MEMS made in a Small Scale Research Lab – Opportunities for Functional Targets

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TECHNISCHE UNIVERSITÄT DARMSTADT

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Institut für Elektromechanische Konstruktionen EMK

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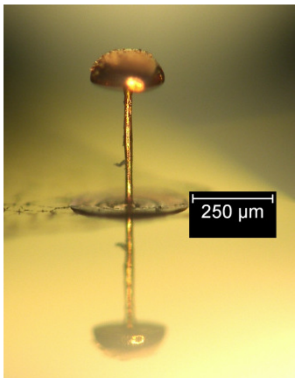

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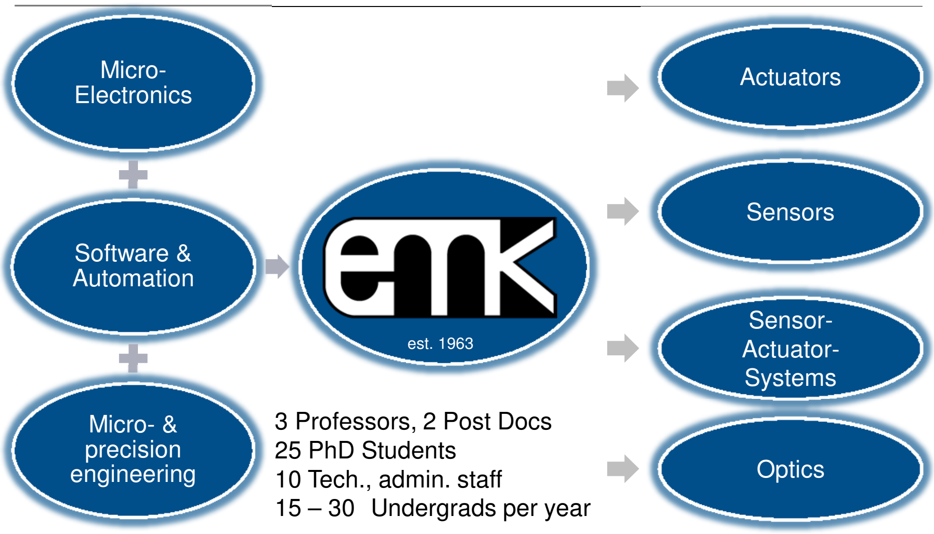

3 Professors, 2 Post Docs
25 PhD Students
10 Tech., admin. staff
15 – 30 Undergrads per year

Cleanroom Laboratory for Microtechnology

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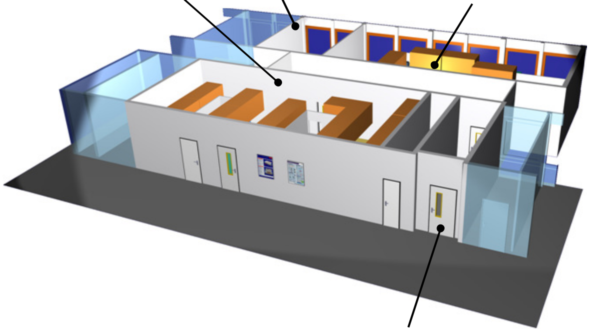
Clean room classification

1.000 - 100 within the laminar airflow boxes

Functionality

- about 60 m² for photolithography, wet etching, electroplating
- about 60 m² for packaging, surface coating, measurement



http://www.emk.tu-darmstadt.de/en/institute/equipment/

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Technology Overview
Substrate Pretreatment

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Sputtering

Alcatel
- DC/ HF Sputtering with RF-Bias
- 4 Cathodes
- Al, Cr, Cu, SiO_2
- Deposition Rates up to 1000 nm/min
- Vacuum Prechamber

Vapour Deposition

Balzers BAK 600
- Electron Beam and Resistance Evaporator
- Al, Cu, Cr, Ni, Ag, Ti, Au, Al_2O_3
- Thickness Controll through Quartz Resonator

Polishing Machine

Logitech PM5
- Precision Polishing Jig with vacuum adapter
- Up to 4“ wafer
- Plate Speed: 0-70 rpm
- Chemical Mechanical Polishing option

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Technology Overview
UV-Lithography I

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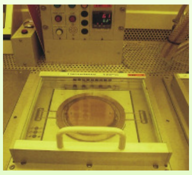
Spin Coater

SÜSS Delta 80 BM
- Rotating Lid
- Up to 4000 rpm

SÜSS LabSpin 6
- Up to 8000 rpm

Photo Resists
- SU-8 2000/3000
- AZ 9260
- AZ 15, 125 (n)XT

Hotplates



2x Hotplate 400
- Programmable Single Plate
- Up to 130 °C

3x GESTIGKEIT PR 5-3T
- Programmable Double Plate
- Up to 300 °C

IR Oven

FH Zwickau
- IR dry system for photoresist
- Up to 6“ wafer
- Max. heat 130 °C
- Maximum substrate weight 150 g

Technology Overview
UV-Lithography II

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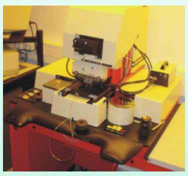
Mask Aligner



SÜSS MA 56 M
- 350 W UV-Lamp
- Up to 4“ Masks
- Manual Alignment
- Up to 20 mW/cm²
- Process Monitoring

Filters
- g, h, i - Line
- g, h - Line
- i - Line

Developer

Sonosys 500
- Frequency 1 MHz
- Power 50 - 500 W

Multi-Bio-3D
- Orbital Shaker

Developer
- mr-Dev 600
- MIF 326, 826
- AZ 400k

Technology Overview

Micro- and Nano Electroplating

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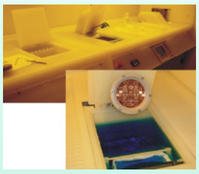
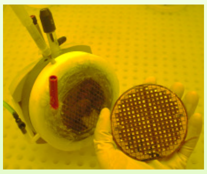
Micro Electroplating



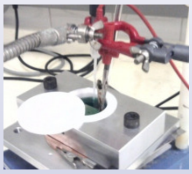
M-O-T µGalv
- Additive free Electrolytes
- Nickel (pH 4), Copper (acid)
- Currents up to 10 A
- Puls-Plating Option
- Plating rate up to 4 µm/min

Micro & Nano Electroplating



silicet trio clip
- 3 electrodes cell for 4“ wafer
- Ion membrane for use with additives
- 1 µA - 3 A reverse pulse plating to extend to 100 kHz
- 2 l volume with particle filter

Nano Electroplating



Nano Electroplating Cell
- Potentiostatic and Galvanostatic Plating
- Pulse- & Reverse-Puls-Plating up to 100 kHz
- Currents down to several nA

Technology Overview

Plasma Activation & Etching

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Isotrop Etching

Muegge STP 2020
- Remote Downstream Plasma Reactor for Polymer Etching (e.g. SU-8, BCB)
- O_2, CF_4, N_2
- RF-Power: 3000 W at 13,56 MHz

Anisotrop Etching

Plasma Technology RIE80
- Parallel Plate Reactor for Substrate Cleaning and Polymer Etching
- O_2, CF_4, N_2
- RF-Power: 300 W at 13,56 MHz

Surface Activation

Technics 300-E Plasma
- Barrel Reactor for Substrate Cleaning and Surface Activation
- O_2, CF_4, N_2
- RF-Power: 300 W at 13,56 MHz

Wet Etching Machine

BUNGARD, Splash Center
- Etching medium: Fe-III-Cl
- Line definition: 100 µm
- Max. board size: 210 x 300 mm

Technology Overview
Packaging Technologies

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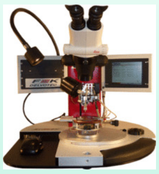
Wire Bonder

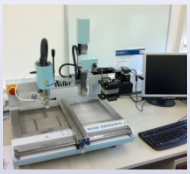


F&K Delvotek 53xx-BDA Bonder
- Ball Bonding down to 18 µm gold wire
- Deep access wedge bonding
- Automated y-axis for automated loops

Micro Assembly

Arteos TOMM 1
- Pic and placer
- Plate- and air-heater
- UV-curing
- Micro-dispenser
- Vacuum chuck

Pick and Place



Cooper Hand Tools WQB 4000SOPS
- Operating range 630 x 630 mm²
- Soldering temperature 50 - 400 ℃
- Down to smallest package sizes

Vacuum Furnace

Heraeus, Nabertherm & Co
- Vacuum option
- Protective gas option e.g. N
- Temperature profile option
- High temperatures up to 1100 ℃

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Technology Overview
Optical Inspection & Characterization

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Thermography

FLIR SC655
- 640 x 480 Pixel
- -20℃ to +150℃
  0℃ to 650℃
- Sensitivity: <0.05℃ @ +30℃

Optical Inspection

Keyence VHX-600
- 3CCD Camera
- 54 Mio Pixel
- Magnification up to 1000x
- 3D Measurement Option
- Measurements of Structural Widths

Laser Vibrometer

Polytec OFV 2502
- 2 sensor heads (OFV 534)
- Velocity demodulation
- 1.5 MHz

Polytec OFV 3001
- Velocity demodulation 0.3 µm/s…10 m/s

High Speed Camera

Mikro GmbH
- 1280x1024 pixel
- 502 fps
- 55 min recordtime

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Technology Overview
Electro Mechanical Characterization I

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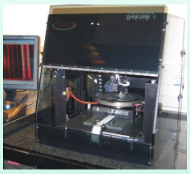
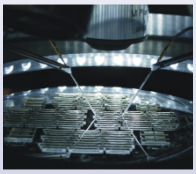
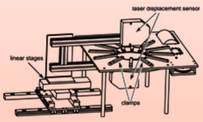
Surface Profiler	Bond Shear Tester	Motion-Analyzer	EAP Characterization
			
DEKTAK 8 Profiler ▪ Measurement of Layer Thickness and Surface Profile ▪ Range from 10 nm up to 1 mm ▪ Stylus Force up to 0,09 mg	**dage Microtester 22** ▪ Testing strength of solder joints, wire bonds and more ▪ Stitch Test Failure Detection ▪ 20 gm & 10 kg Load ▪ Resolution +/- 0,5% of load	**MEMS-Analyzer** ▪ 2048 x 2048 Pixel ▪ 15 fps, 800 MBit/s ▪ Repeatability < 30 nm ▪ Force Measure-ments up to 1 N ▪ Field of View up to 11,7 x 11,7 mm²	**EAP-Analyzer** ▪ Static / dynamic deflection (line scan) ▪ Frequency response ▪ Preload simulation ▪ Sheet resistance ▪ Force-displacement

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Technology Overview
Electro Mechanical Characterization II

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High-Pressure Static Tester	High-Pressure Dynamic Tester
	
COP-7000 ▪ 500 MPa=5000 bar ▪ silicon oil ▪ Room temperature **Pressure sensor** ▪ P3MBP 5000 bar (HBM) **Piston gauge** ▪ 5ppm @ 5 000 bar ▪ 1 kg / 50 bar	**MAXIMATOR** ▪ up to 1000 bar ▪ Periodic load at 0.1 Hz to 20 Hz ▪ Curve shape rectangular, trapezoid or sinus ▪ 4 pressure connectors

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Technology Overview
Electrical Measurement Equipment

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Signal Conditioning	Impedance Analysis	DAQ-Systems	Peripherals
			
Stanford Research SR 560 ▪ low-noise preamplifier ▪ battery operating option **Krohn-Hite 3382** ▪ programmable dual-channel filter ▪ 0.1 Hz – 200 kHz ▪ Butterworth or Bessel response	**Agilent 35670A** ▪ dynamic signal analyzer ▪ 122 µHz - 102.4 kHz, 16-bit ▪ swept sine option ▪ GPIB **HP 4284 A** ▪ Precision LCR-Meter ▪ 20Hz – 1 MHz ▪ GPIB	**Data Acquisition** ▪ DMM, LCR-Meter ▪ Multi-Purpose DAQ (16 bit, 1,25 MSa) ▪ 8ch Bridge Input Module (24 bit, 25 kSa) **Universal Control** ▪ PXI, cRIO ▪ AI, AO, DIO, SPI, Bridge	**LeCroy WaveRunner 44Xi-A** ▪ 400 MHz, 5 GSa **Agilent DSOX3024A** ▪ 200 MHz, 4GSa **Hameg HMP4040** ▪ programmable power supply **Hameg HMF2525** ▪ 25 MHz Arbitrary Signal generator

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High AR Metal Pillars
UV Direct LIGA Processing

Si + SiO2 Cr Al
Cu SU-8 AZ 125nXT

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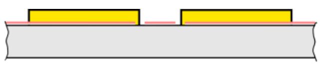
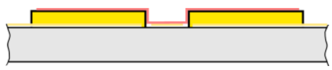
- Structured electrode layer: Cr + Cu 100 nm

- Sacrificial layer: SU-8 5 µm

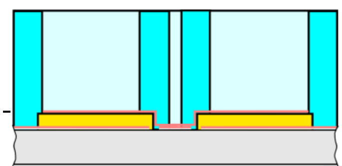


- Structured seed layer:
  Cu 200 nm + Al 20 nm



- Exposed photoresist, undeveloped:
  AZ125nXT 400 µm

$l_W = 400\ \mu m, d_W = 30$ -



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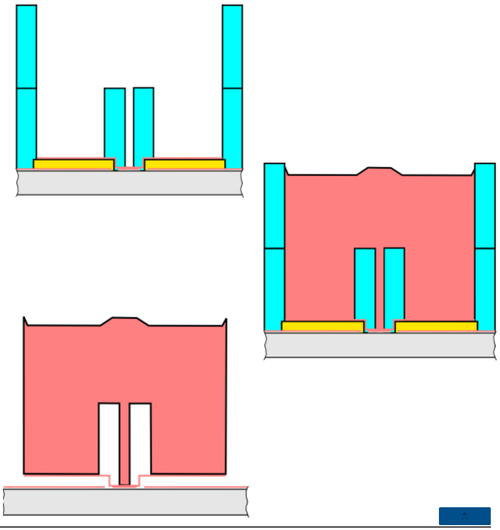
High AR Metal Pillars
UV Direct LIGA Processing

Si + SiO2 Cr Al
Cu SU-8 AZ 125nXT

- Structured mold for electroforming: AZ125nXT 2 x 400 µm
- Filled mold: 700 µm Cu
  - Current: DC, pulse, pulse reverse
  - Contacting: pillars and blocks grown simultaneously
- Stripping
  - Dry etching with reactive oxygen radicals (muegge/R3T)



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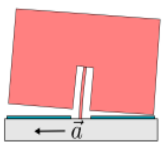
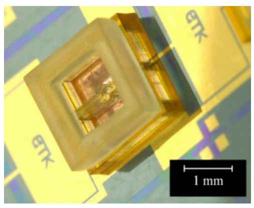
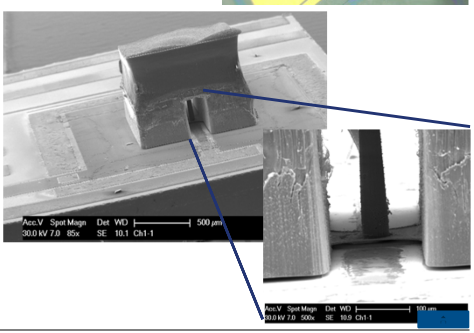
High Aspect Ratio (AR) Metal Pillars
for Minimal Footprint MEMS Suspension

- Inertial sensor
  - 1 device: 2 axes acceleration sensor and 1 axis gear rate sensor
  - Acceleration: seesaw
  - Gear rate: crosstalk due to Coriolis force





- Scale-bridging: wire diameter (d)
  - UV lithography: d = 40 µm, AR 10:1
  - XR lithography: d = 4 µm, AR 25:1
  - IT lithography: d = 400 nm, AR 75:1
- Focus on technology
  - Galvanoform with high Aspect Ratio and multiple layers
  - Electroplating with heterogenous AR



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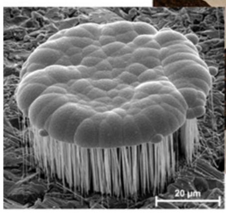
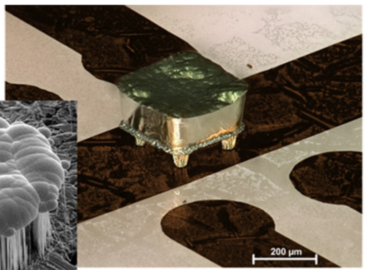
ELEMENT - Electromechanical Sensors Based on One-Dimensional Nanostructures

Development of an inertial sensor

- Use of high elastic nanowires with very high aspect ratio (500:1)
- Assembling nanowire-arrays (50 µm diameter) as spring elements
- Nanoscale enables the use of noble metals with excellent physical properties
- Detection of the inertial mass displacement using a magnetoresistive sensor principle



Platinum nanowire array, wire diameter: 150 nm



Nickel structure on vertical wire arrays

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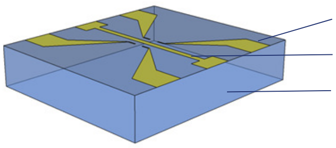
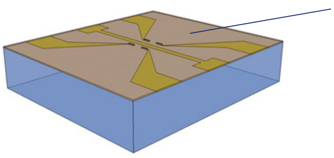
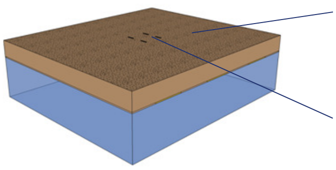
Process for batch nanowire integration in micro systems



- Structuring of heater and circuit paths for the nanowire arrays



- Application of a lamination film
- Structuring of holes for uncovering the seed layer



- Lamination of the ion track etched polymer template
- Electrodeposition into the pores until overgrowth

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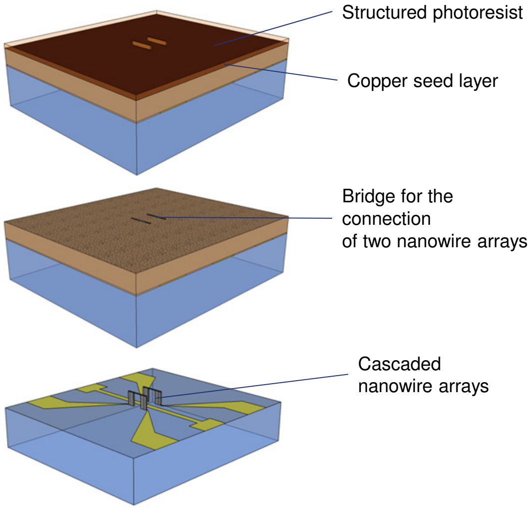
Process for batch nanowire integration in micro systems



- Application of the Cu seed layer
- Application and structuring of the photoresist that acts as a mold for the bridge
- Electroplating of the bridge

- Stripping of the photoresist
- Etching of the Cu seed layer

- Removal of the polymer template
- Removal of the lamination film

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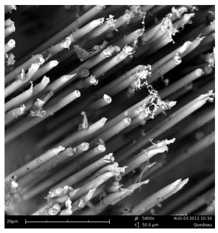
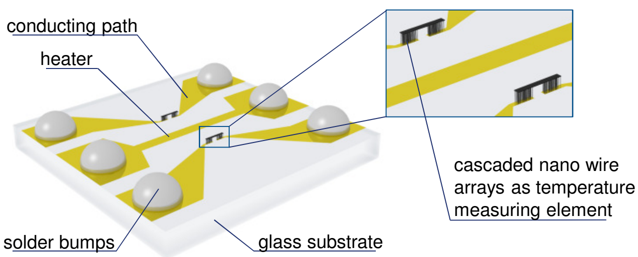
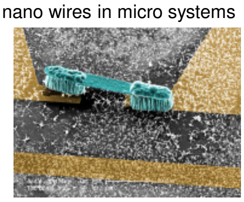
3-DOING – 3-Dimensionale Mikro-Nano-Integration für die Gasflusssensorik

- Funded Project by BMBF, VDI/VDE-IT
- Duration: 01/2011 – 12/2013
- Development of a gas flow sensor which uses metallic nano wires as sensitive elements
- Improvement of the measurement perfomance, especially for photoacoustic devices



Integration of metallic nano wires in micro systems





cascaded nano wire arrays

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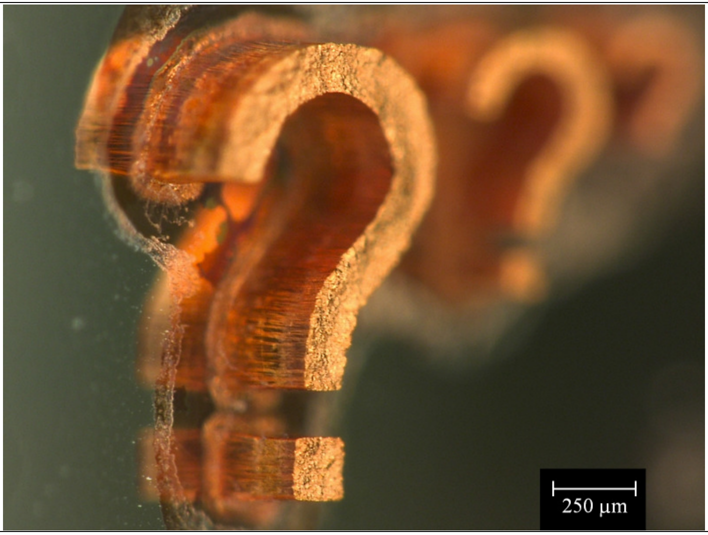
Questions?



