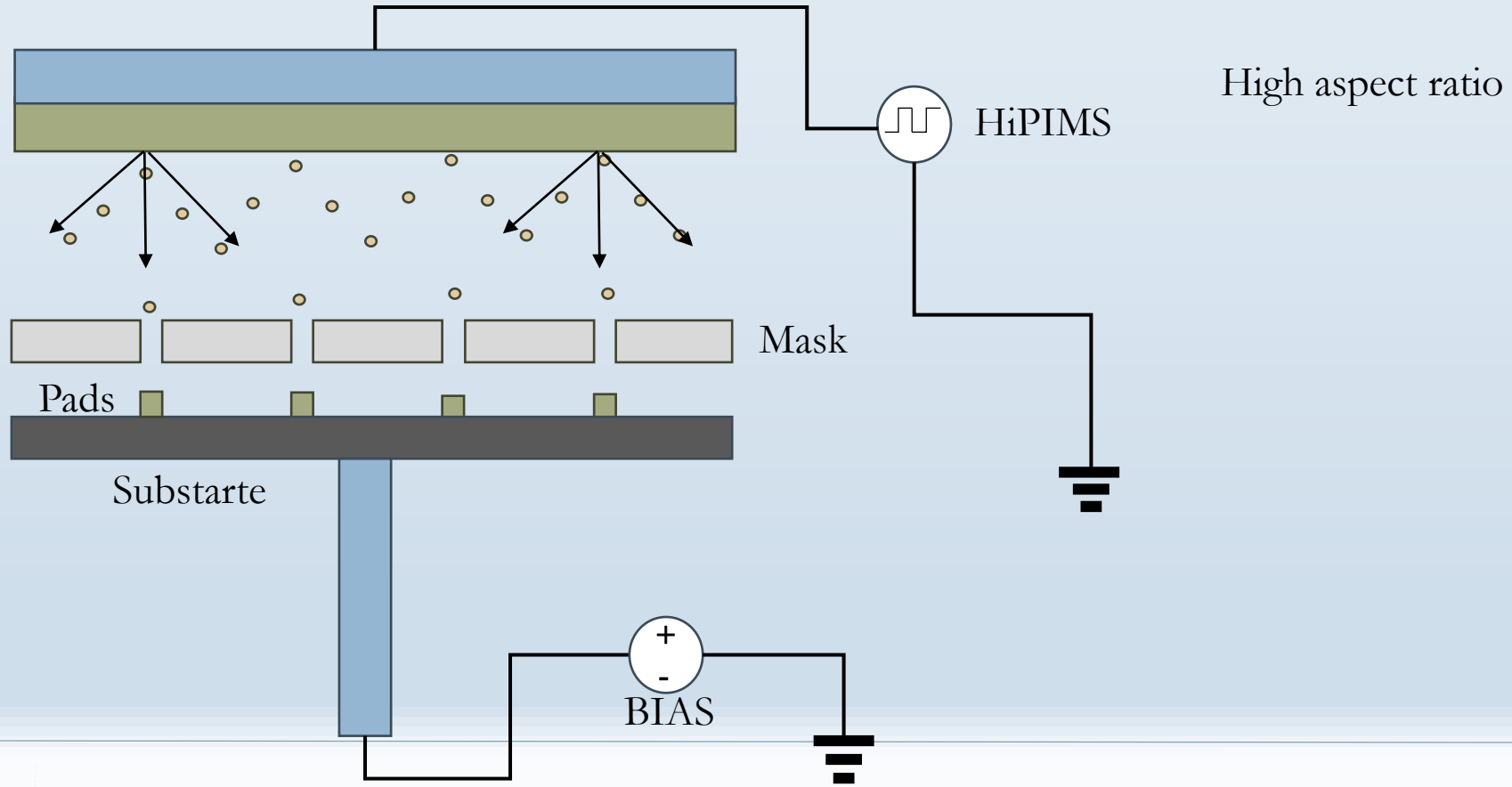




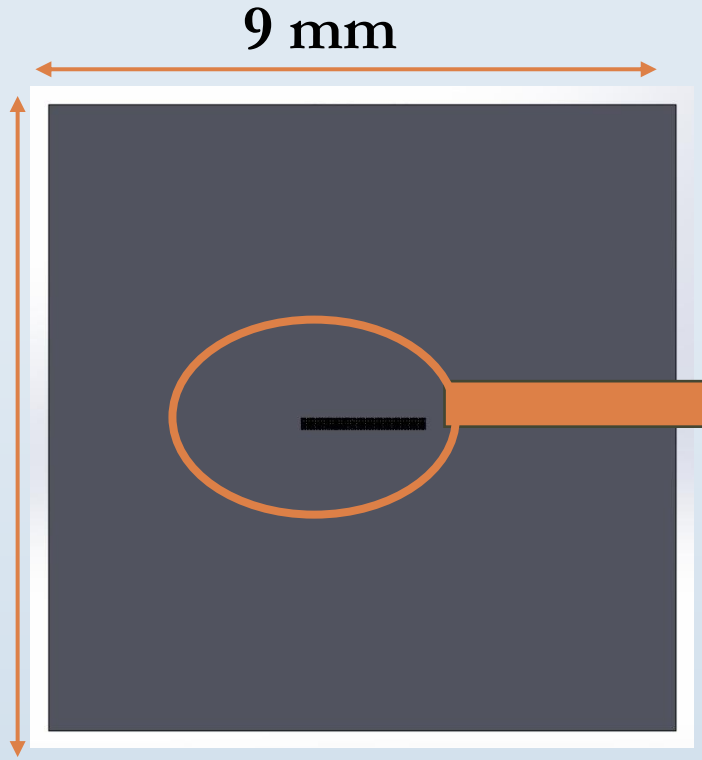
LASER mask process

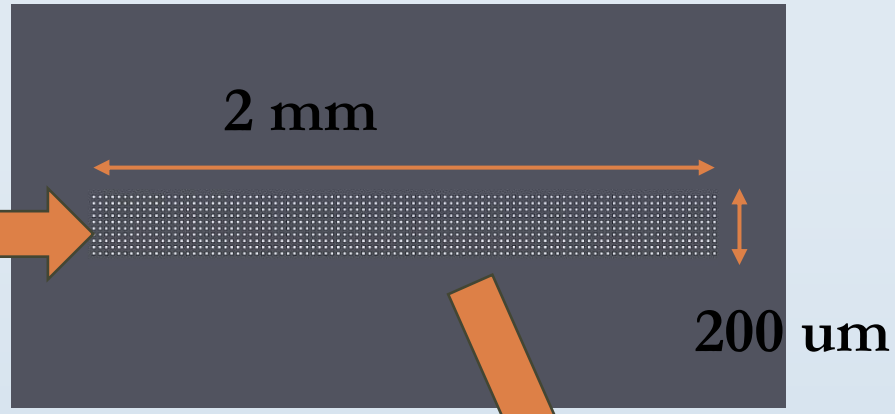
Physical Mask for phonon trap fabrication

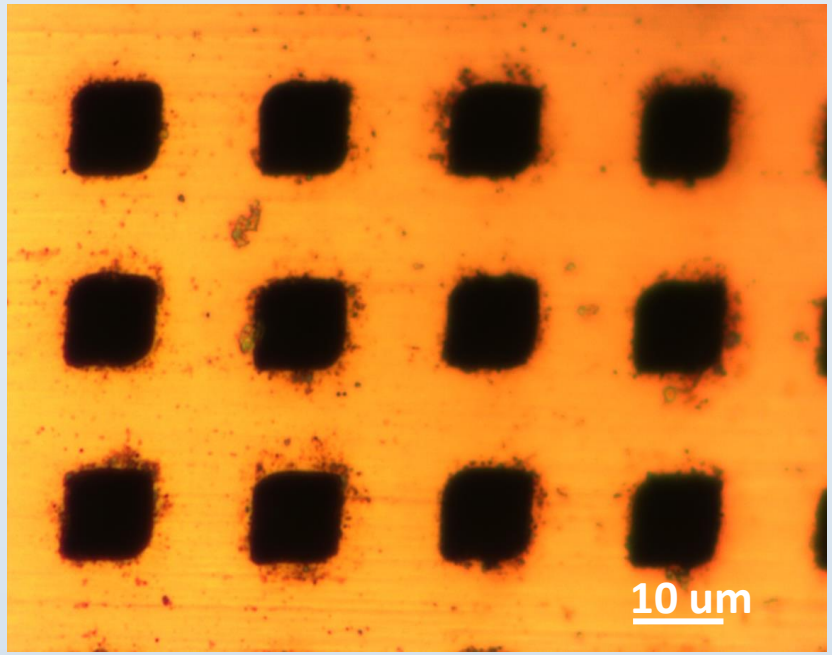
An alternative phonon trap fabrication way has been investigated starting from a stainless steel foil (with a thickness around 50 um) **LASER processed with microholes** with the same dimension phonon pads. The idea is the use the **high aspect ratio** depositions characteristic of the HiPIMS combined with the possibility of micromachining using laser technology