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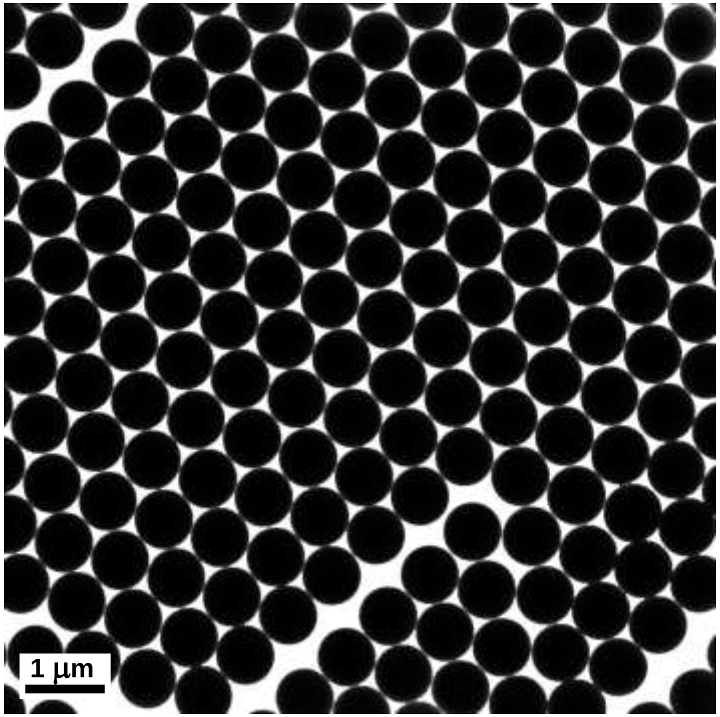
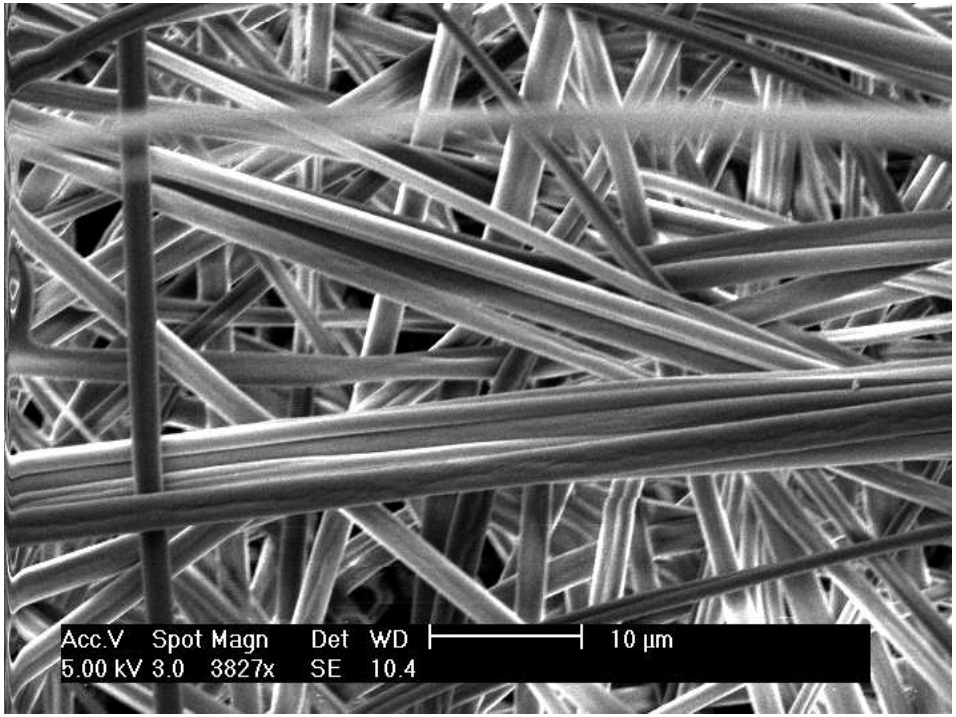
FROM MONODISPERSE BEADS & FIBRES TO MICRO & NANO STRUCTURES

C.G. Schäfer and G.P. Hellmann

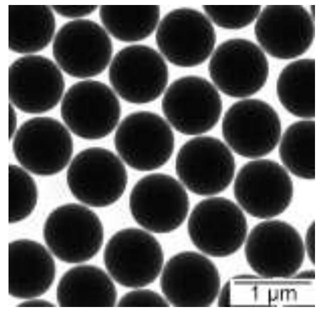
4th Target Fabrication Workshop 2012

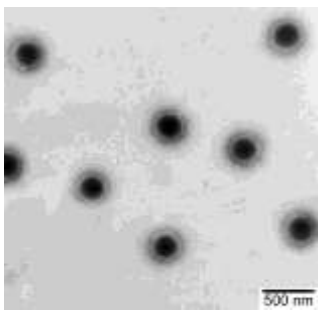


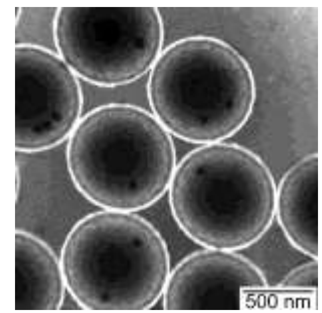


Fraunhofer LBF

MONODISPERSE BEADS



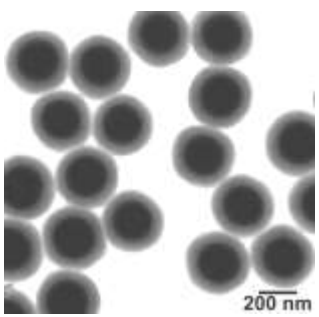


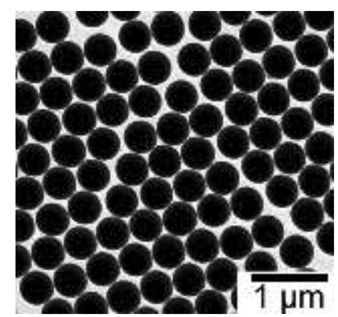


polymer

polymer-polymer

polymer-silica





20nm-2µm

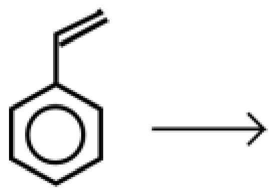
silica-polymer

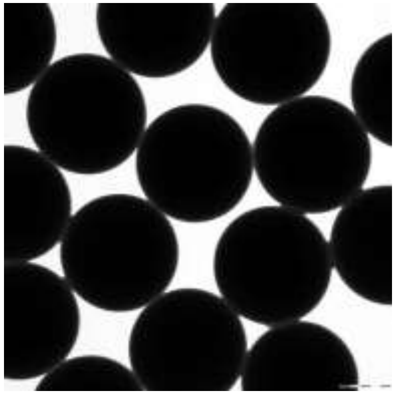
silica

Fraunhofer LBF

Polymer Beads
Synthesis

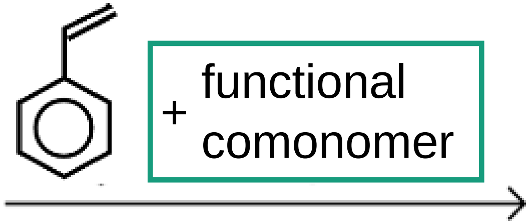
emulsion polymerisation

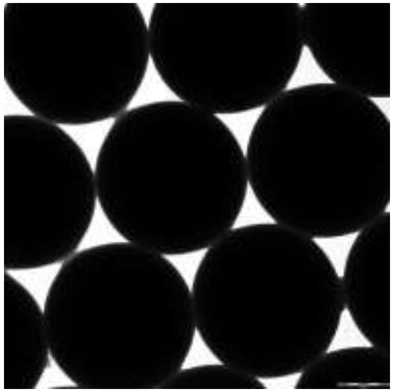




beads
50-500nm

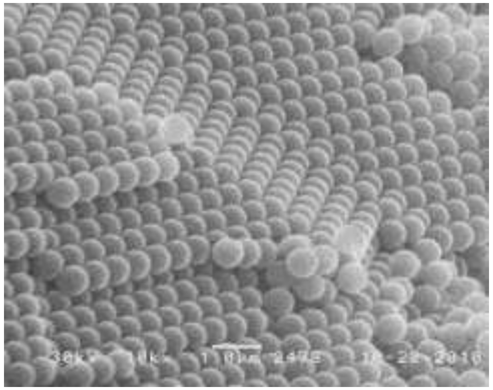
growing/swelling

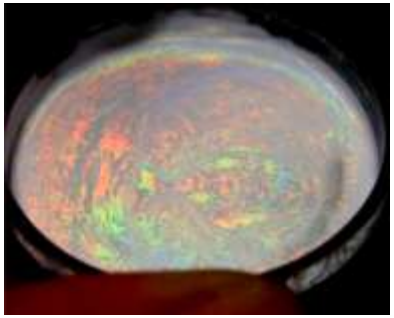




beads
100-2000nm

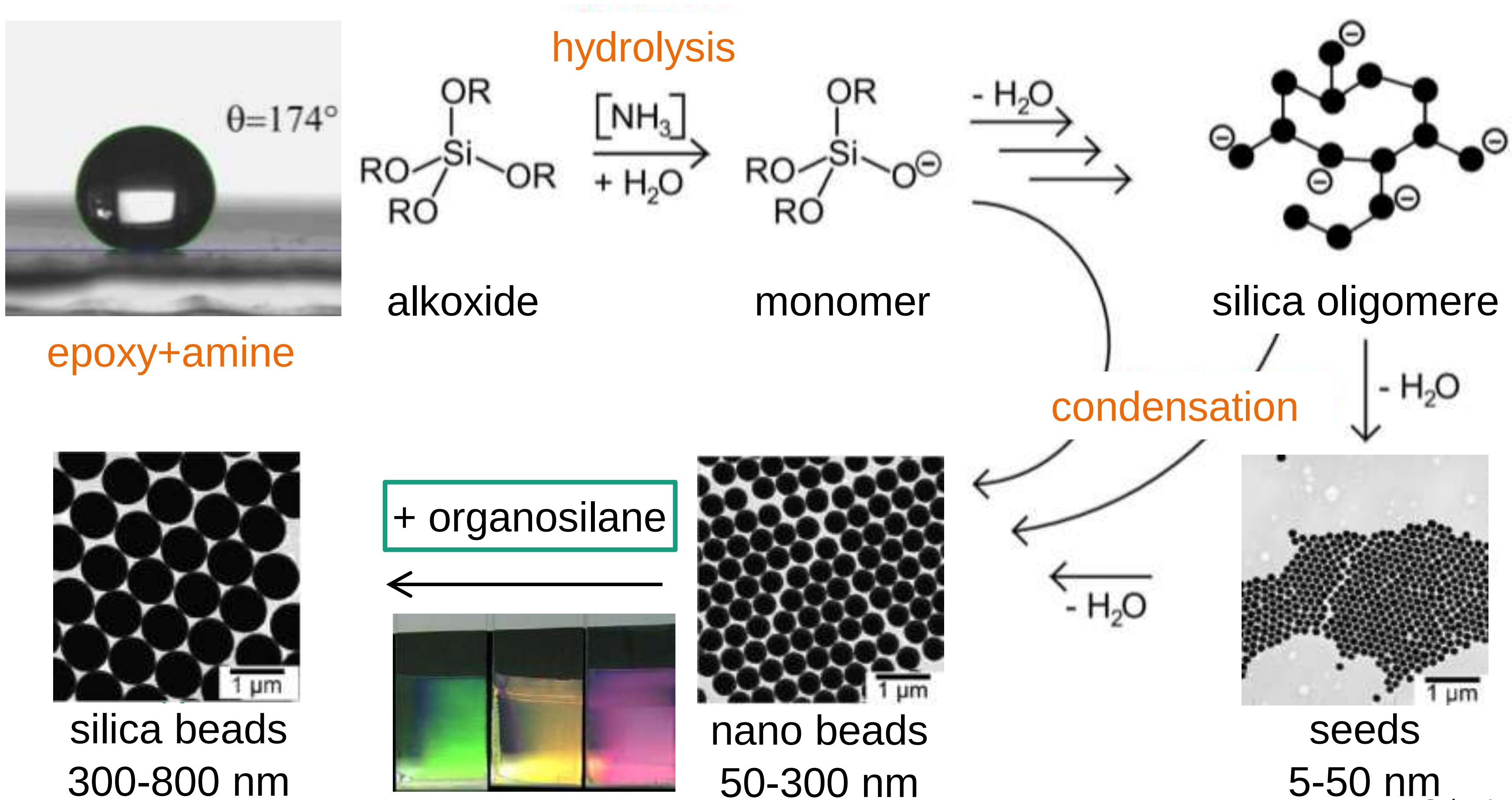
beads from acrylates+styrenes by various techniques:
emulsion, emulsifierfree, mini-/microemulsion and swelling polymerisation





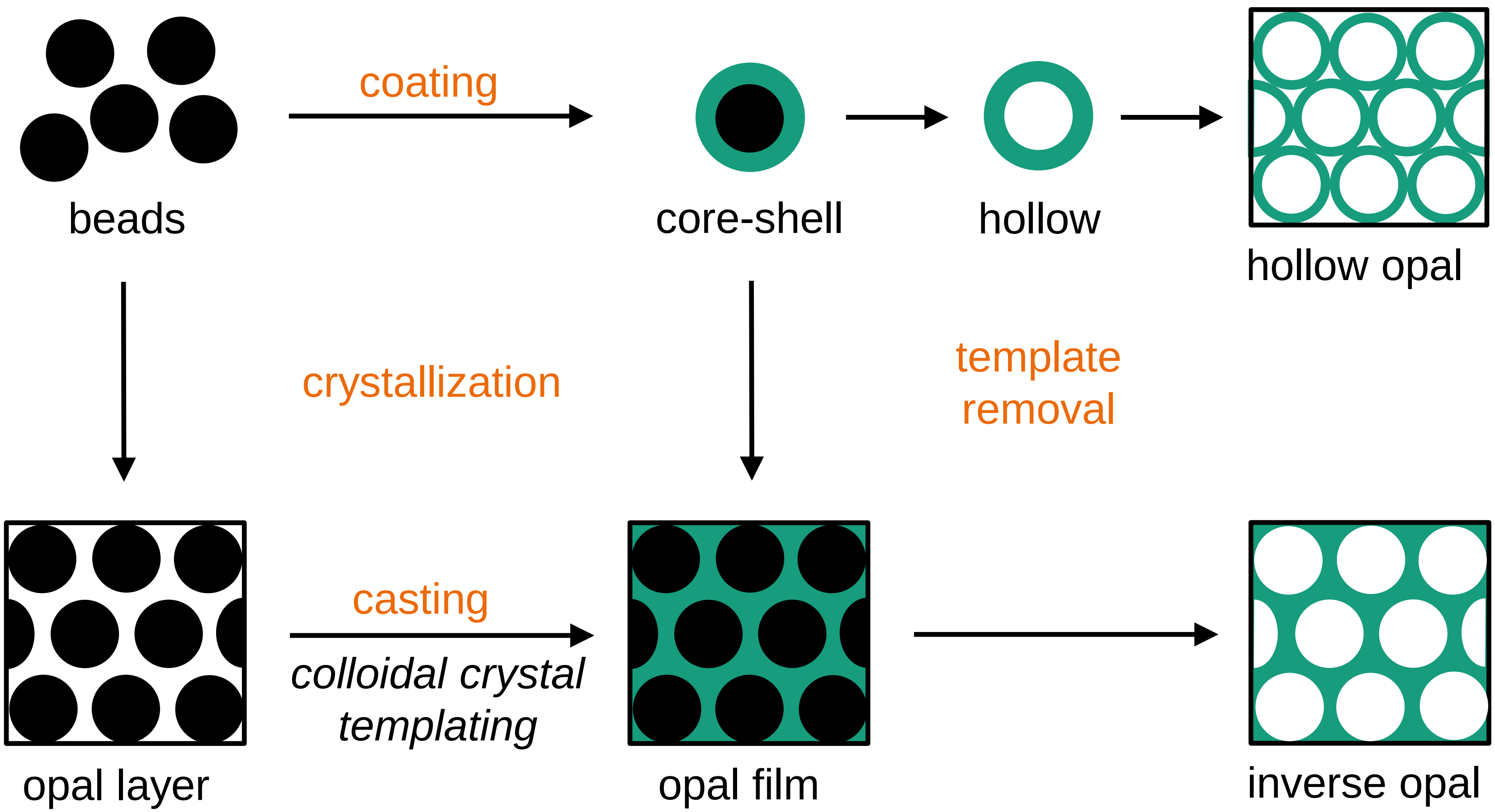
Fraunhofer LBF

Silica Beads
Stöber Process



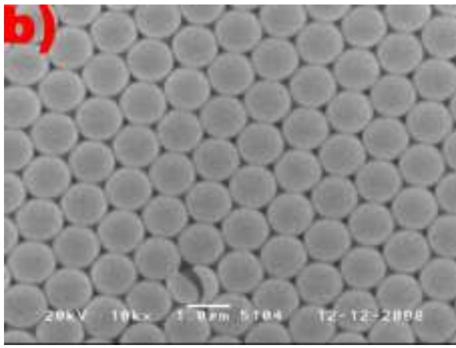
Fraunhofer
LBF

Strategies to Structured Materials
Coating, Casting, Colloidal Crystal Templating

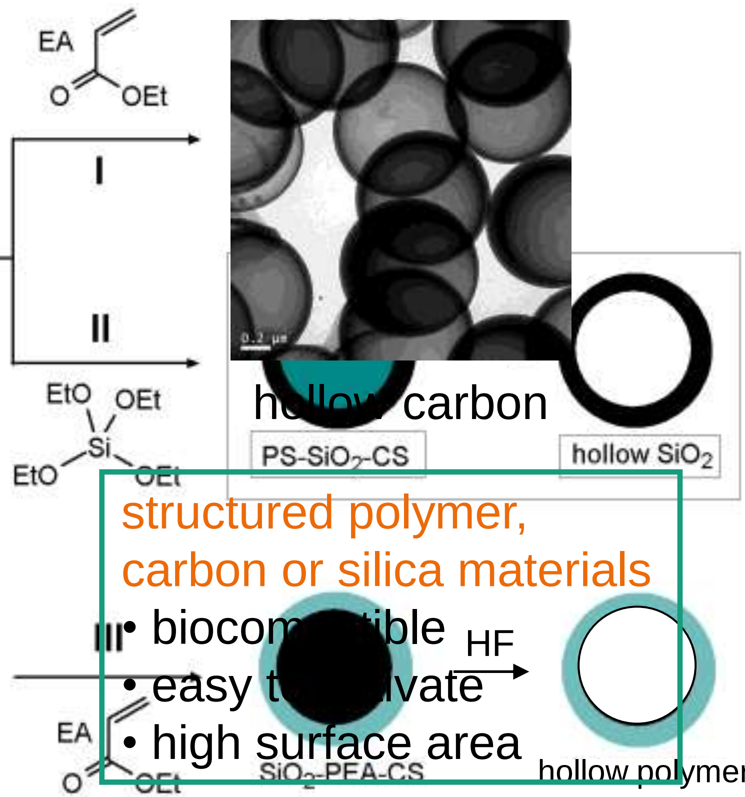


Fraunhofer LBF

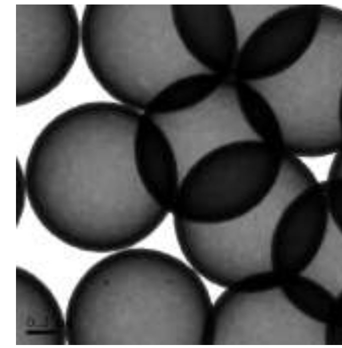
Coating
Hybrid Particles and Hollow Spheres



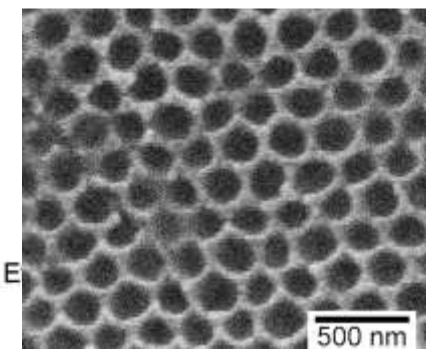
hollow opal



hollow carbon



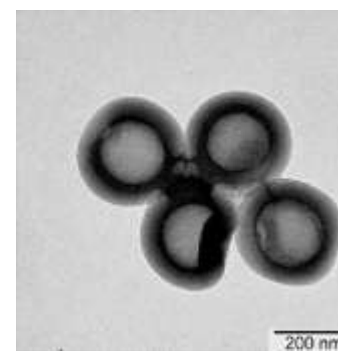
hollow silica



polymer inverse opal

structured polymer, carbon or silica materials

- biocompatible
- easy to activate
- high surface area

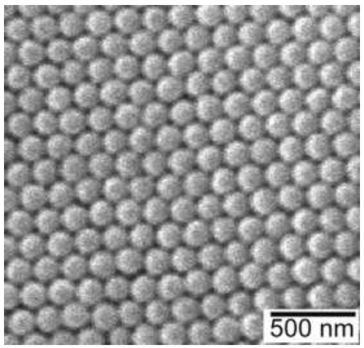


hollow polymer

Fraunhofer LBF

Casting and Colloidal Crystal Templating

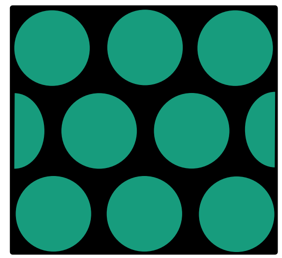
Inverse Opals and Double Opals



polymer opal

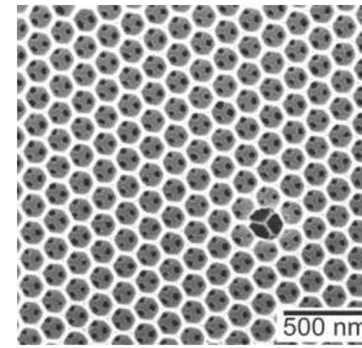
infiltration

sol-gel solution

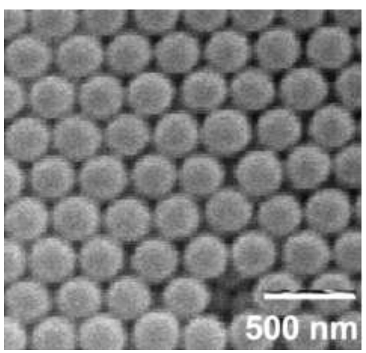


opal film

calcination



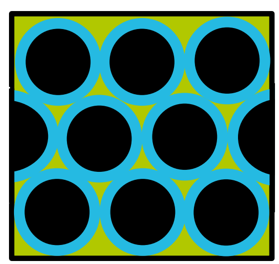
inverse opal



silica-polymer

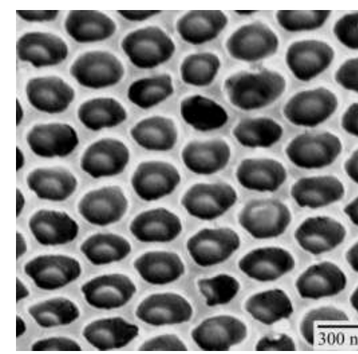
infiltration

sol-gel solution



opal film

calcination

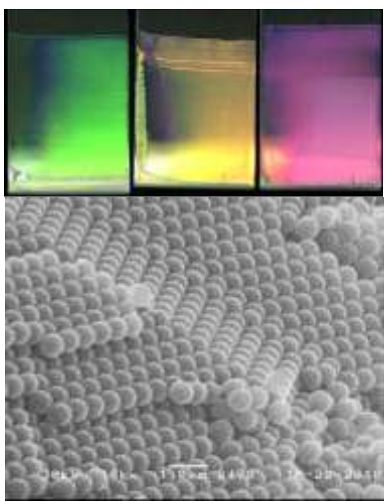


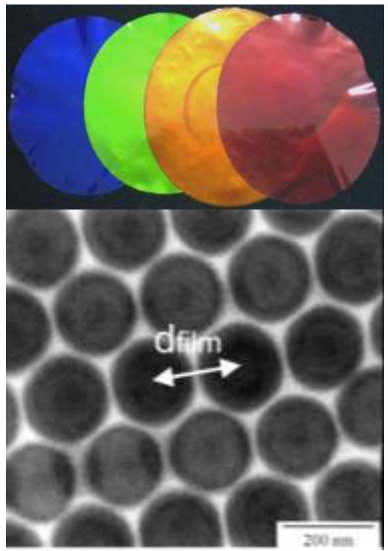
double opal

Fraunhofer LBF

Structured Materials
Colloidal Crystals

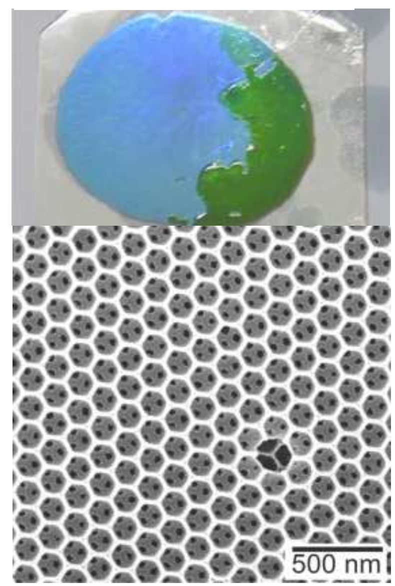
opal layers:
- silica
- polymer
- polymer-silica
- silica-polymer
- hollow silica

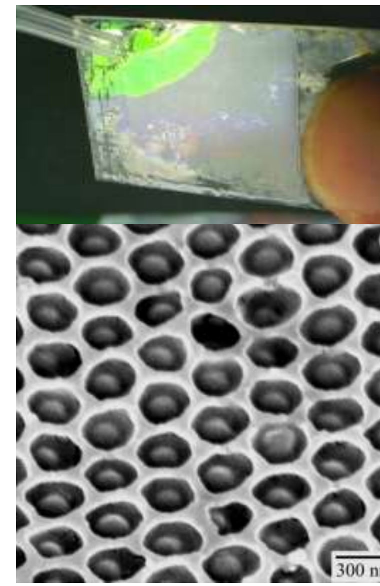




opal films:
- silica-polymer
- polymer CS

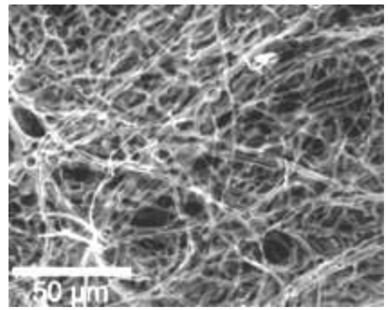
inverse opals:
- polymer
- silica
- TiO_2
- SnS_2

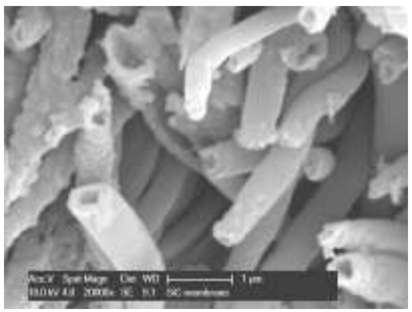


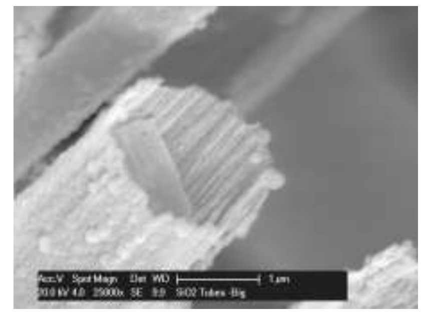


double opals:
- silica-TiO_2
- silica-SnS_2

FIBRES AND POROUS MATERIALS



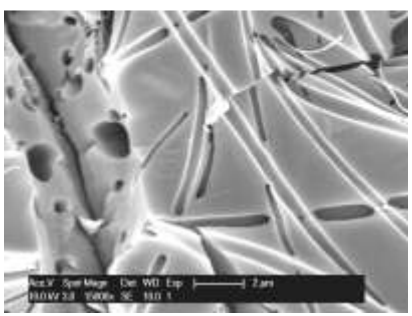


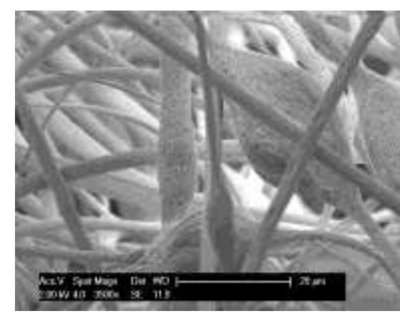


fluorescent tubes

tubular membrane

inorganic tubes





channel membrane

polymer fibres

Fraunhofer LBF

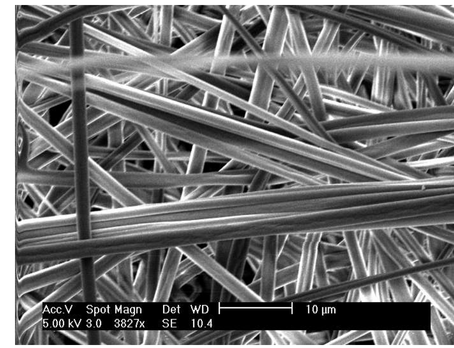
Polymer Fibres
Electrospinning

setup

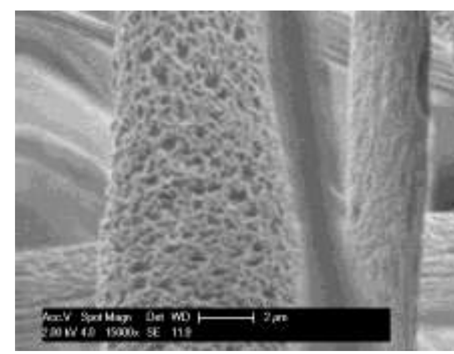
macroscopic

polymer fibre mat

SEM



porous fibres

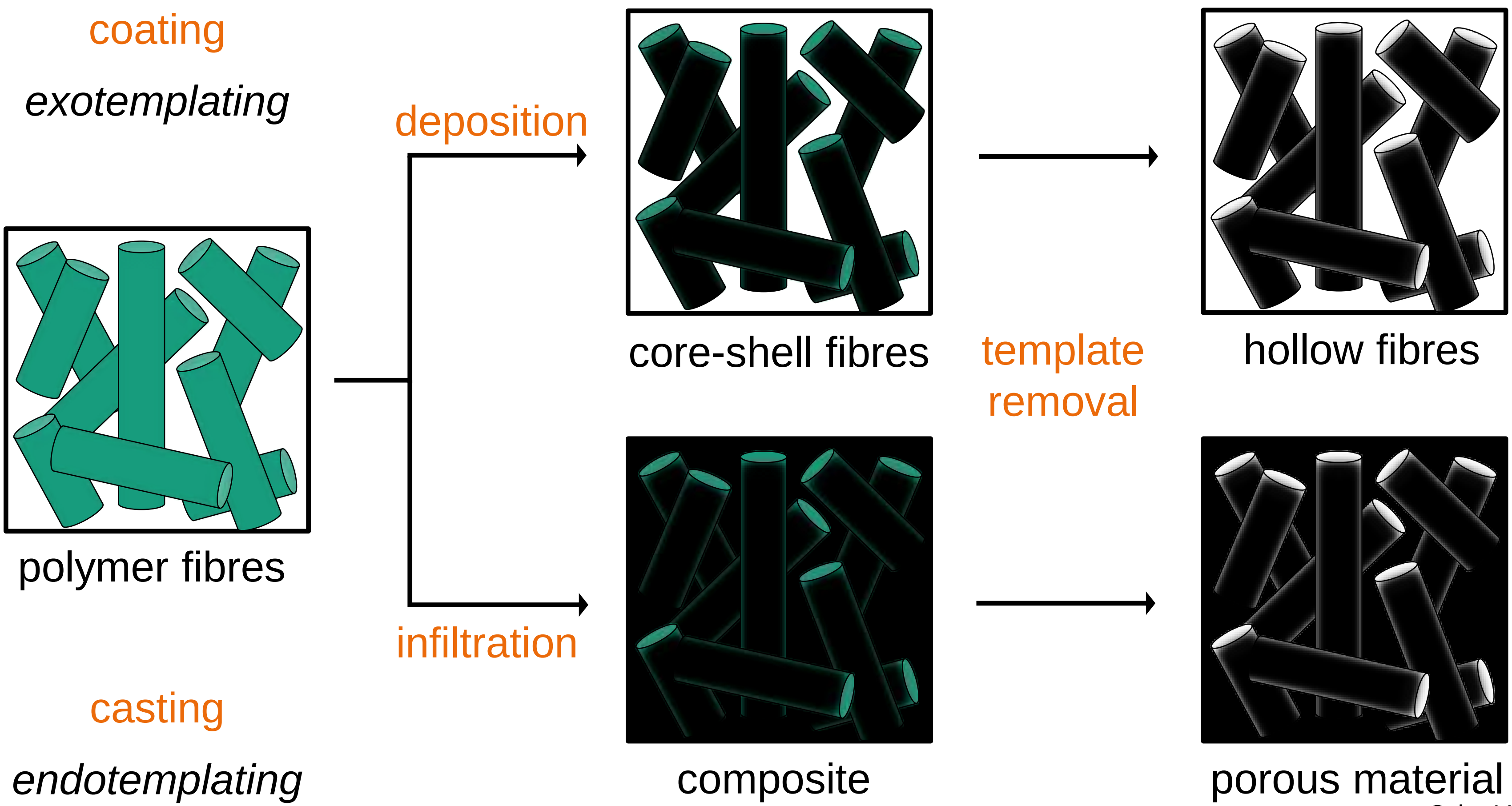


fibres from PMMA or PS,
uniform in size and shape,
variation of the diameter
by the spinning parameters

structured materials???

Fraunhofer LBF

Strategies to Structured Materials
Coating, Casting and Membrane Templating



Fraunhofer LBF

Coating
Hollow Fibres

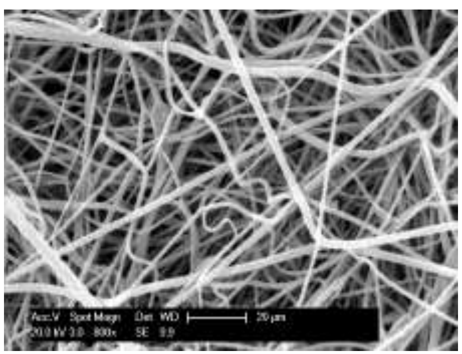
Stöber process

calcination

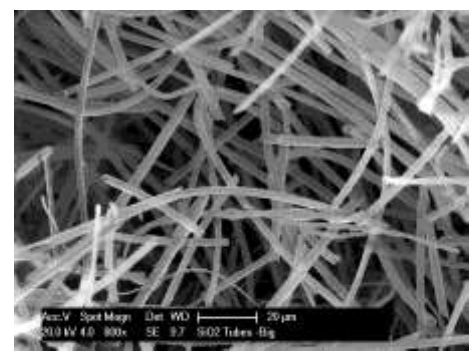
polymer fibres

core-shell fibres

hollow fibres

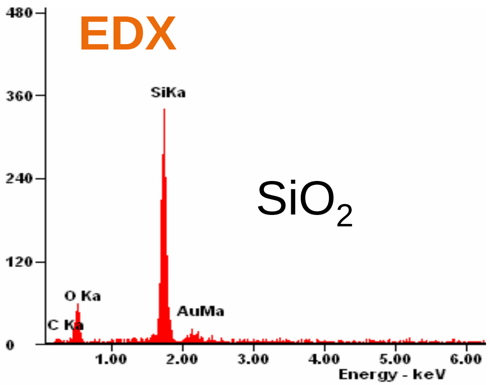


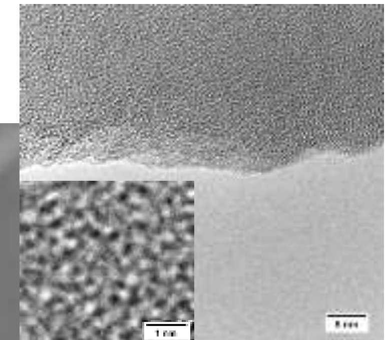
production of inorganic tubes from silica or ceria by sol-gel coating:
tuning of the interface



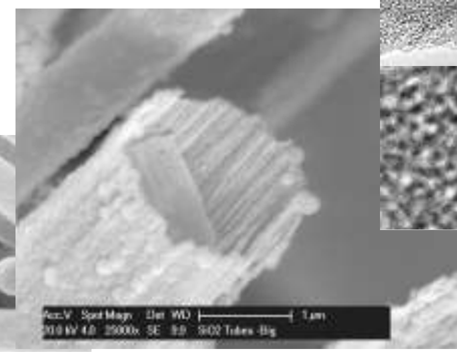
Fraunhofer LBF

Hollow Silica Fibres
Structure Hierarchy

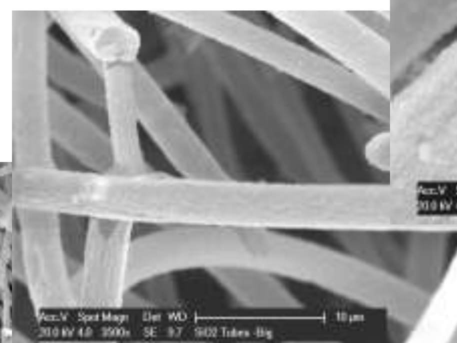




amorphous

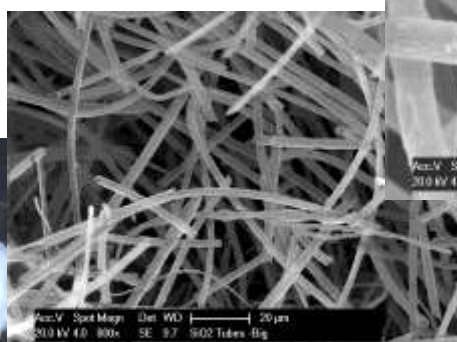


particles



hollow

mat



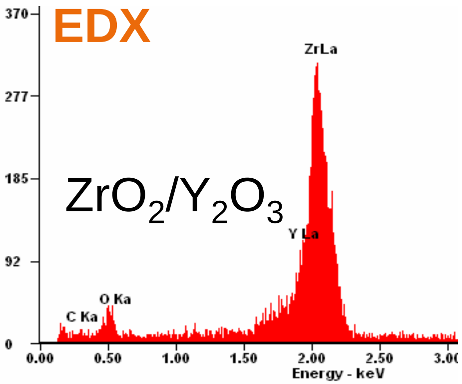
fibrous

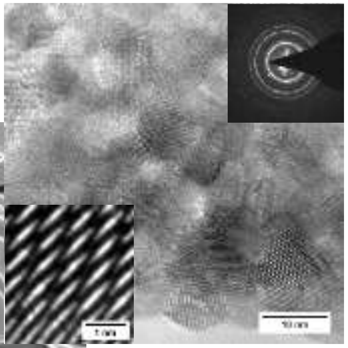
hierarchical structured
hollow silica fibre mat,
composed of amorphous
silica nanoparticles

Fraunhofer LBF

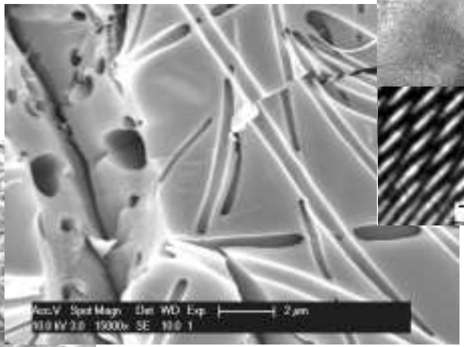
Casting

Hierarchical Structured Channel Membranes

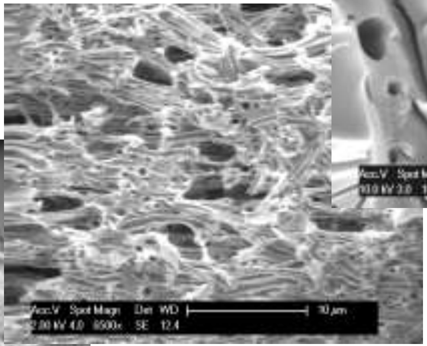




crystalline

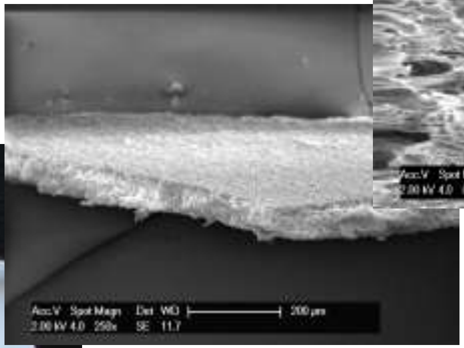


channels



porous

film

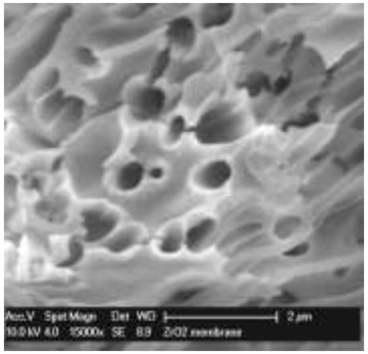


layer

hierarchical structured Y_2O_3 doped ZrO_2 solid electrolyte channel membrane composed of crystalline domains

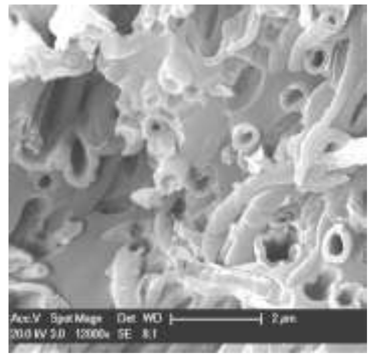
Fraunhofer LBF

Membrane Templating
Tubular Structured Membranes

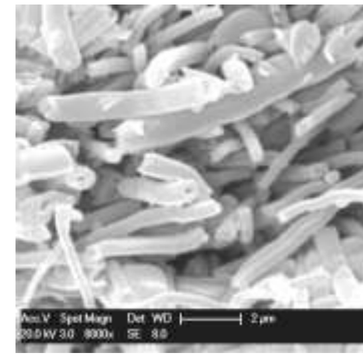


channel
membrane

coating
propene
700°C

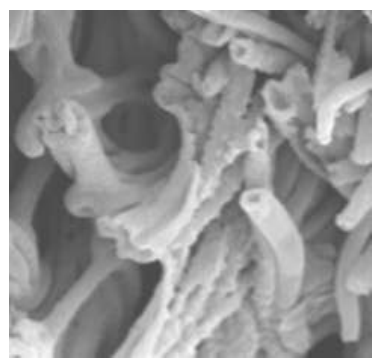


template
removal
HF
+ 1600°C



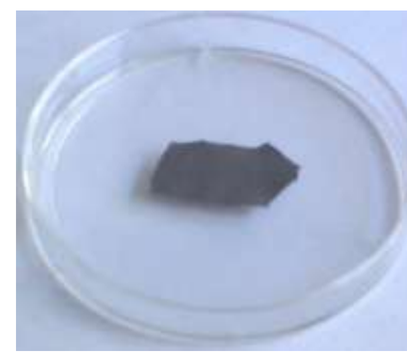
graphite
hollow fibres

conversion 1600°C



SiC hollow fibres

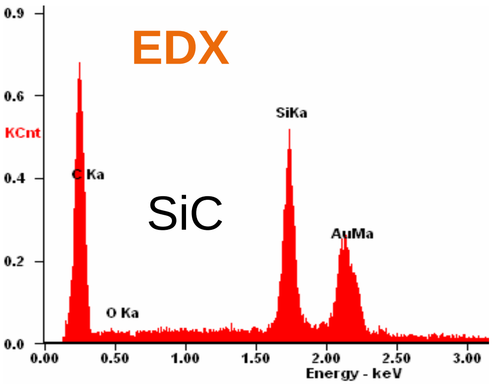
conservation of
the superstructure:
tubular structured
membranes composed
of submicron tubes