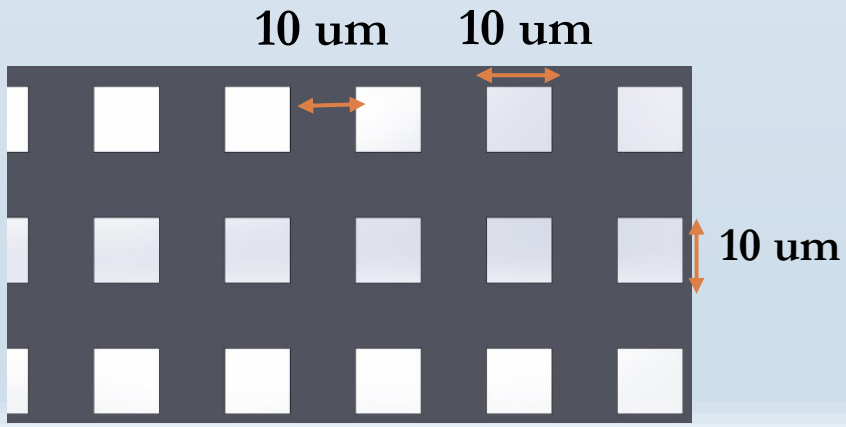


Physical Mask for phonon trap fabrication : Design mask for LASER process



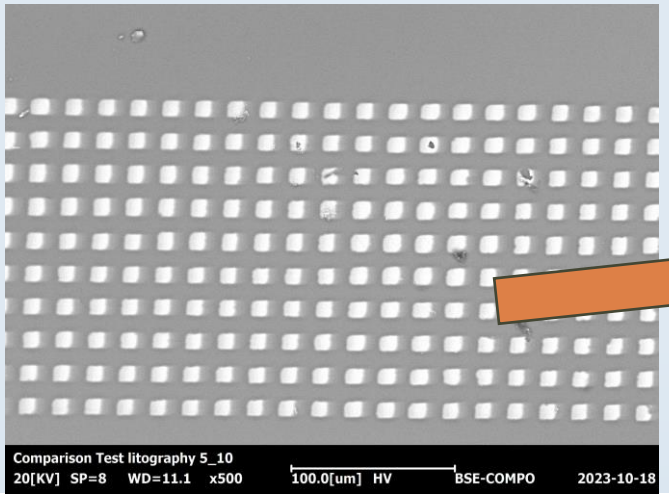


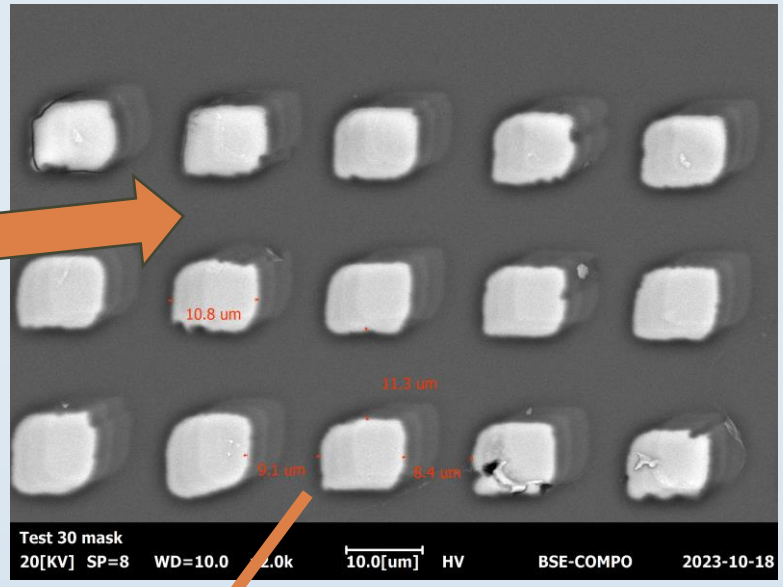




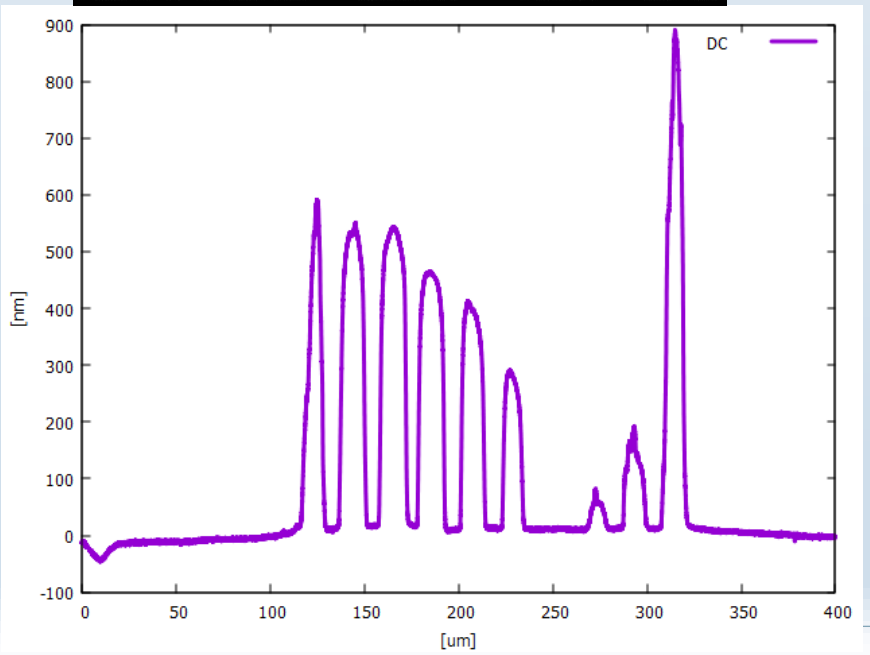
- Thickness 50 um of stainless steel

SEM and profilometer characterisation