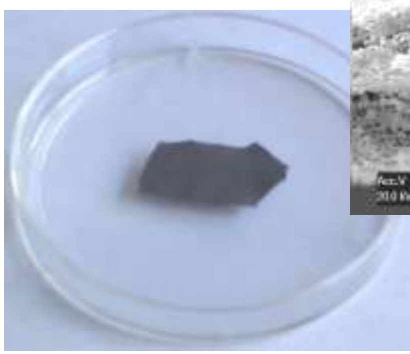
Fraunhofer
LBF

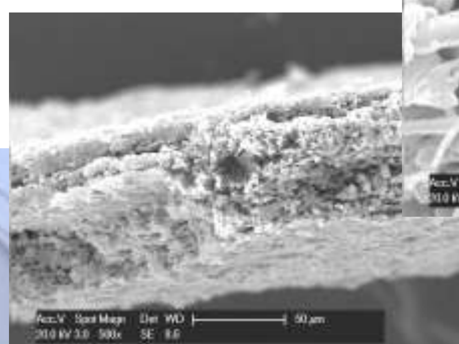
Tubular Structured SiC Membrane

Structure Hierarchy

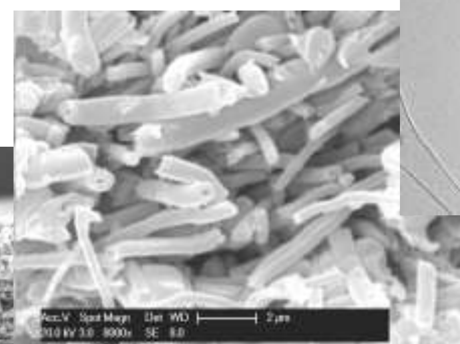


film

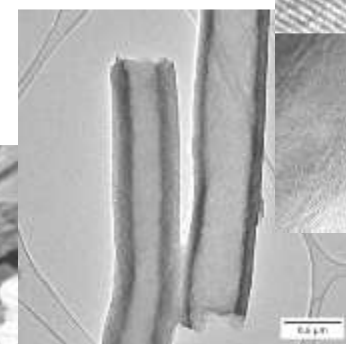




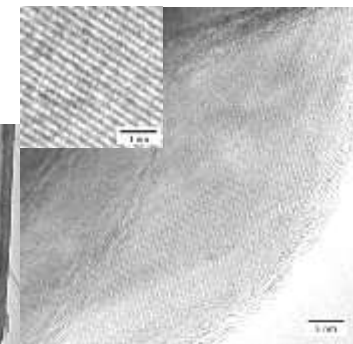
porous



fibrous



hollow

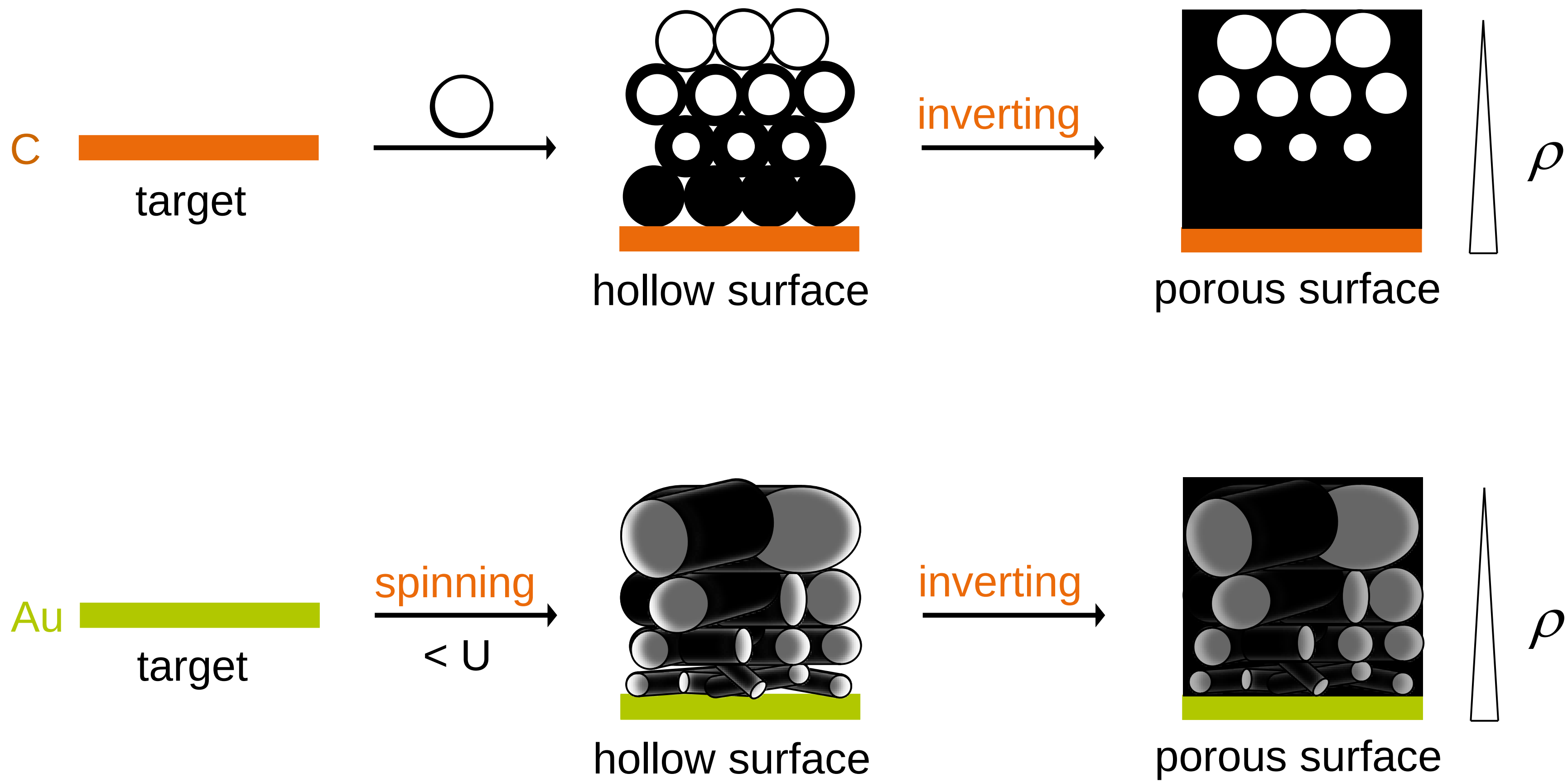


crystalline

hierarchical structured SiC membrane composed of crystalline tubes

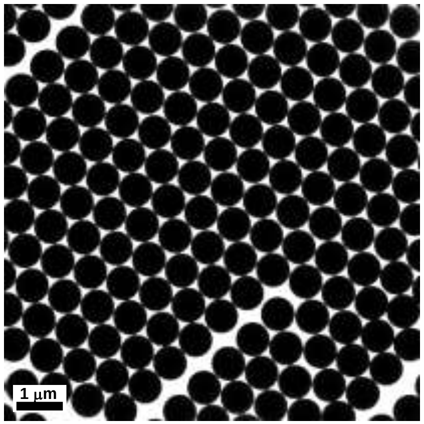
Fraunhofer LBF

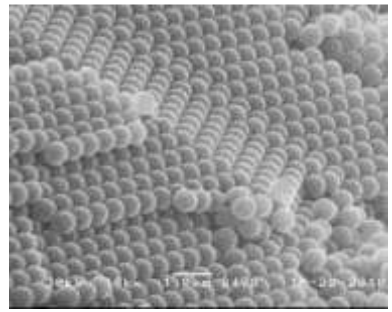
STRUCTURED TARGETS

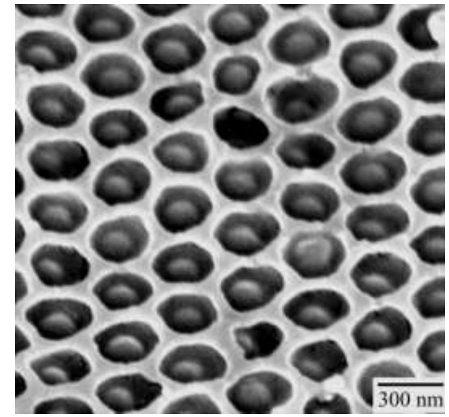


Fraunhofer LBF

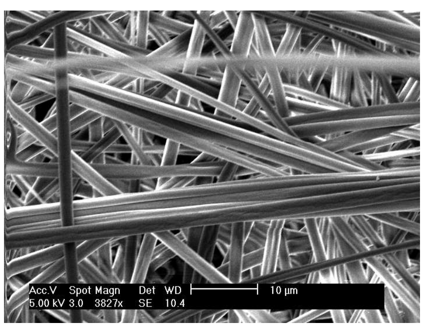
SUMMARY

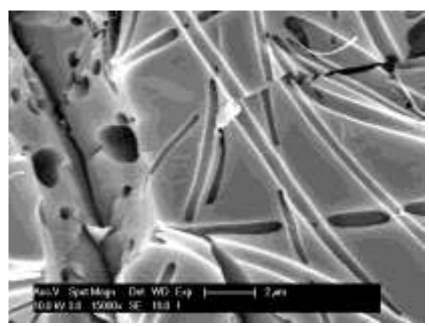






production of hierarchic macro-, micro- and nano-structured materials

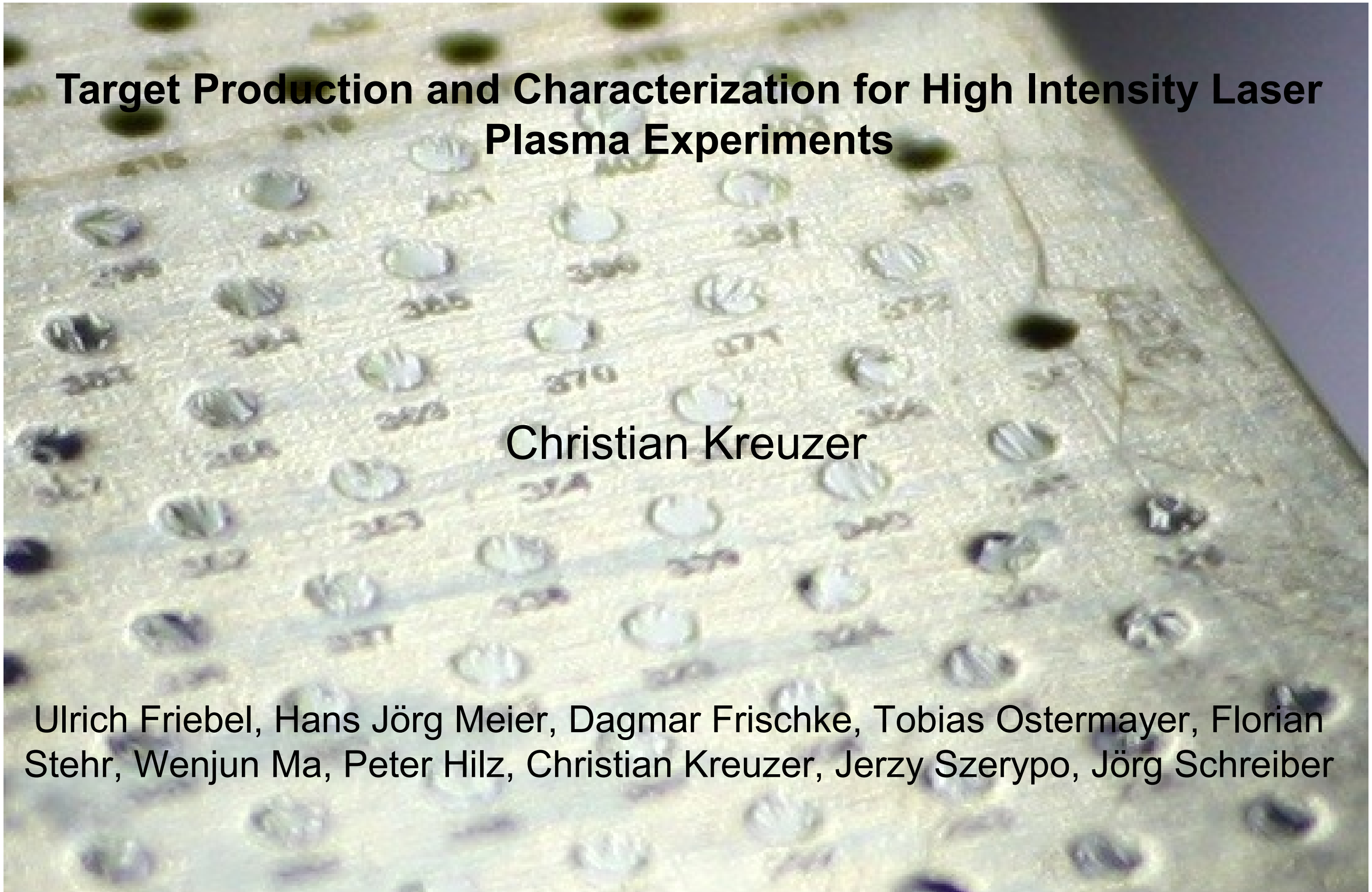




Fraunhofer LBF

LMU LUDWIG-MAXIMILIANS-UNIVERSITÄT MÜNCHEN

Munich-Centre for Advanced Photonics



Target Production and Characterization for High Intensity Laser Plasma Experiments

Christian Kreuzer

Ulrich Friebel, Hans Jörg Meier, Dagmar Frischke, Tobias Ostermayer, Florian Stehr, Wenjun Ma, Peter Hilz, Christian Kreuzer, Jerzy Szerypo, Jörg Schreiber

LMU LUDWIG-MAXIMILIANS-UNIVERSITÄT MÜNCHEN

TUM

MAX-PLANCK-GESELLSCHAFT

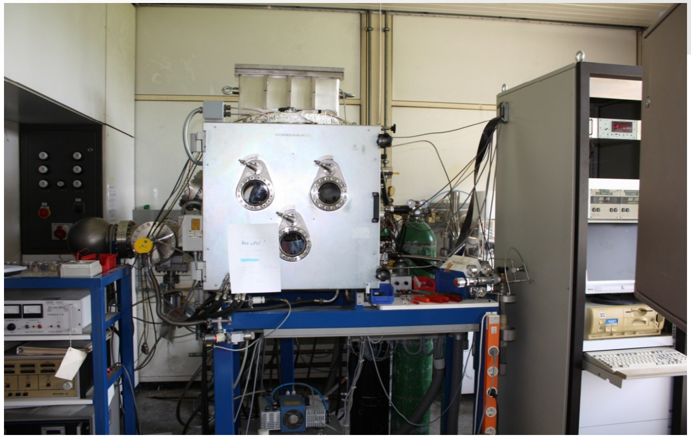
der Bundeswehr Universität München

SIEMENS

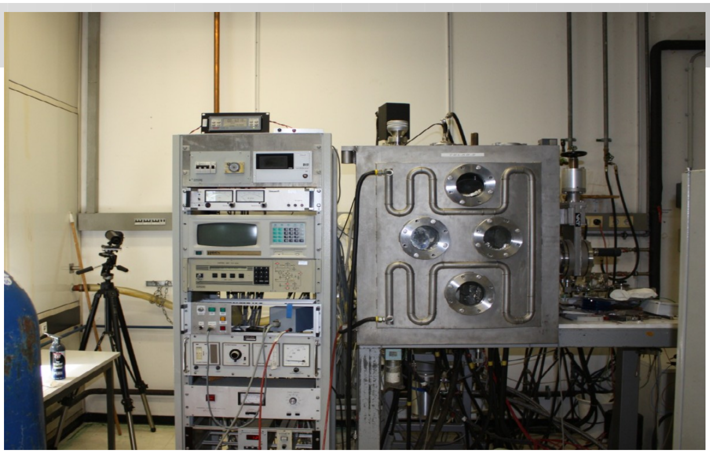
Introduction of the (small) target lab in Munich:

-Vacuum deposition methods for thin metal and other element foils
-Ultra thin DLC foils
-Low density nanotube targets
-High proton content plastic foils
-FIB targets
-Levitated MLT-targets
-Characterization of thin films

Evaporation and sputtering



Sputter deposition



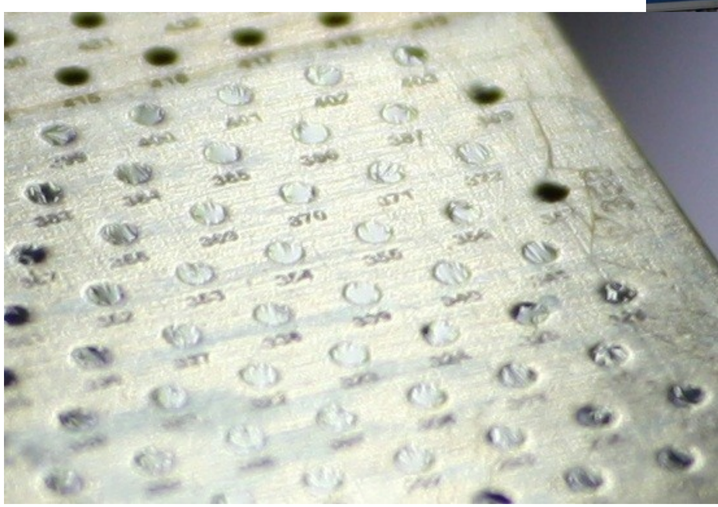
Thermal and electron gun evaporation

Filtered Argon storage box for oxygen
and water free storage of sensitive targets

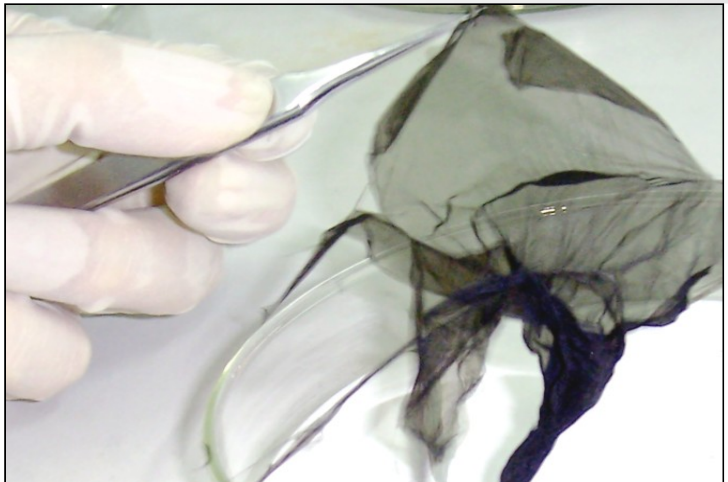
DLC Production

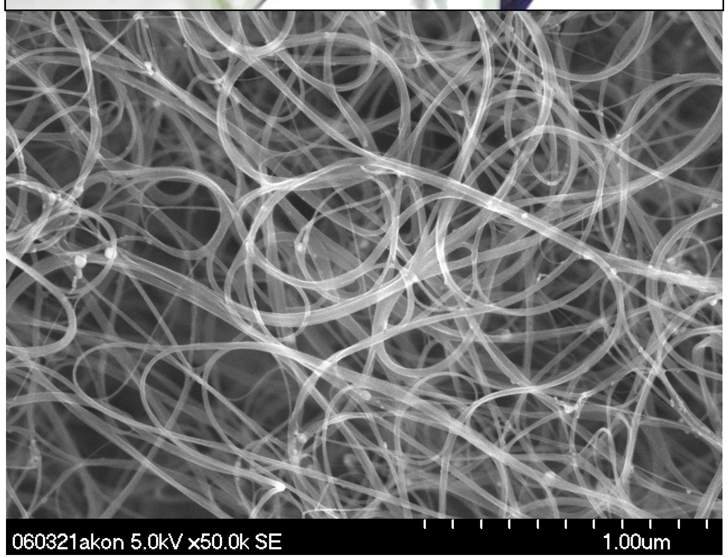
-FCVA system

- DLC foils in the range of 3 to 40 nm



CVD deposition

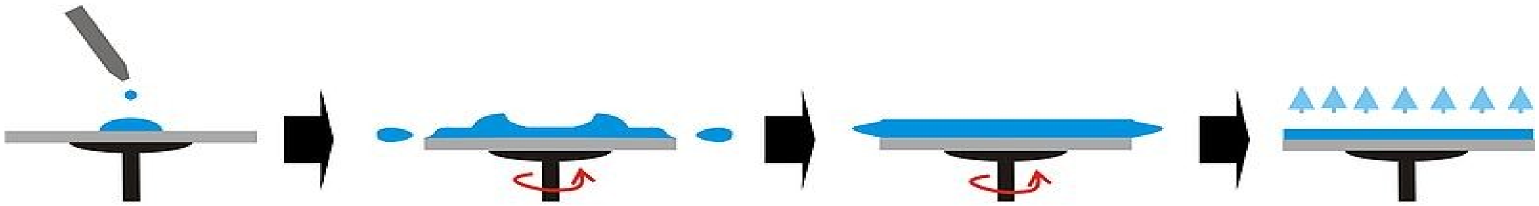




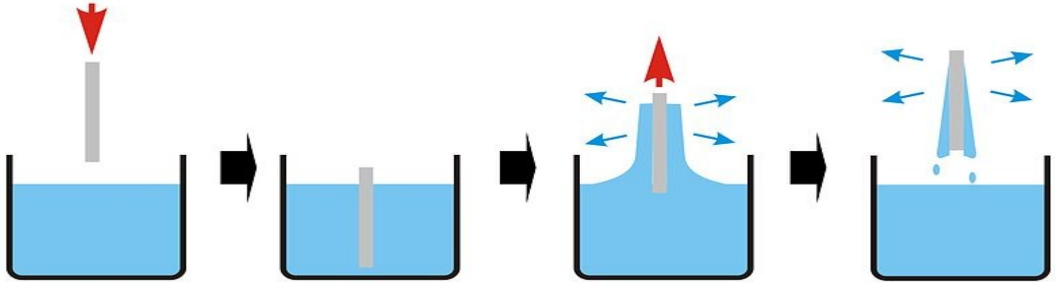
CVD system capable for temperatures up to 1500 °C
Ideal for producing low density CNT nets

For more details Wenjun Ma will give a special talk to this topic

Chemical solution deposition



Spin Coating



Dip Coating

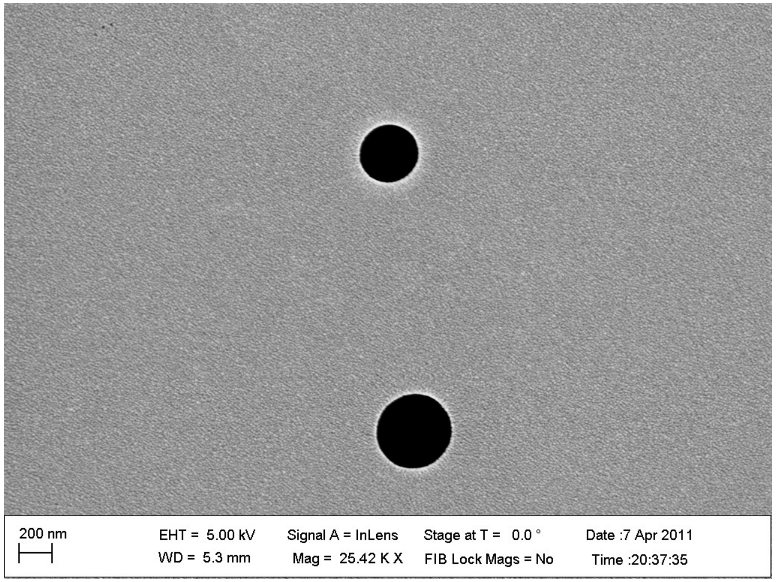
Small portable spin coater
With rotating speed up to
300 rps

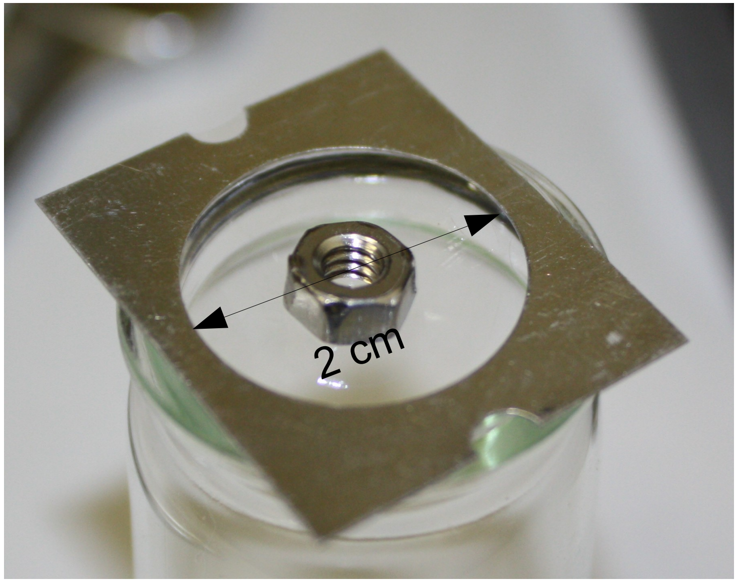
LMU LUDWIG-MAXIMILIANS-UNIVERSITÄT MÜNCHEN

Plastic targets

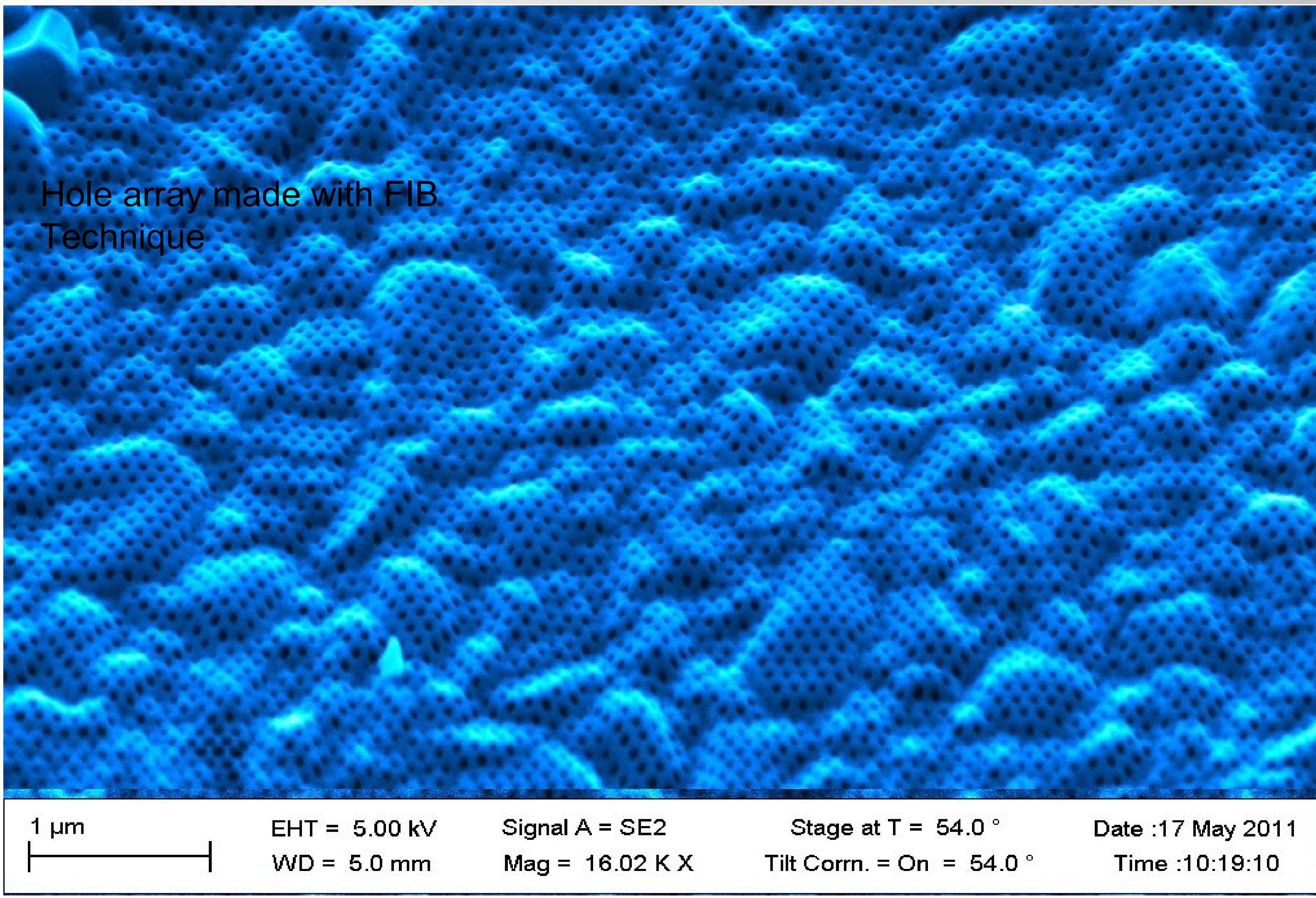
Munich-Centre for Advanced Photonics

-Method for easy to handle high proton content targets
-Thinnest foils down to 5 nm possible
-Strong and flexible foils can be spun over large areas
-Very flat surfaces possible



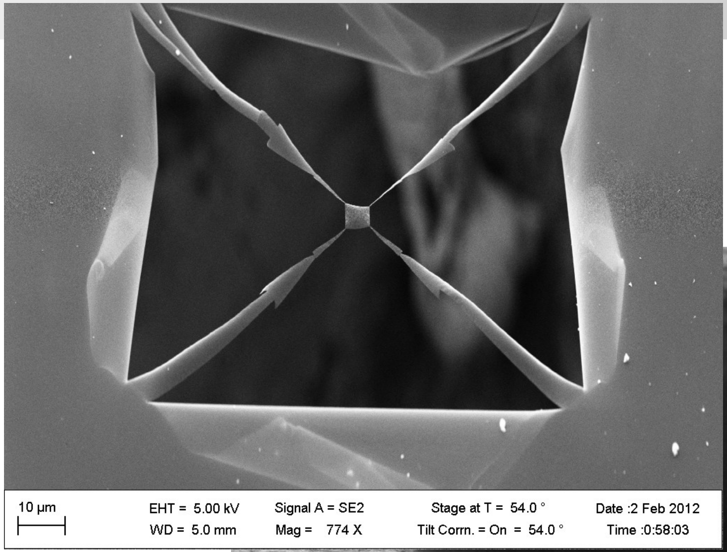


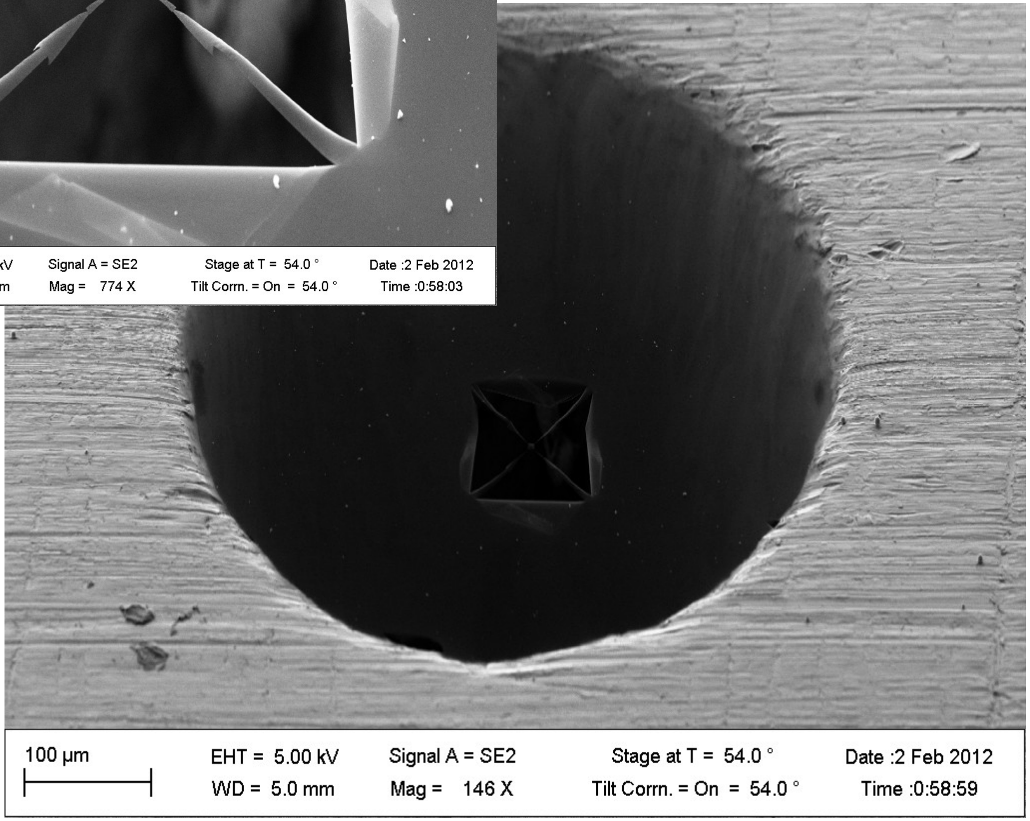
FIB manipulation

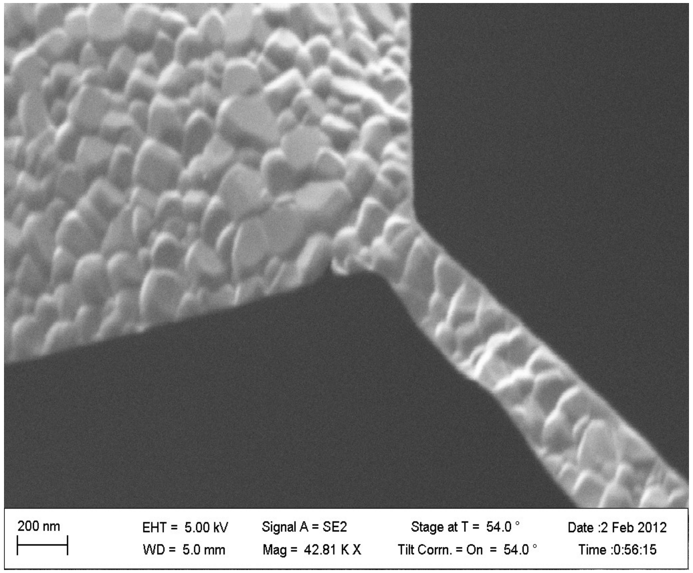


FIB manipulation

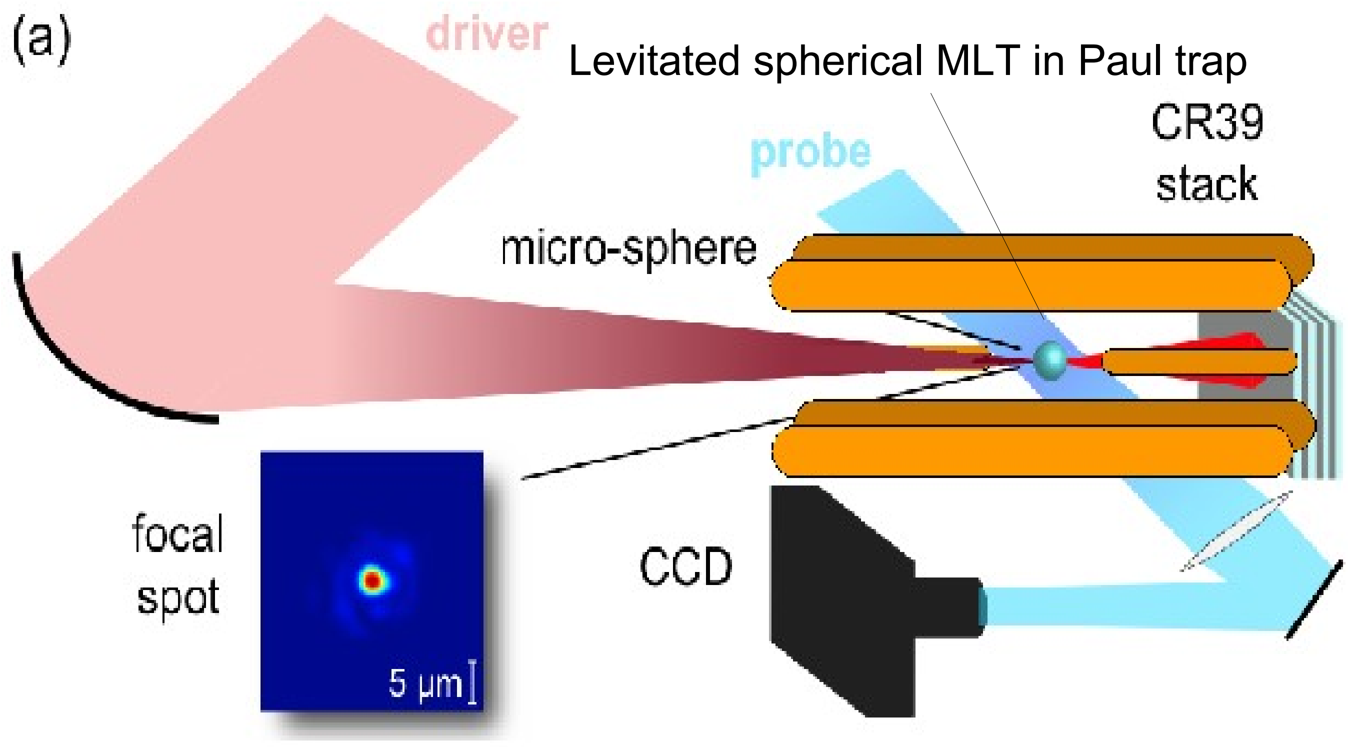
FIB cut out
MLT from DLC foil







Paul trap



Peter Hilz will give a special talk about this topic

Characterization

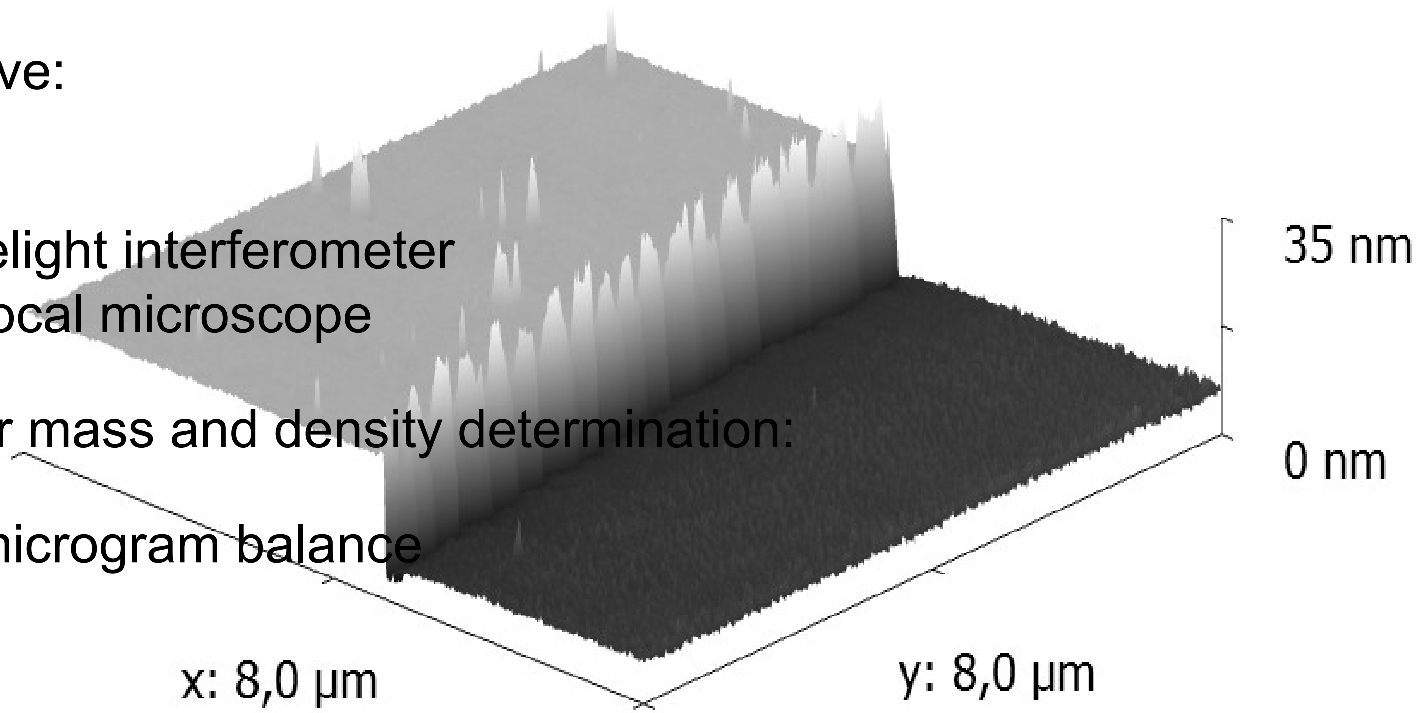
Mainly thickness determination:

We have:

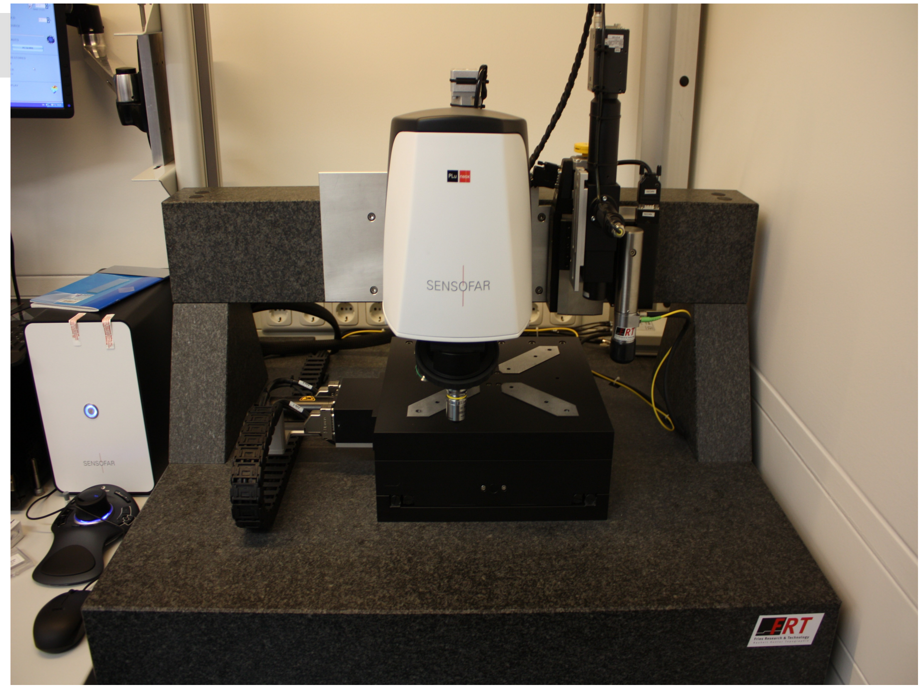
- AFM
- Whitelight interferometer
- Confocal microscope

And for mass and density determination:

-Sub microgram balance



Instruments f. Characterization



Sub microgram Balance

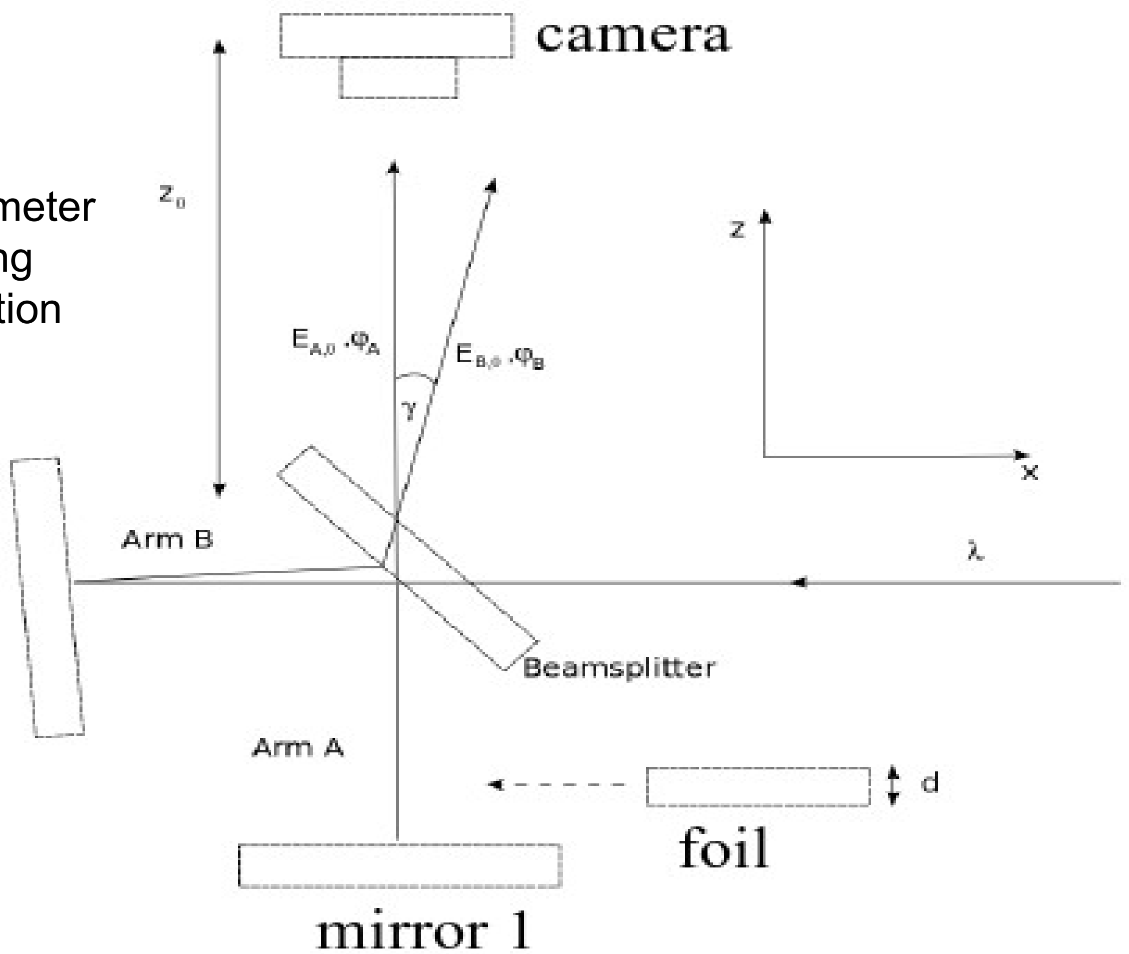
-Resolution 100 ng
-max load 5 g

AFM, whitelight interferometer and Confocal Mikroscope

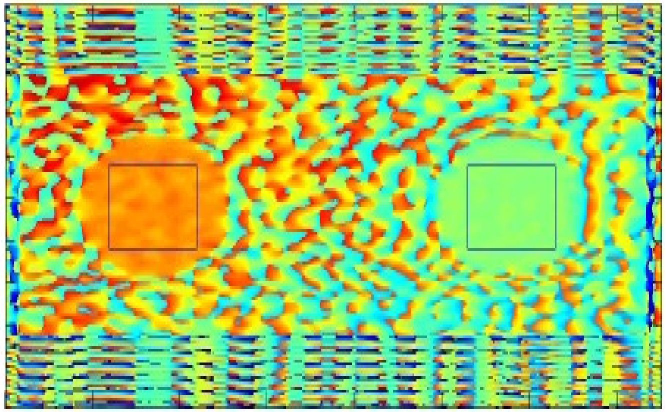
-Resolution down to 0.1 nm possible (for AFM)
-Covering all thickness ranges of interest from ultra thin (nm range) to thin (several µm range)

Freestanding Characterization

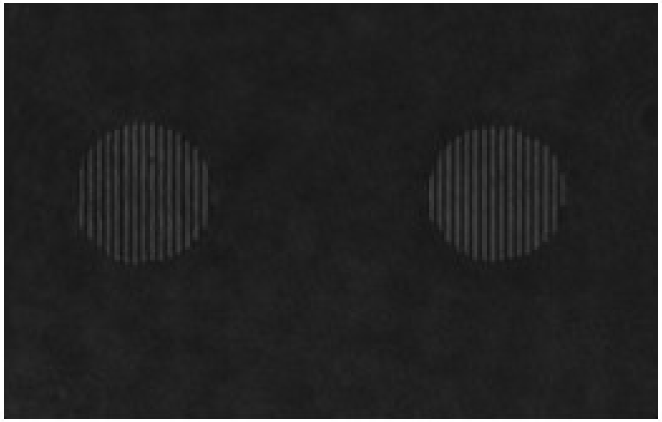
Michelson interferometer
Used for freestanding
thicknessdetermination



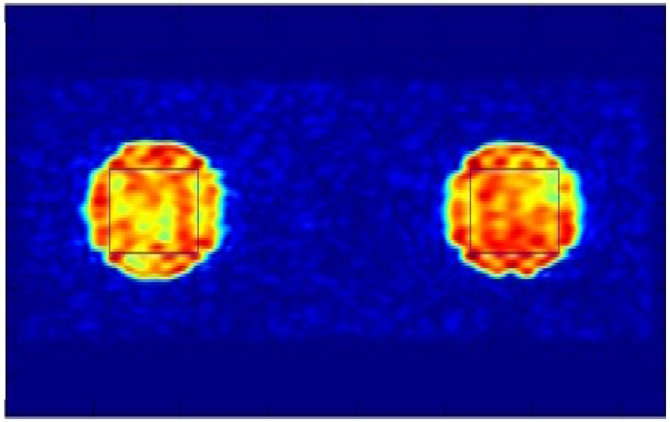
Freestanding Characterization



Phase difference with and without foil



Raw image before conversion



Amplitude measurement

<u>But:</u>

Not just simple phase measurements possible
Also absorption has to be taken into account

Thank you for your attention

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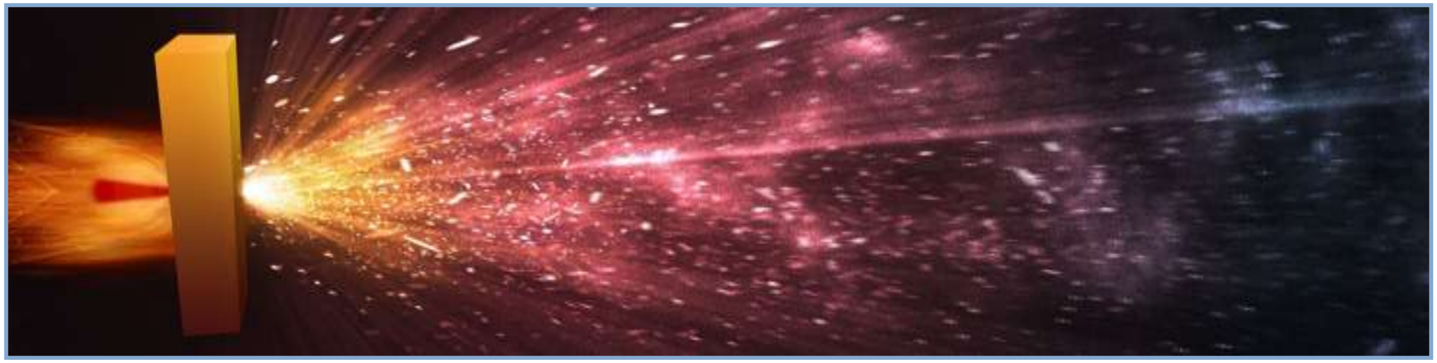
Novel multi-layered foam-attached targets for advanced ultraintense laser-driven proton acceleration