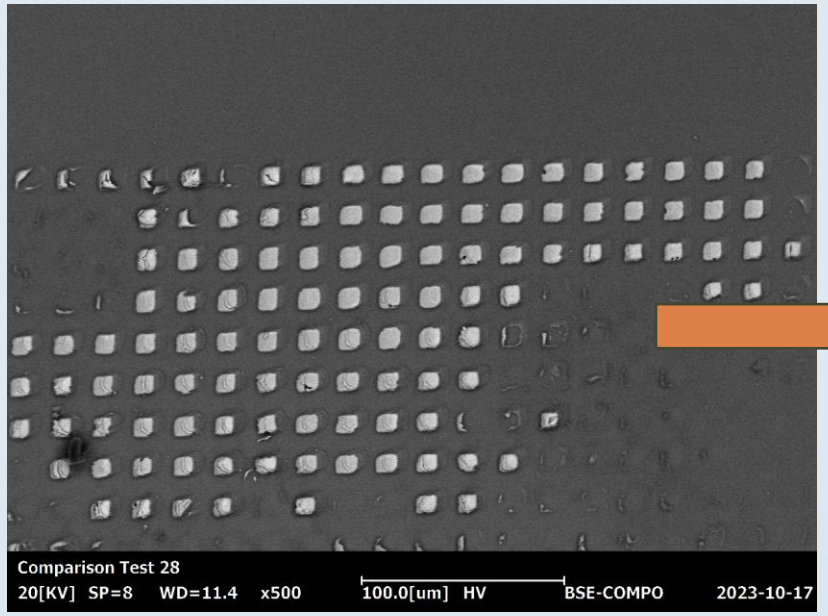
Mask sample holder



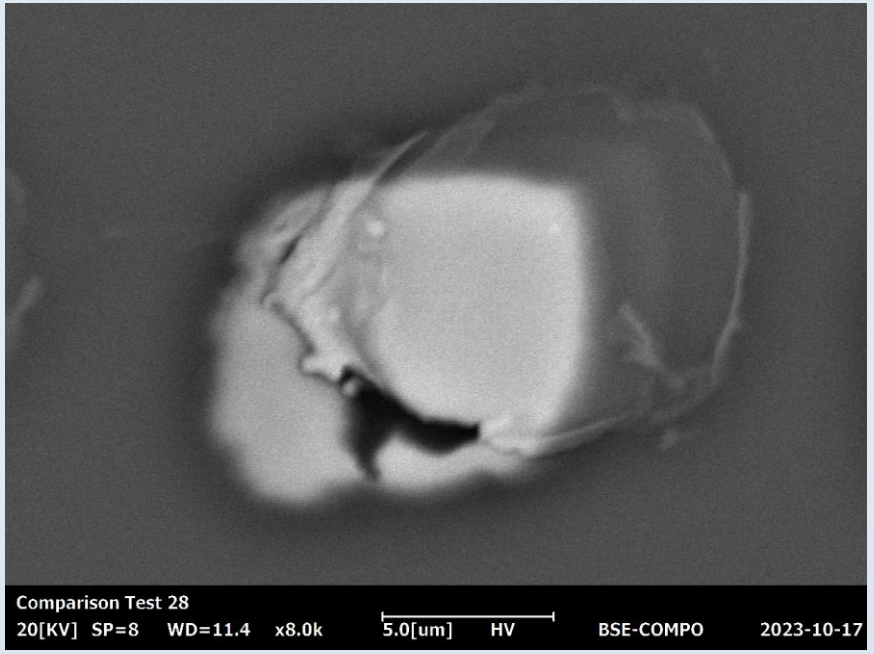
Profilometry

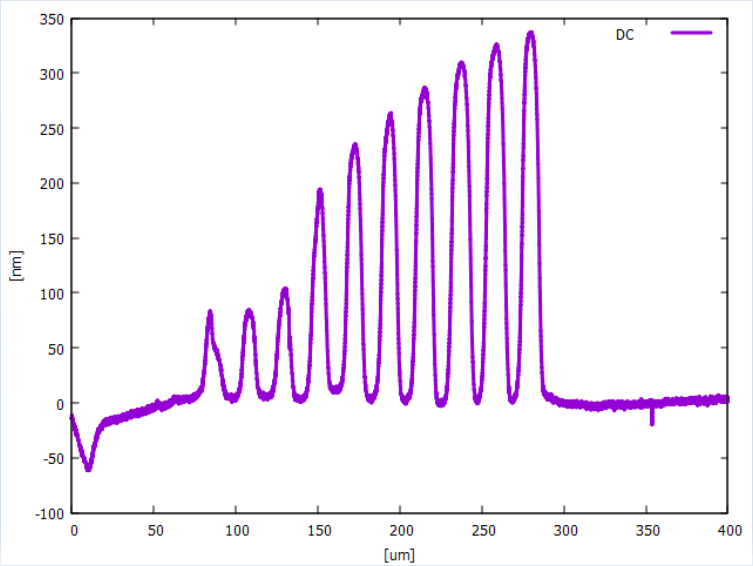
Shadowing effect on deposition

Mask over the substrate



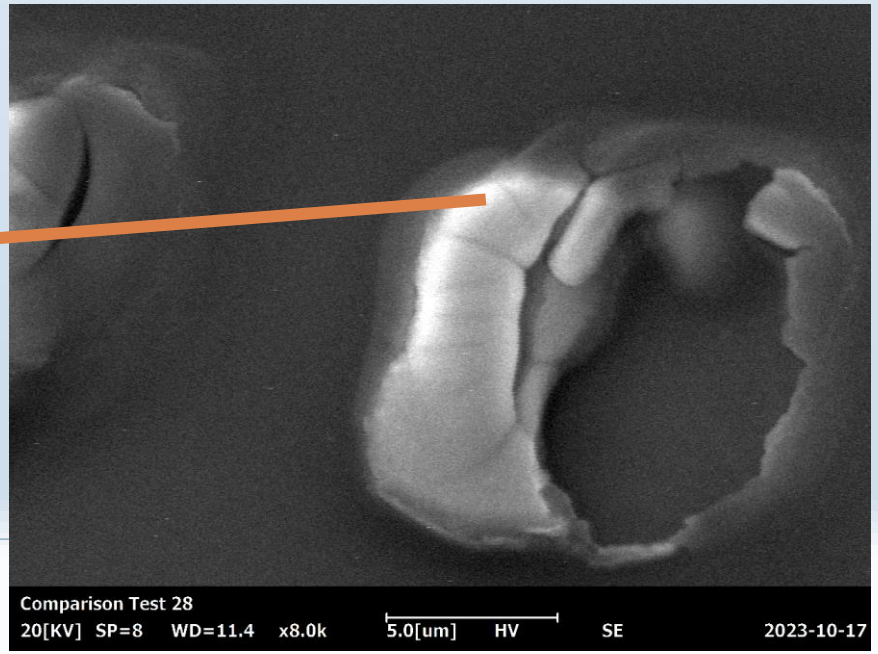
Some pads have poor adhesion