Alessandro Zani
Department of Energy – Politecnico di Milano

4° Target Fabrication Workshop 2012
Mainz, August 21st 2012

4th Target Fabrication Workshop
19-23 August 2012, Erbacher Hof, Mainz, Germany

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Interaction in the near-critical regime

Key role played by PLASMA DENSITY n_e

Critical density: $n_c(\mathrm{cm}^{-3}) \simeq \frac{1.1 \times 10^{21}}{(\lambda/\mu\mathrm{m})^2}$

Underdense plasmas: $n_e < n_c$

- **Gas targets**: interaction volume = entire plasma
- Collisionless absorption of laser energy: electron acceleration:

$$E_{max} \sim \sqrt{\frac{n_e}{10^{18}}} f\left(\frac{\omega}{k}\right) \mathrm{GV/cm}$$

[A. Modena et al. *Nature* **377**, 606 (1995)]

Overdense plasmas: $n_e > n_c$

- **Solid targets**: interaction volume = skin depth $d_s \simeq \left(\frac{\lambda}{2\pi}\right)\sqrt{\frac{n_c}{n_e}}$
- Collisionless absorption of laser energy: fast electrons generation

[P.Mulser,D.Bauer "High Power Laser-Matter Interaction", Springer (2010)]

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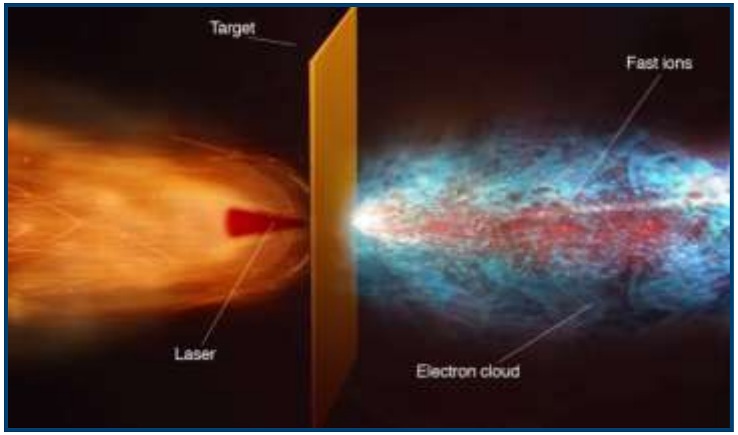
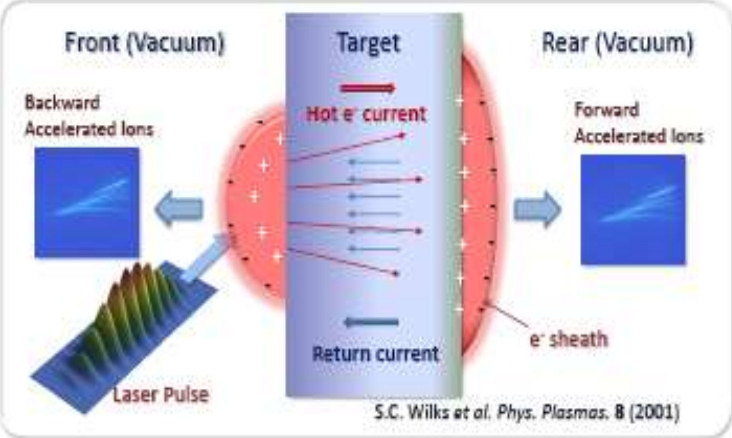
Laser-driven ion acceleration





Target Normal Sheath Acceleration (TNSA):

- Relativistic electron expansion into a solid target leads to high charge separation at solid-vacuum interfaces

High electric fields (MV/μm) and proton acceleration (MeV)

- Maximum proton energy is limited by laser absorption

H. Daido et al. *Rep. Prog. Phys.* **75(5)**, 056401 (2012)
A. Macchi et al. *Rev. Mod. Phys.* (to be published)

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Road towards enhanced TNSA (I)

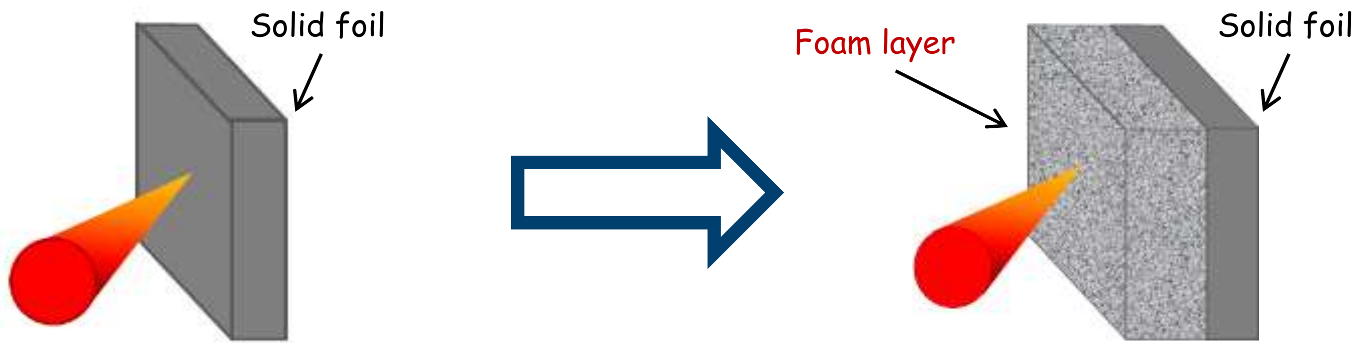
Evident interest in <u>"intermediate" conditions</u> $n_e \sim n_c$

Scalings predicting more efficient absorption and fast electron generation

[L.Willingale et al. *Phys. Rev. Lett* **96**, 245002 (2006); **102**, 125002 (2009)]
[S.S.Bulanov et al. *Phys. Plasmas* **17**, 044105 (2010)]
[T. Nakamura et al. *Phys. Plasmas* **17**, 113107 (2010)]

<u>"Advanced" TNSA regime</u>

Multi-layered targets: low-density layer + solid foil



"ordinary" scheme

"advanced" scheme

Road towards enhanced TNSA (II)

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2D/3D Particle-In-Cell numerical simulation results:

[A.Sgattoni et al. *Phys. Rev. E* **85**, 036405 (2012)]

- enhanced TNSA, gain factor in excess of 2 for maximum proton energy
- optimal foam thickness depends on laser intensity and foam density
- high energy absorption by the target

Experimental part of the work

- Multilayered target **manufacturing**

  A proper control of foam physical properties

  (density, adhesion to solid..) is NOT straightforward

- First **experimental** investigation of proton acceleration

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Multi-layered target production (I)

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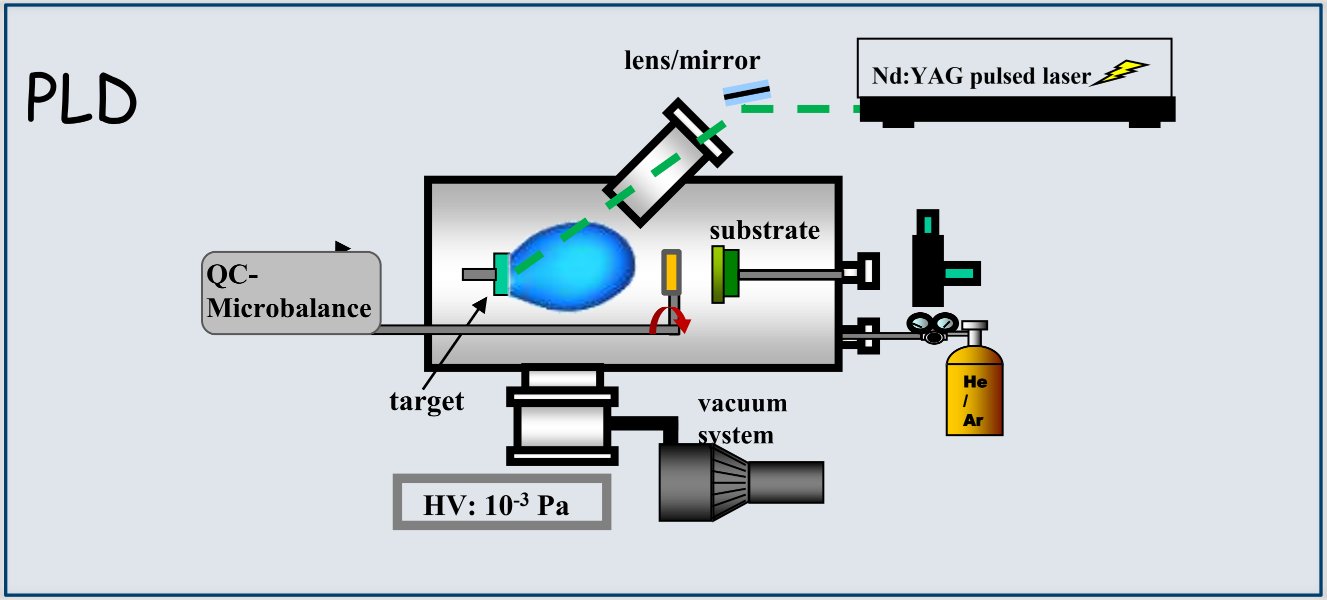
Goal: Near-critical carbon foam attached onto a solid substrate

- Why carbon? Low Z and volatile oxides
- densities around mg/cm^3 for laser wavelength ~1 μm
- Production technique: **Pulsed Laser Deposition (PLD)**
  - ✓ Large choice of materials and substrates
  - ✓ good adhesion properties
  - ✓ possibility to obtain controlled nanostructures



Multi-layered target production (II)

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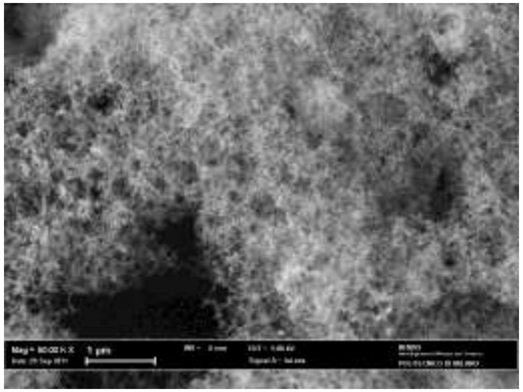
Deposition parameters:
- Wavelength: 532 nm
- Gas pressure: 0 - 1000 Pa
- Target-substrate distance: 8,5 cm
- Fluence: 0,8 J/cm^2

Target: Pyrolitic graphite

Substrates:
- Si<100> -> test depositions for characterization
- Al (10-1.5-0.7μm) -> target fabrication

Carbon foam morphology: SEM analysis



Structure at high magnification is clearly very open and porous

(Pore size is tens of nm)

On a mesoscale structures arrange differently by varying one process parameter:

gas pressure / **gas type** / **inlet gas flow**

morphology

structure

density

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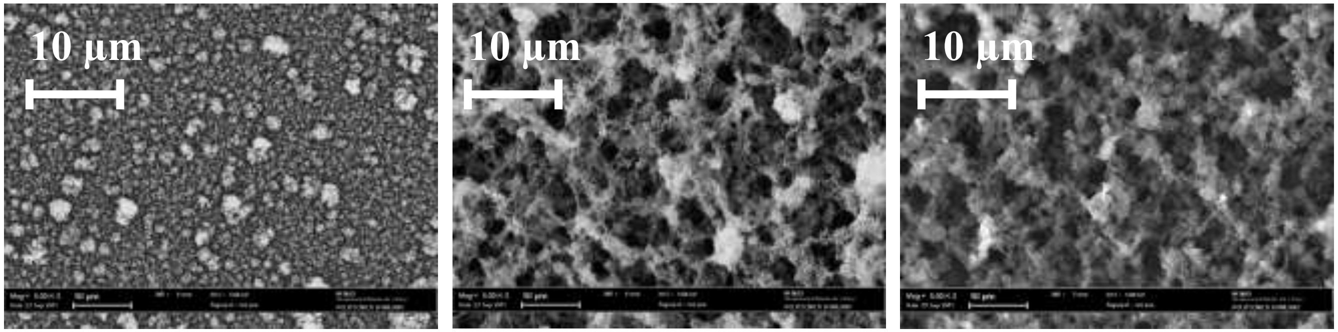
Process parameters: morphological characterization

A. Zani et al,
Ultra-low density carbon foams produced by pulsed laser deposition, in preparation

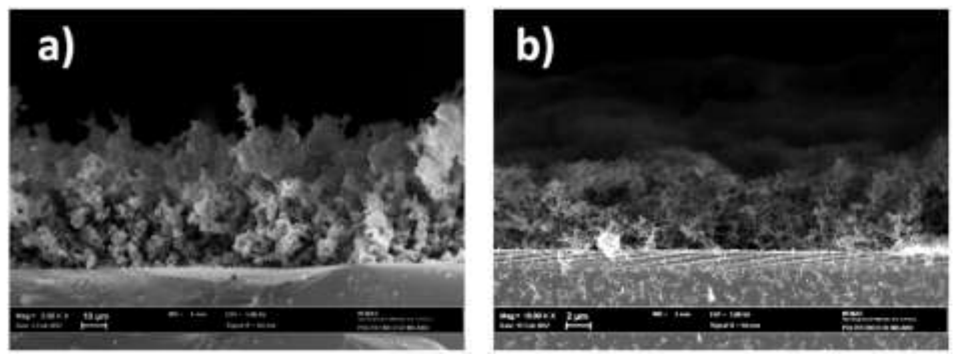


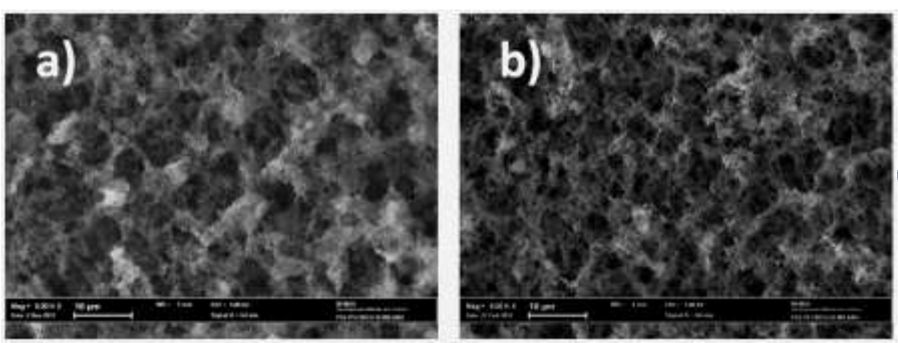
Ar pressure

30 Pa | 100 Pa | 300 Pa

Ambient gas type:

- He (500 Pa) a)
- Ar (100 Pa) b)





Ambient gas flow (Ar):

- 1 sccm + transverse dir.: a)
- 100 sccm & || dir.: b)

Process parameters: structural characterization

A. Zani et al, *Ultra-low density carbon foams produced by pulsed laser deposition*, in preparation

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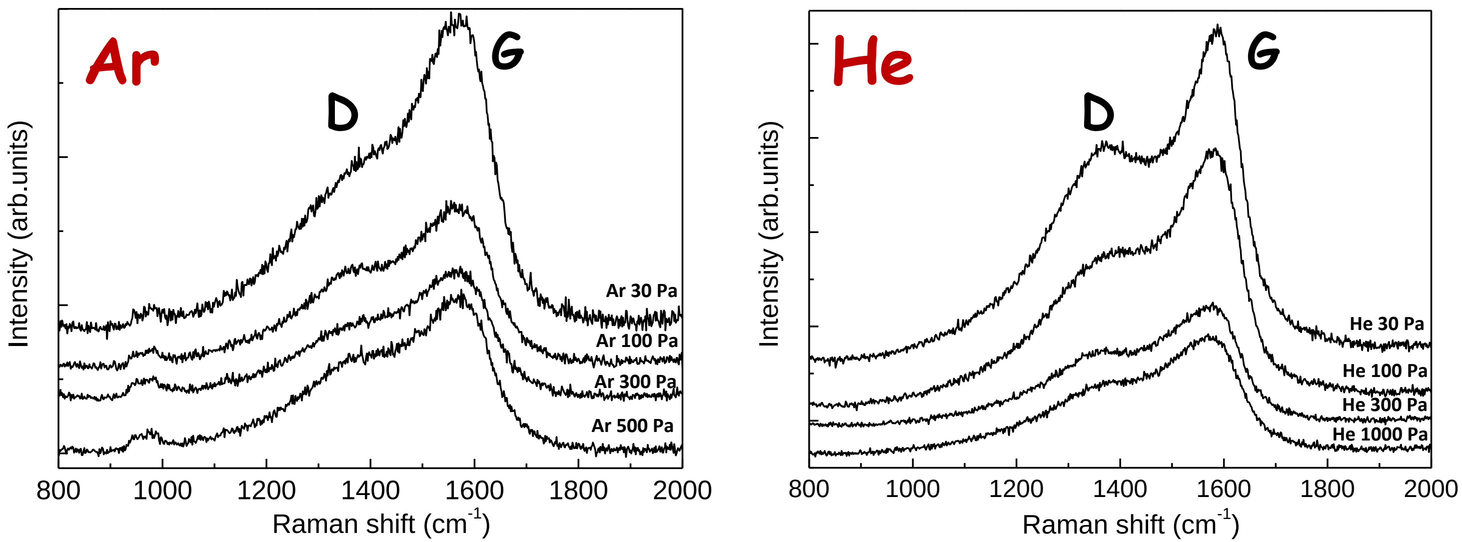
- Raman spectroscopy is a very common technique for structural characterization of carbon materials
- I_D/I_G gives information about the amount and type of sp^2 bonds and about the typical dimensions of crystalline domains

Results (following the procedure in Ferrari et al. *PRB* **61** 14195 (2000))

- Prevalence of sp^2 bonds
- All deposition conditions show the same nanostructure



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Density measurement (I)

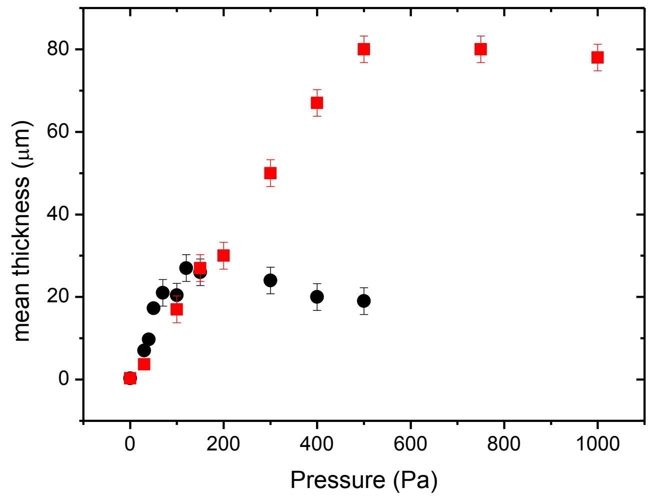
Performed combining:

- Areal density measurement
- Thickness measurement

Microbalance (red/black)

EDXS (green/magenta)

SEM

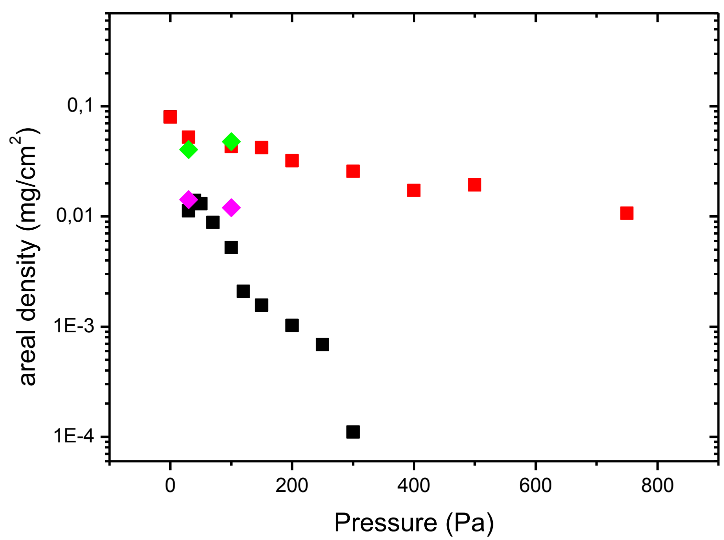


He (red): saturation at 80μm and good coverage till 1000Pa

Ar (black): saturation at 20μm and scarce coverage after 400Pa

He (red): almost constant in the whole pressure range

Ar (black): nearly 1 order of magnitude lower due to relevant scattering between C and Ar



Density measurement (II)

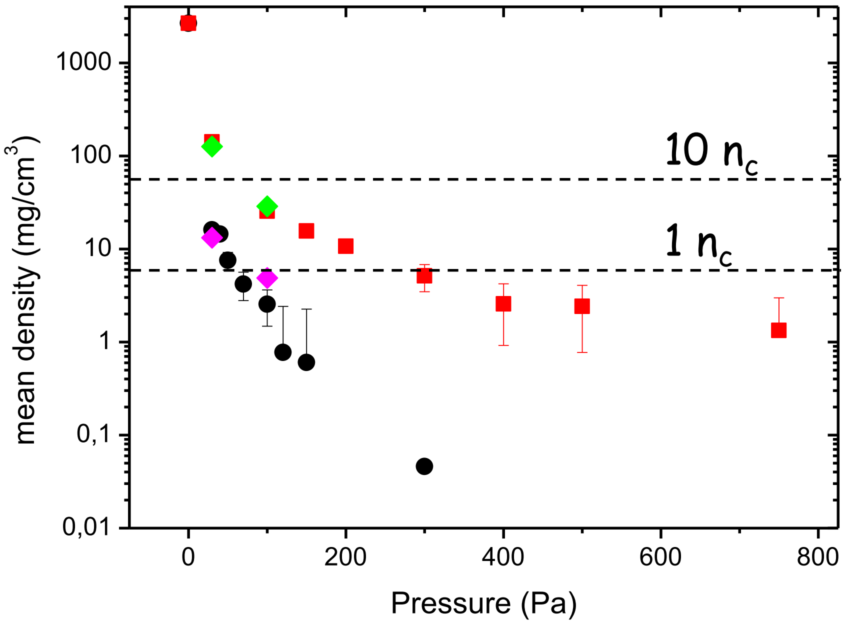
A. Zani et al, *Ultra-low density carbon foams produced by pulsed laser deposition*, in preparation

✓ Assuming:

- fully ionized carbon
- λ=0.8 μm incident laser

⟹ $\rho_{cr}(C) \approx 5.7$ mg/cm^3

✓ Able to reach in a controlled way near-critical densities!



Noteworthy:

- Inlet gas flow does not affect any physical properties but the surface uniformity
- EDXS density measurements are still work in progress BUT evidence that microbalance becomes scarcely reliable above 100-200 Pa in Ar

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1. Ultraintense laser-driven ion acceleraction
    - Interaction in the near-critical regime
    - Road towards enhanced TNSA
2. Target production and characterization
3. First preliminary experimental results
4. Conclusions

First preliminary experimental results (I)

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Test of foam-attached targets on UHI100 facility at CEA-Saclay

- broad intensity range ($5x10^{16}$ - $5x10^{19}$ W/cm^2)

  varying individually: focal spot, energy and duration

- examined several different experimental conditions

- High (10^{12}) and low (10^7) contrast shots
- "Bare" target (Al) thicknesses: 0.7 - 1.5 - 2 - 6 - 10 – 20 30 - 100 μm
- "Foam-attached" targets
  foam thickness: from 9 to 22 μm
  foam density: 0.5 – 1 – 2 n_c
  Al substrate thickness: 0.7 – 1.5 – 10 μm

→ **Very reliable set of data**

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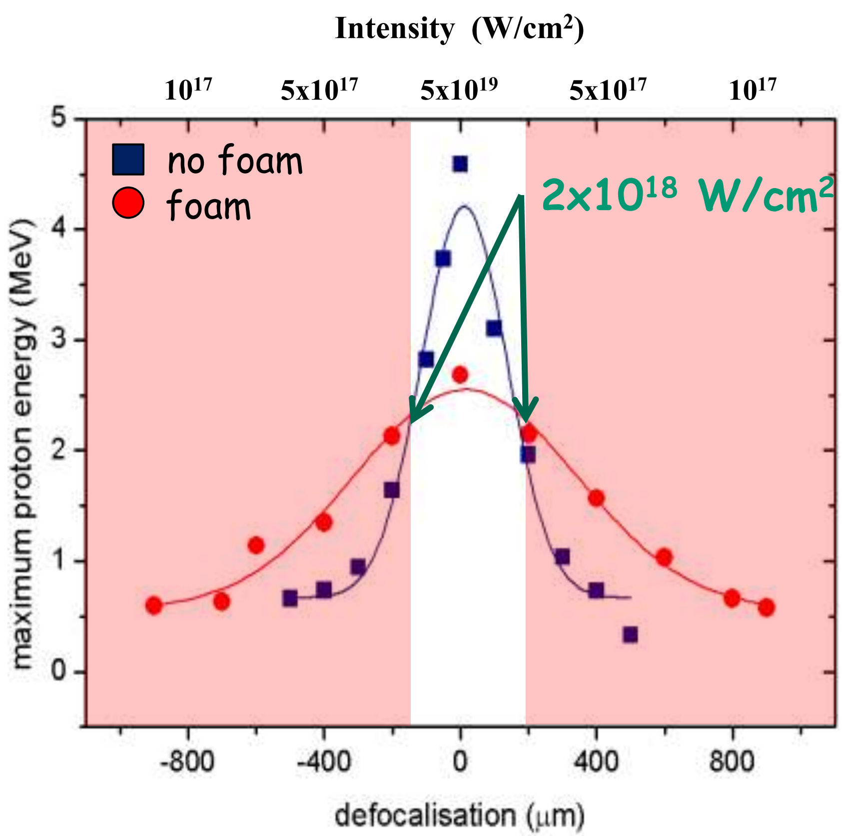
First preliminary experimental results (II)

→ Different interaction conditions seem to appear when a foam is present



At sufficiently low intensity ($<10^{18}$ W/cm^2) proton response with foam targets appears to be definitely higher.

In this region maximum proton energy gain factor using a foam is between **2÷4**

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Contents

Conclusions

- In the near-critical regime it is possible to enhance ultraintense laser absorption as well as TNSA process: "foam-attached targets"
- Potential in producing:
  - ✓ foam materials having controlled density-composition in the near critical regime
  - ✓ foam layers directly grown on solid surfaces (solving adhesion problems)
  - ✓ materials with controlled density profile

Next…

- ✓ achievement of independent control of foam parameters (density, uniformity, thickness)
- ✓ Deeper **physical comprehension** of first experimental results
- ✓ Other forthcoming **experiments** (>10^{20} W/cm^2)

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Acknowlegments

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P. D'Oliveira, Ph. Martin

A. Macchi, A. Sgattoni

Cryogenic Targets for Laser and Particle Beams

4th Target Fabrication Workshop | Mainz | August 21, 2012

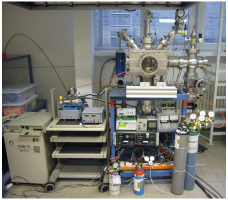
TECHNISCHE UNIVERSITÄT DARMSTADT

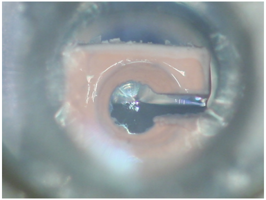
Stefan Bedacht

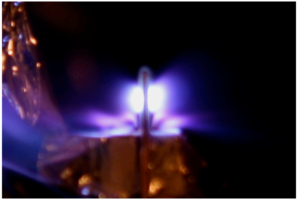
Technische Universität Darmstadt

Institut für Kernphysik

AG Hoffmann







Introduction

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Cryogenics

Cryogenics is the branch of physics dealing with the production and effects of very low temperatures, *i.e.*, temperatures below 100 K.

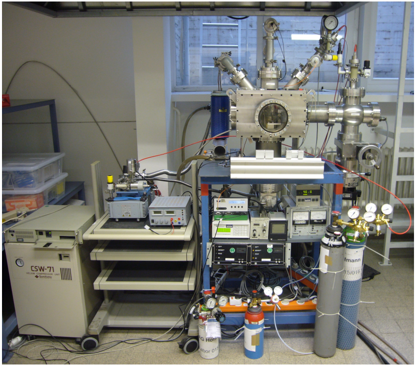
Goals

1. fabrication of thin solid hydrogen targets
2. characterization of the surface quality of the targets
3. using the targets for laser and particle beam experiments

Setup

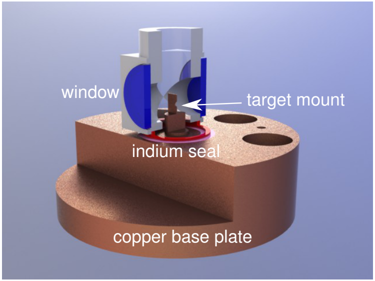
Requirements

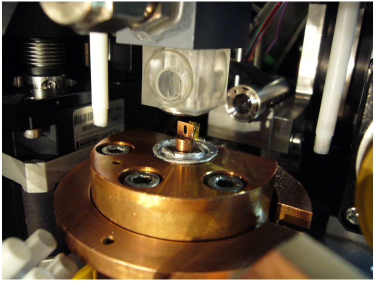
- vacuum chamber
- cooling device
- pure gases
- pressure control
- temperature control
- target diagnostics



Cryogenic test rig at TU Darmstadt.

Growing Chamber





- copper base plate features good heat conduction
- high tightness due to indium seal
- windows for real time optical diagnostics
- motorized polycarbonate growing chamber

Target Geometry

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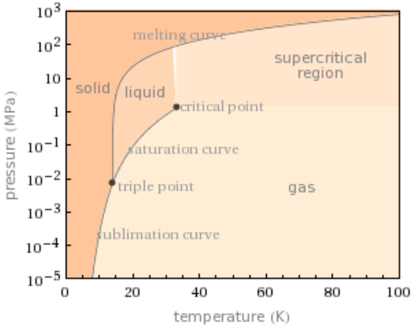
Different growing chambers. [J. Menzel]

- target geometry is determined by the geometry of the growing chamber and the target mount
  - thickness: µm to cm
  - diameter: mm to cm
- growing process takes about 1 min to 30 min
- thickness can be reduced by thermal evaporation

Growing Procedure



Phase diagram of hydrogen. [*Wolfram|Alpha*]

1. ensure vacuum better than 10^{-5} mbar
2. cool copper base plate down to less than 10 K
3. attach growing chamber to base plate
4. adjust gas pressure and temperature
5. fill growing chamber with target gas
6. wait for target to solidify

Target Thickness Measurement – Electron Gun

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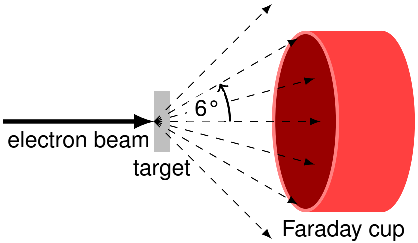
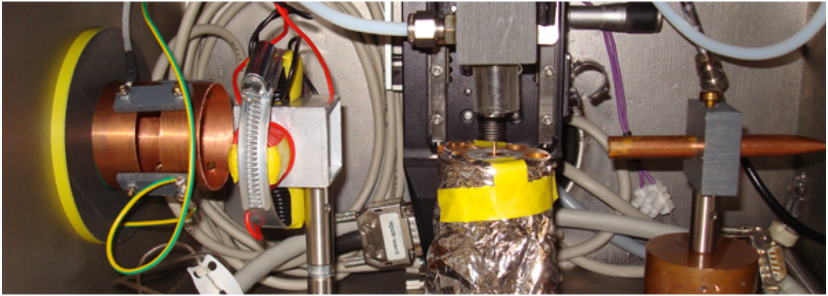


- electron beam: 14 kV, 5 µA, 2 mm in diameter
- current detected by the Faraday cup is correlated with target geometry
- experimental results are compared with results of *Geant4* simulations

Target Thickness Measurement – Electron Gun



Electron gun setup. [J. Menzel]

Target Thickness Measurement – Electron Gun

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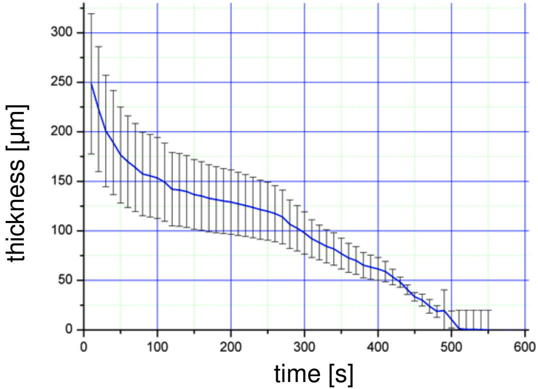

Deuterium target thickness vs. time. [J. Menzel]

Target Thickness Measurement – Interferometry

Commercial chromatic confocal sensor and interferometer. [*Precitec Optronics*]

Capabilities

- measuring range 3 µm to 250 µm
- sampling rate 32 Hz to 2000 Hz
- chromatic confocal and interferometric mode
- lateral resolution 20 µm to 2 µm
- vertical resolution 14 nm to 10 nm

Difficulties

- reflective geometry
- geometric constraints

Target Properties

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Advantages

- pure targets
- free standing
- adjustable thickness (µm to cm)
- large diameter (few mm^2 to cm^2)
- medium repetition rate (2 to 3 targets per hour)
- solid state density (e.g. $0.09\,g\,cm^{-3}$ for solid hydrogen)

Disadvantages

- immobility
- complex setup & alignment

Laser Breakout Afterburner (BOA)

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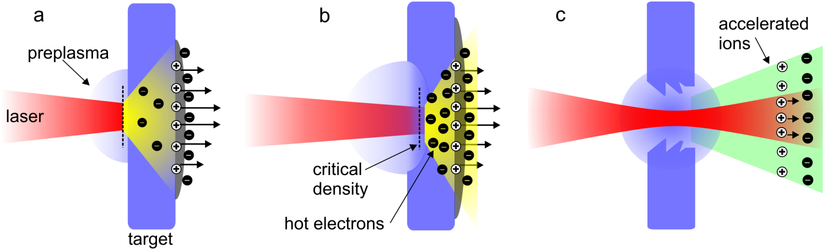
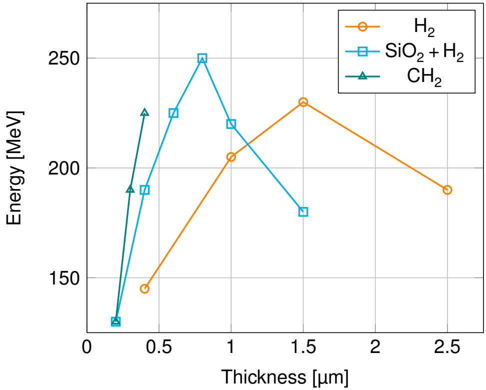


Target Normal Sheath Acceleration (TNSA)

Intermediate phase

Laser Breakout Afterburner (BOA)

BOA – Proton Energy



Laser Parameters

- 120 Joule in 500 fs
- intensity of 10^{21} W cm^{-2}
- contrast greater than 10^9
- linear polarization

Simulation by Lin Yin, Los Alamos National Laboratory

Energy Loss in Plasma

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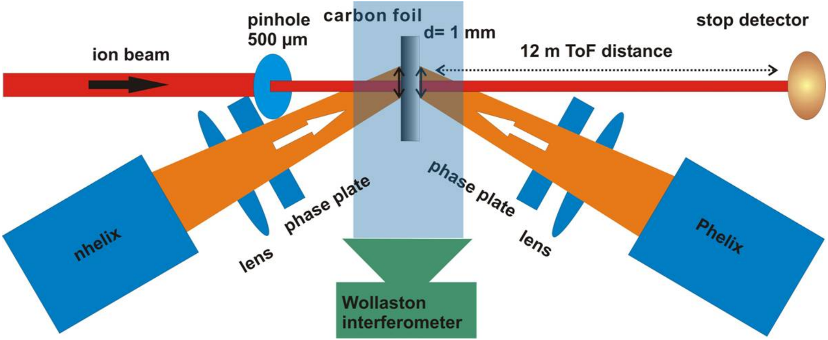

Laser setup at *Z6* target area at *GSI*, Darmstadt.

Energy Loss in Plasma – Deuterium Target

Cryogenic deuterium target irradiated by two high energy laser pulses. [J. Menzel]

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Summary

- pure targets
- homogenous solid state density
- growing process takes about 1 min to 30 min
- initial target thickness adjustable between µm and cm
- targets made from hydrogen, deuterium, nitrogen, argon, and neon
- setup can be implemented at target areas like *Z6*, *GSI*
- preliminary experiments with cryogenic nitrogen and deuterium targets were performed at *GSI*

Outlook

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Future Goals

- precise surface/topology characterization
- cryogenic layer on ultra thin plastic substrates
- use cryogenic targets in laser accelerated ion experiments
- use cryogenic targets to measure the energy loss of heavy-ion beams in a fully ionized plasma

Acknowledgements

TECHNISCHE UNIVERSITÄT DARMSTADT

Collaborators

- Prof. Dr. Dr. h.c./RUS Dieter Hoffmann
- Prof. Dr. Markus Roth
- Dr. Gabriel Schaumann
- Dr. Jurij Menzel
- Alexandra Tebartz
- *GSI* Plasma Physics Group

Financial Support

- *Federal Ministry of Education and Research*, Germany
- *HiPER* Project

The End

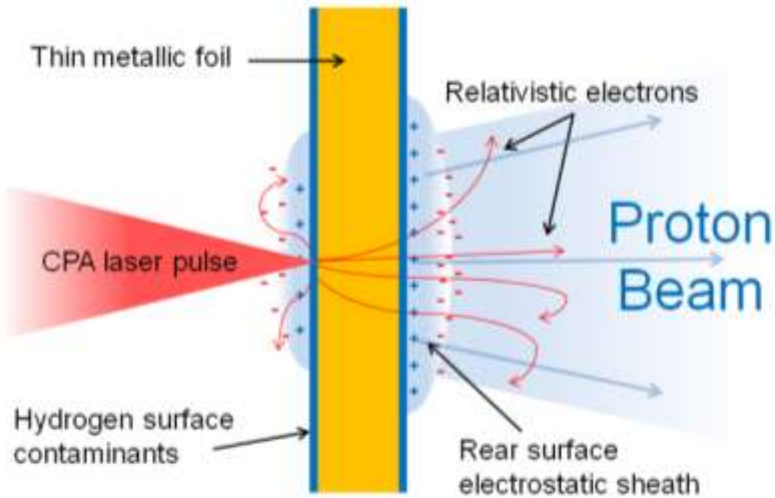
Thank you for your attention!

Development of Cryogenic Windowless Targets

Stephanie Tomlinson

Martin Tolley, Chris Spindloe, David Neely, Paul Holligan, Tom Bradshaw,
Mike Courthold, Chris Pulker , Marco Bourghesi

Introduction



- Potential applications include tumor therapy, radiography and laser driven fusion
- Light Sail Radiation Pressure Acceleration (LSRPA).
- Maximum energy available scales favourably with decreasing target density

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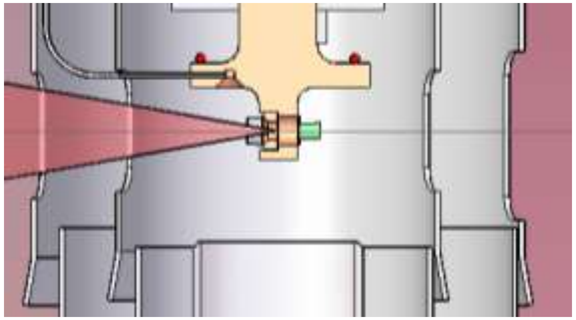
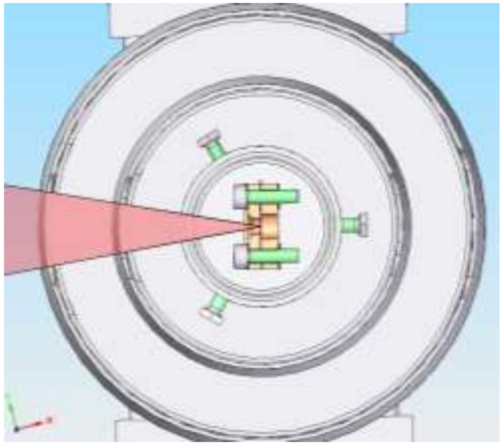
Parameters

Target parameters defined by:

- Laser
- Blast region
- Alignment tolerance
- Thickness for light sail regime
- Material & purity





Aim:

- 2-5mm diameter
- 50 micron thickness
- Windowless

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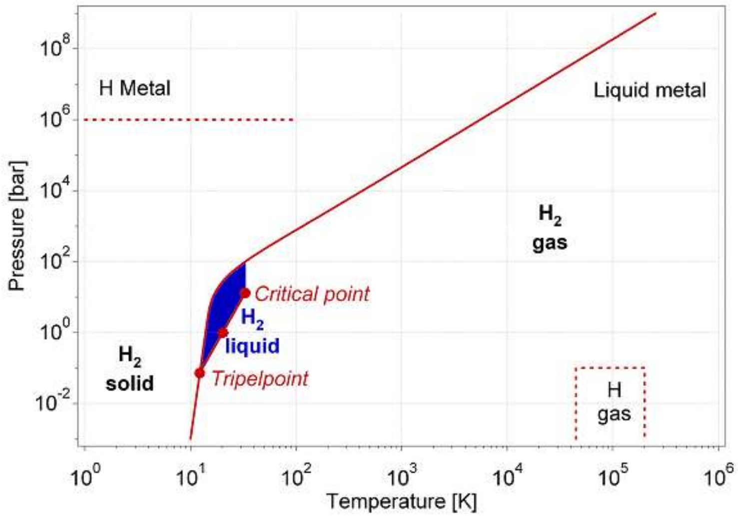
Proposed Method

- Condensation method
  - Local wet vapour
  - Condense onto substrate
  - Flow & surface tension
  - Solidify
  - Vacuum



	Hydrogen	Deuterium
Pressure at Critical Point (bar)	13	16.6
Temperature at Critical Point (K)	33.5	38.4
Pressure at Triple Point (bar)	0.07	0.17
Temperature at Triple Point (K)	13.8	18.7

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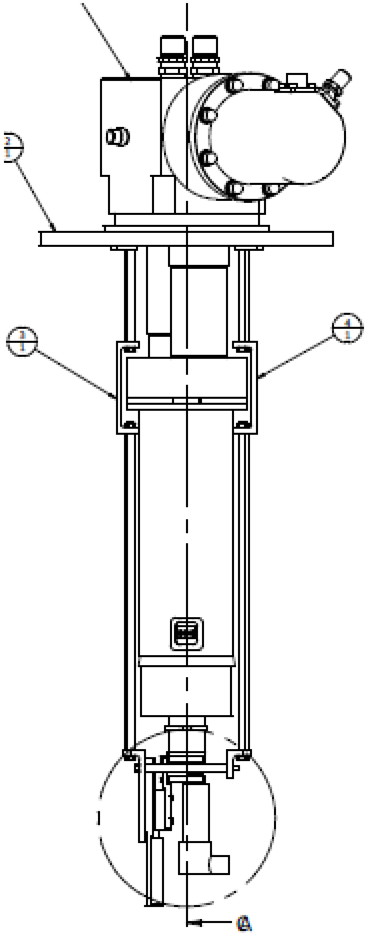
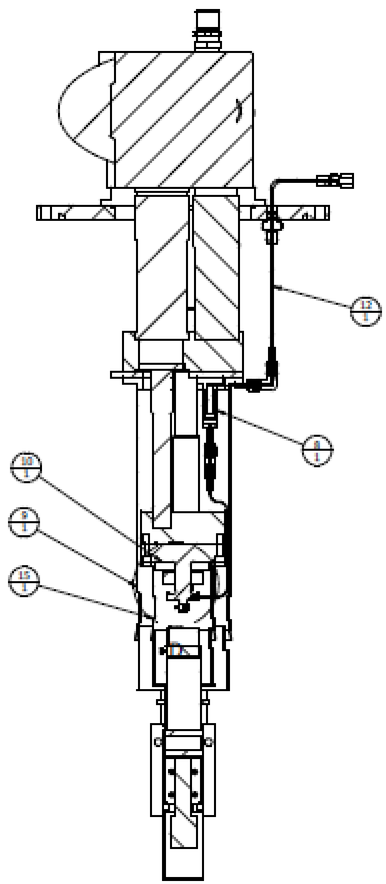
Design - Overview





SECTION A-A

Cryocooling

- Pulse Tube
  - – Cryogen free
  - – No moving parts in coldhead

1st Stage Capacity			40W @ 65K
2nd Stage Capacity			1.0W @ 4.2K
Lowest Temperature 2nd Stage			<3K
Cooldown Time 2nd Stage			<80min.
1st Stage Vibration (x,y,z)	±3μm	±2μm	±6.3μm

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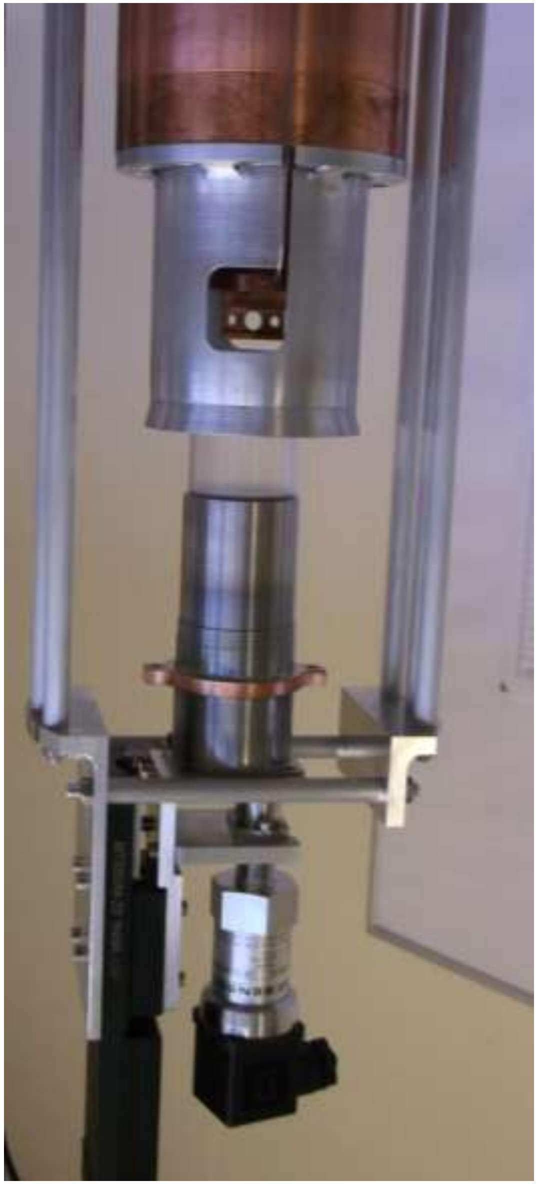