Profilometric characterisation revealed that the shape of the pads is smooth.

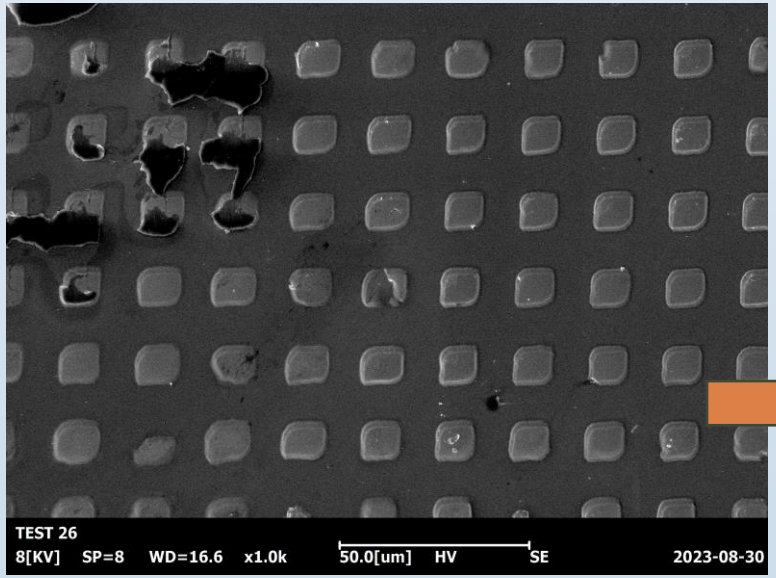
Edge film growing

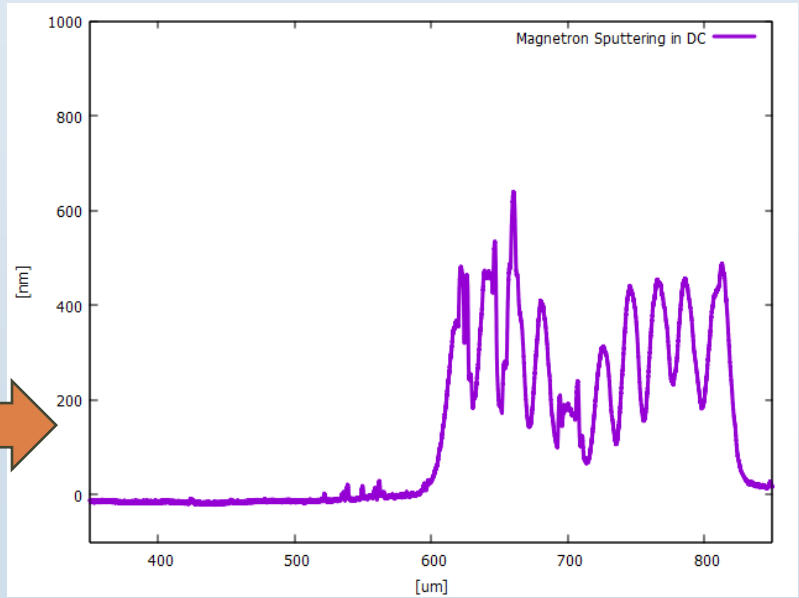


Comparison test using magnetron sputtering techniques

Same parameters, same power in DC and without bias

Decreased Shape-factor





LASER mask process

Advantages:

- Pure materials non organics material are introduced in the deposition
- it is possible to use many times the same mask

Disadvantages:

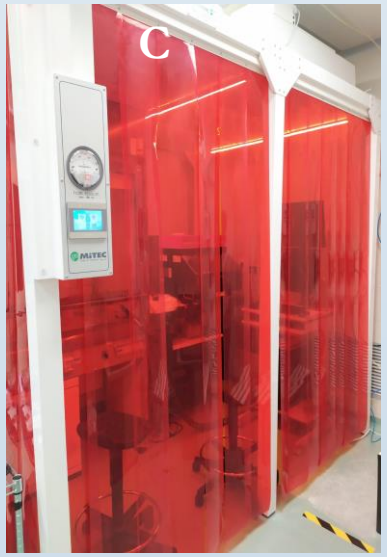
- Limited by dimension of the laser cut (lowest round 10 um)
- Adhesion and shape of the pads are still to be improved
- The mask has to be cleaned after each deposition
- Not easy to handle

Photolithography fabrication

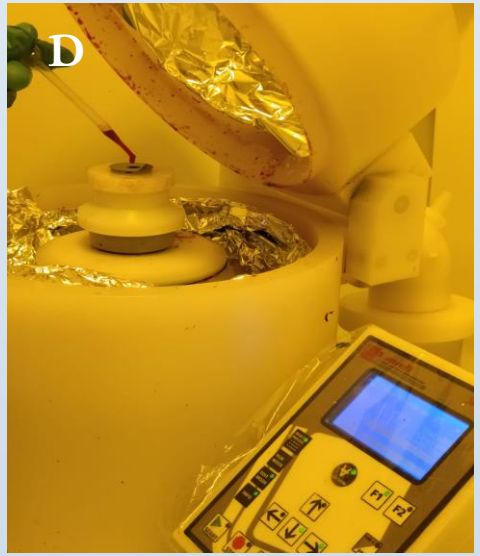
Photolithographic fabrication step

A. Cleaning step (alcohol+acetone and nitrogen flow).
B. Plasma oxygen cleaning (20 sccm O2 at 0.8 mbar)
C. Removal of organic matter Clean room processing ISO 05
D. Spin coating +resist AZ-1505
E. Heating 100 °C 5 min
F. Lithography (lithographic machine based on high-speed direct write without using mask (resolution of few um).)
G. Deposition step HiPIMS (With the same parameters)
H. Treatment with specific removal for photoresists

Plasma Oxygen cleaning



Clean Room ISO 05



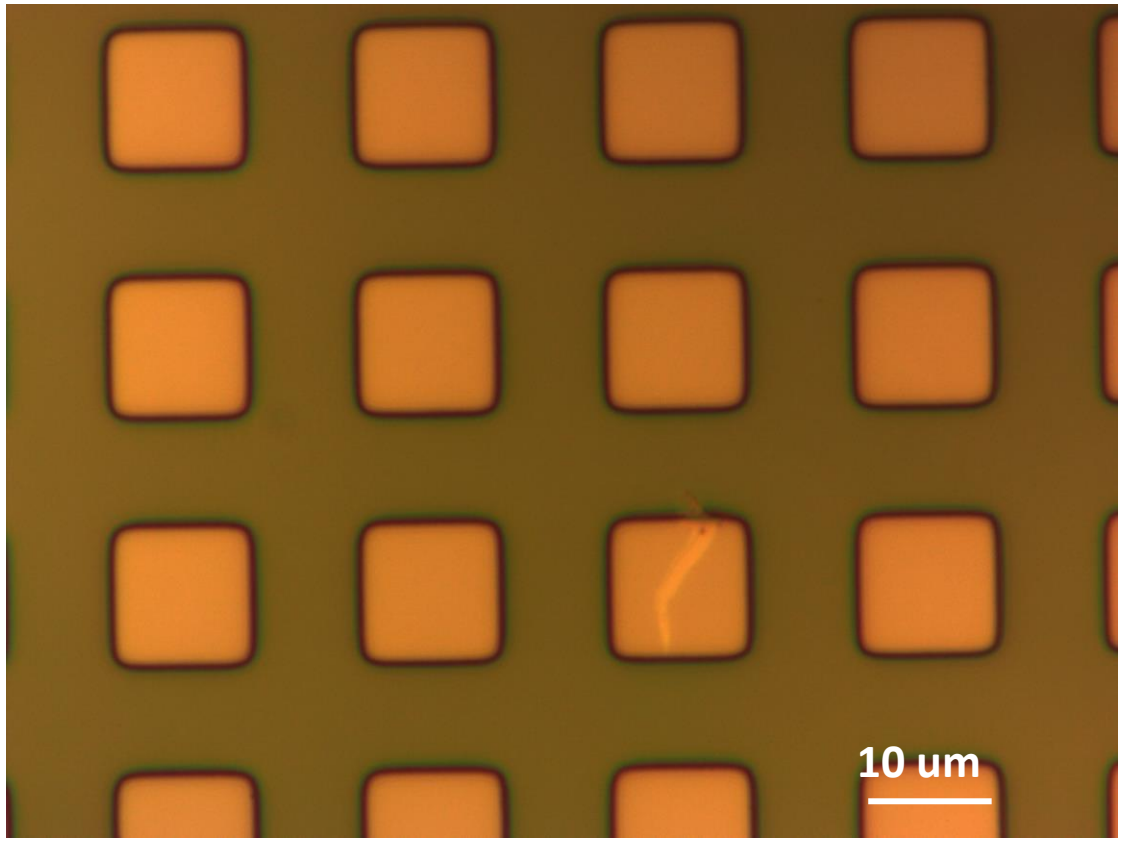
Spin coating

Lithographic machine

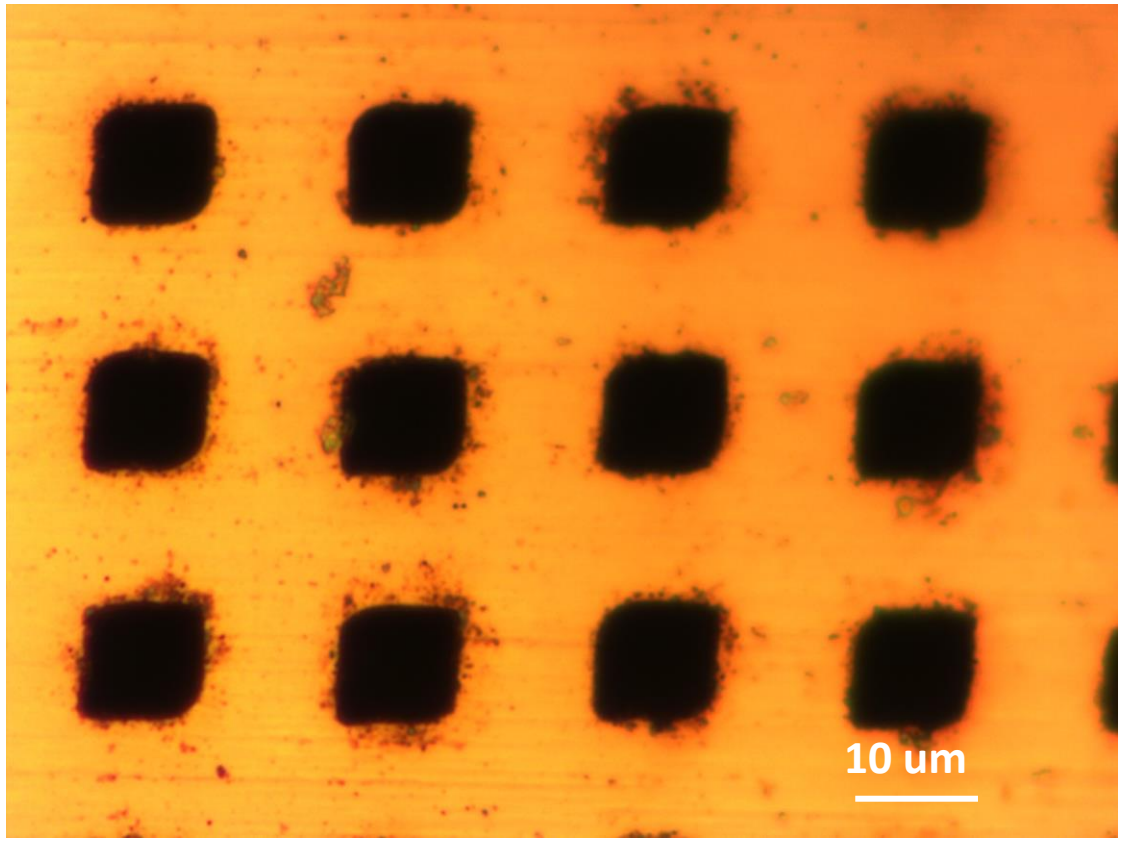
Deposition

Lift-off

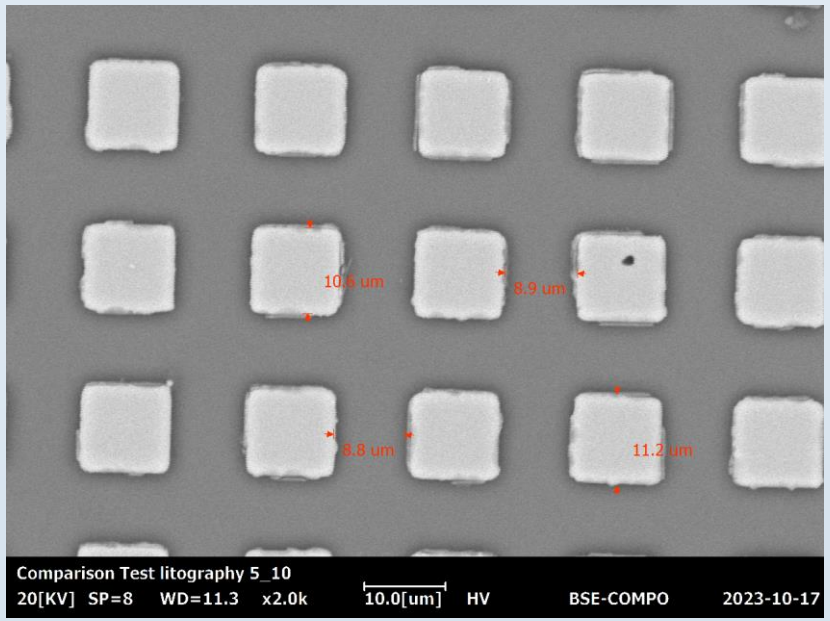
Photolithography fabrication

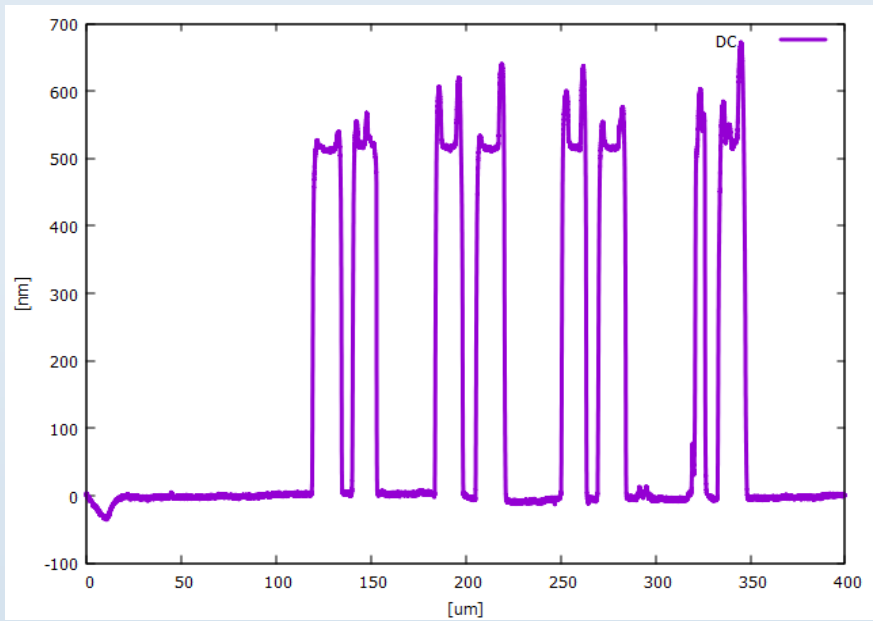


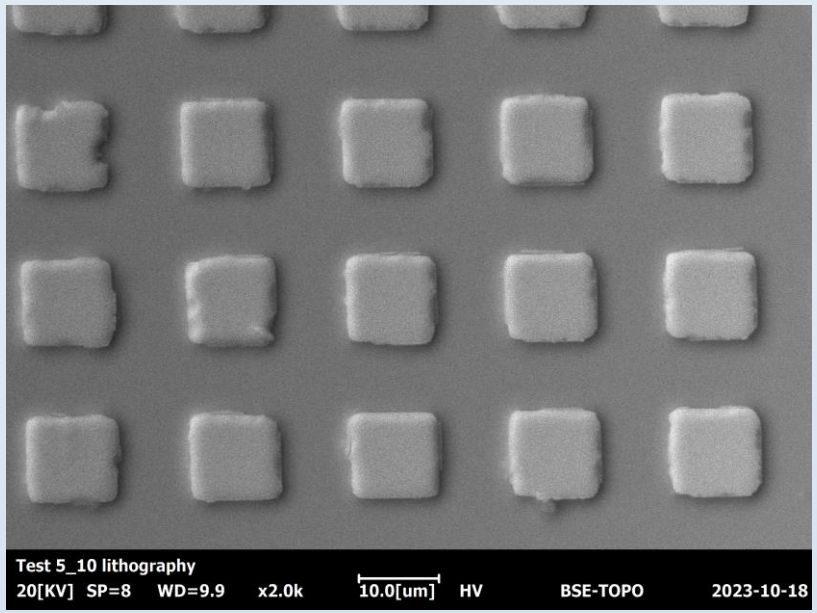
LASER mask process



SEM and profilometer characterisation







- The **lift off step** has to be improved in order to avoid defects (Can affect the phonon trap behaviours?) on the surface pads and holes
- An **higher aspect** ratio is reached in comparison with physical mask techniques
- Generally seems to be much reproducible but **more step** are required and we are not equipped at INFN LNL with lithography technology

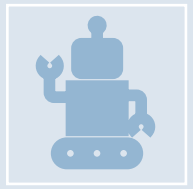
Future Works …

Tc characterization on a sapphire substrate:

1)Sample HiPIMS 1 um

2)Sample HiPIMS 100 nm

3)Sample MS 1um



Optimization photolithography process (also with physical mask?)

Best geometry (pads dimension and thickness) so that increase the phonon trap efficiency

Other materials ?

Testing on a resonator