Design

- Local Hydrogen Boundary
  - Small volume
  - Seal
  - Transparent
  - Removable
  - Low conductivity

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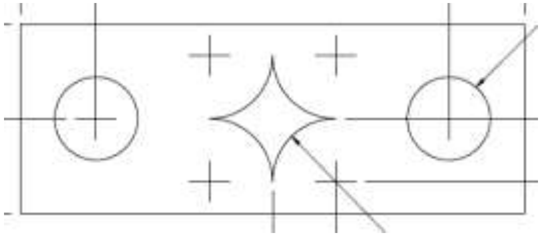
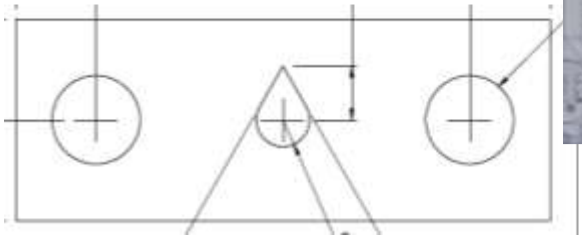
Design

- Target mount and foils
  - photo-etched in copper
  - smallest feature accuracy of ±25μm
  - Range of diameters





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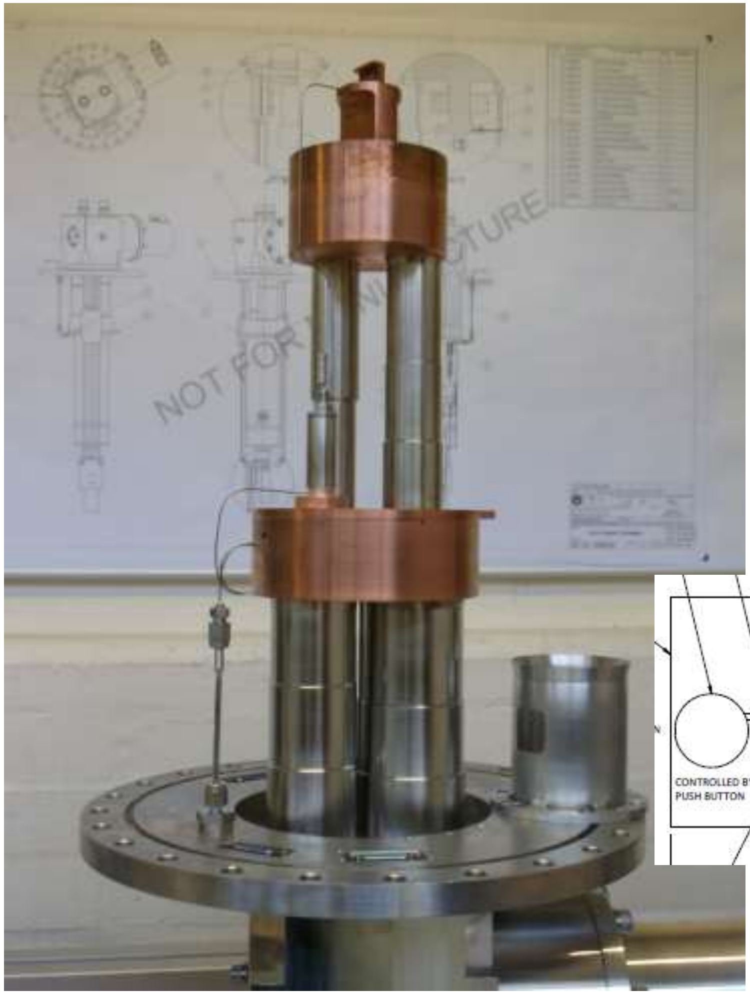
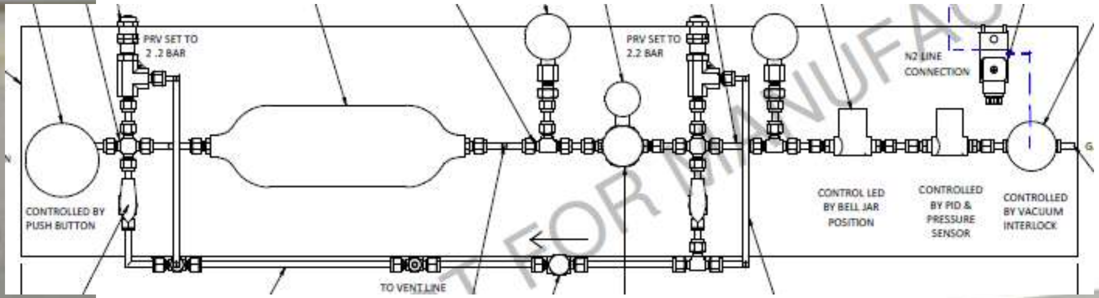
Design

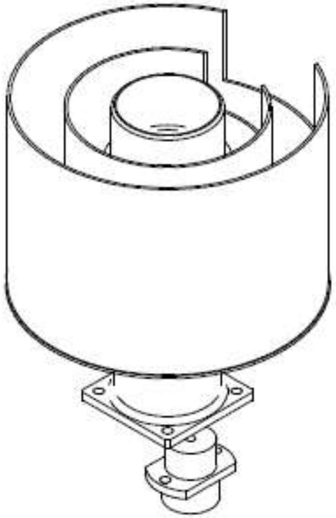


- Gas Feed
  - Capillaries
  - Heat Exchanger
  - Pressure & Valves



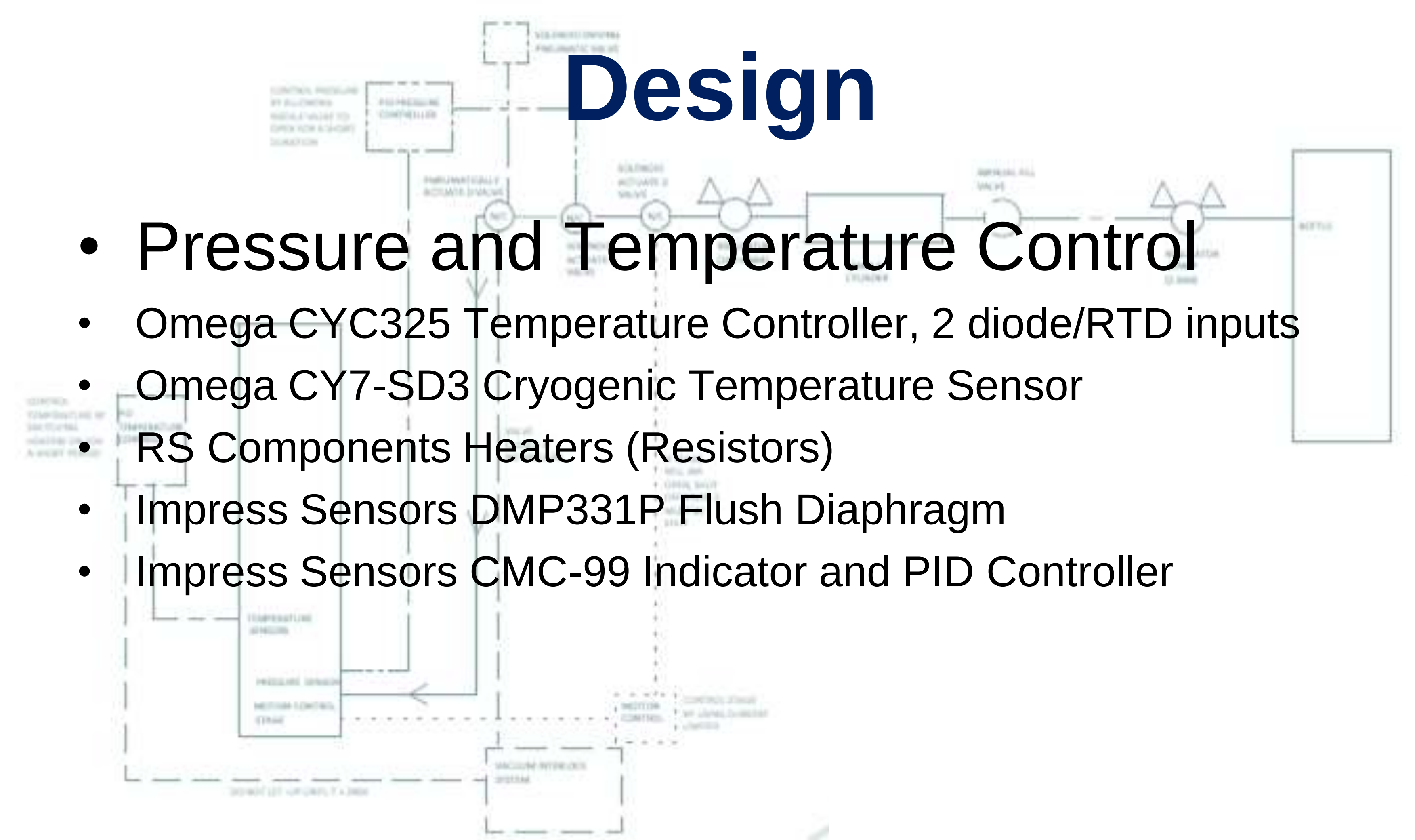
Design

- Heat Loads
  - Warm Gas
    - Pre-cooled
  - Room Radiation
    - Shields
    - Apertures
    - Move with boundary
    - Fixed to cold stages
  - Latent Heat



Design

- Pressure and Temperature Control
- Omega CYC325 Temperature Controller, 2 diode/RTD inputs
- Omega CY7-SD3 Cryogenic Temperature Sensor
- RS Components Heaters (Resistors)
- Impress Sensors DMP331P Flush Diaphragm
- Impress Sensors CMC-99 Indicator and PID Controller



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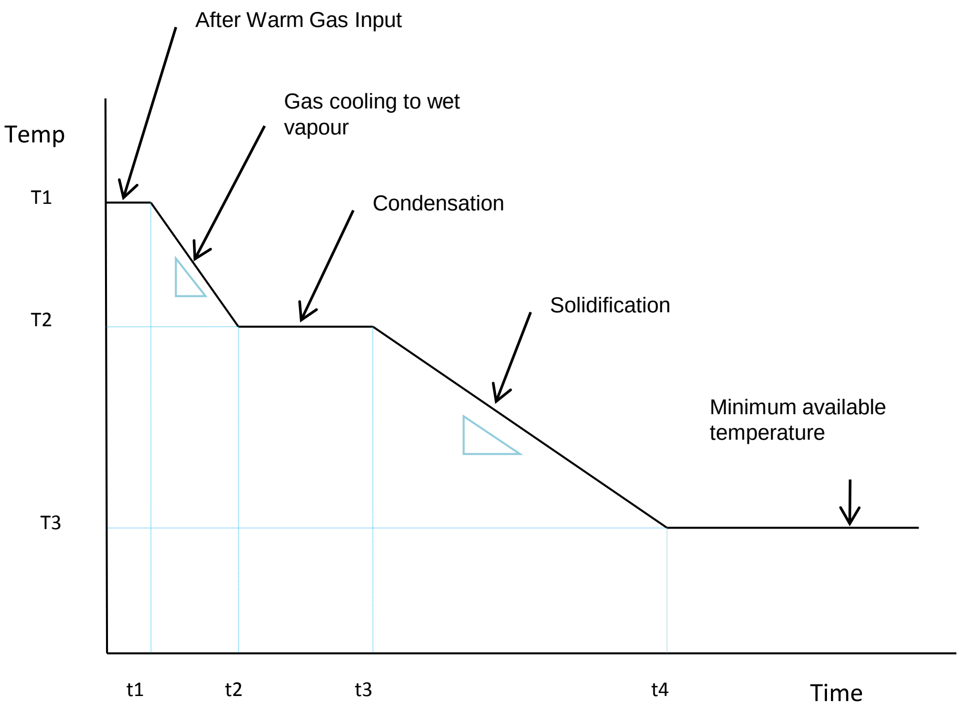
Testing

- Current Status
  - Fully assembled
- Engineering Tests
  - Pressure systems functioning
  - Pressure and temperature controllable
  - Temperature and pressure profiles



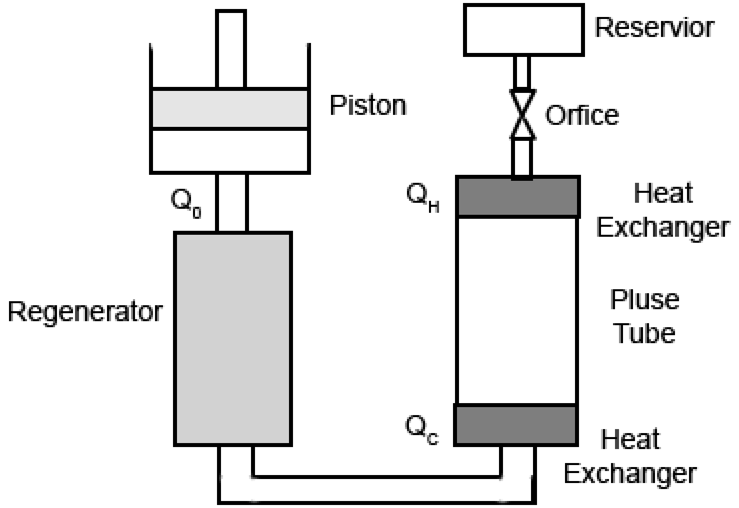
Characterisation

- Target parameters
  - Thickness
  - Foil design, surface roughness, feature accuracy
  - Time to produce targets
  - Sublimation rate
  - Repeatability
- Laser Testing
  - Alignment
  - Blast region
  - Surface Contamination

Thank you for listening.
Any questions?

Design - Cooling

- Pulse Tube Principle
  - Adiabatic Compression
    - Regenerator absorbs heat
    - Gas in pulse tube is heated
    - Rejects heat
  - Adiabatic Expansion
    - Gas in pulse tube cools
    - Absorbs heat as it flows through cold heat exchanger
    - Regenerator heats gas
  - Net effect of cycle
    - Average enthalpy flow from cold to hot end
    - Constant temperature gradient in regenerator



Fabrication of Ultrathin Near Critical Density Targets

Wenjun Ma

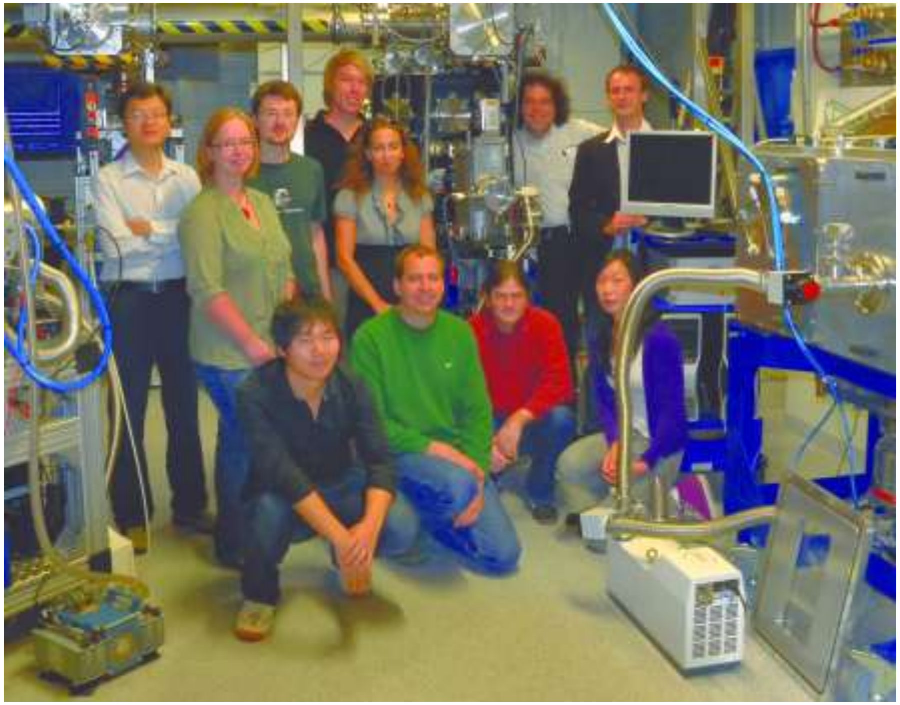
Department of Physics , LMU , Garching, Germany

<u>Group members</u>

J. Bin, K. Aligner, P. Hilz, D. Kiefer, C. Kreuzer, H. Wang, T. Ostermayr, J. Szerypo, H.J. Maier, D. Habs, J. Schreiber

4th target fabrication workshop, Mainz 2012.08.21

Team goal: laser-driven ion acceleration and its biomedical applications



Ludwig-Maximilians-Universität München:

K. Allinger, J. Bin, P. Hilz, D. Kiefer, W. Ma, Sebastian Raith, T. Ostermayr, Joerg Schreiber

K. Khrennikov, S. Karsch et al.

H. Wang, J. Szerypo, T. Tajima, X.Q. Yan, D. Habs, F. Krausz

W. Assmann, S. Reinhardt, W. Draxinger

S. Rykovanov, H. Ruhl

Technische Universität München

J. Wilkens , Nicole Humble, et al.

Why Near Critical Density Targets?

Group velocity of plane EM waves in plasma

$$v_g = c\left(1 - \frac{n}{n_c}\right)^{1/2} \rightarrow 0$$

Very high absorption efficiency:

- soft X-ray source
- ablation layer for ICF targets
- hot electron source for ion acceleration

Strong coupling between laser and plasma:

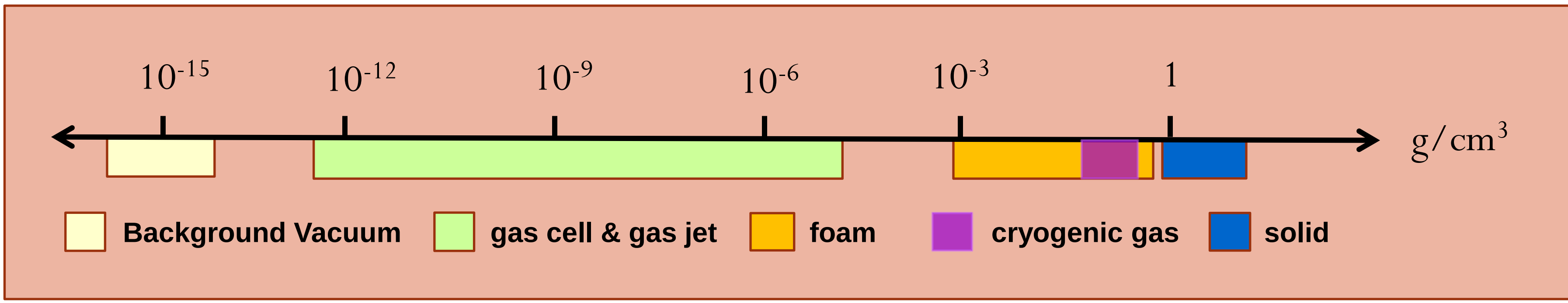
- pulse shaping
- relativistic plasma shutter

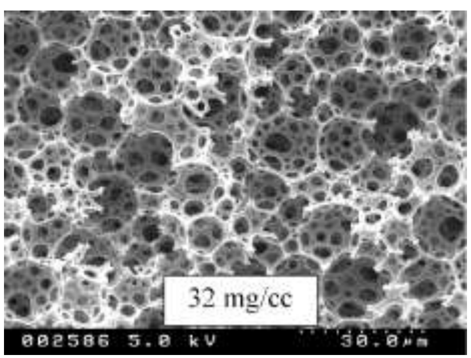
Critical density

$$n_c = \frac{m_e \omega}{4\pi e^2} = 1.1 \times 10^{21}\ /(\lambda/\mu m)^2 cm^{-3}$$

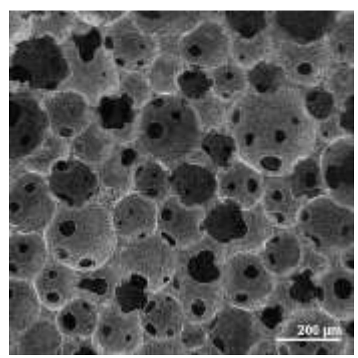
For λ=800 nm, fully ionized light atoms (C,N,O)

$$\boxed{\rho \sim 6\ mg/cm^3}$$

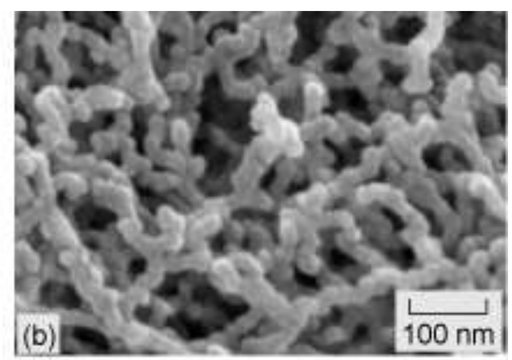




PolyHIPE foam



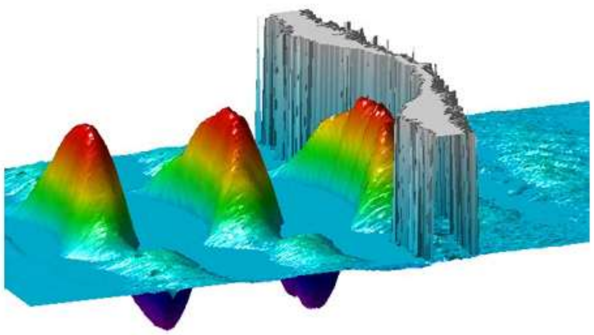
Polystyrene foam



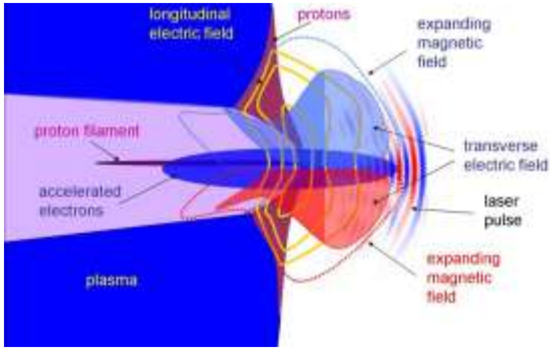
Silica aerogel

Near Critical Density Targets for Laser-driven Ion Acceleration

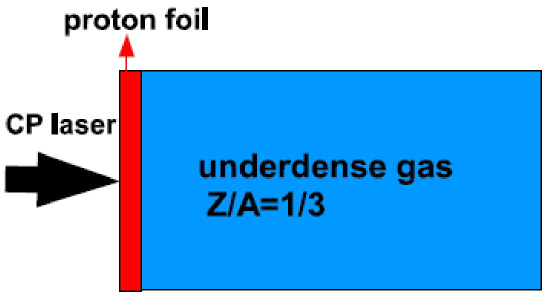
Enhanced TNSA & RPA



Magnetic vortex acceleration



Two-stage acceleration



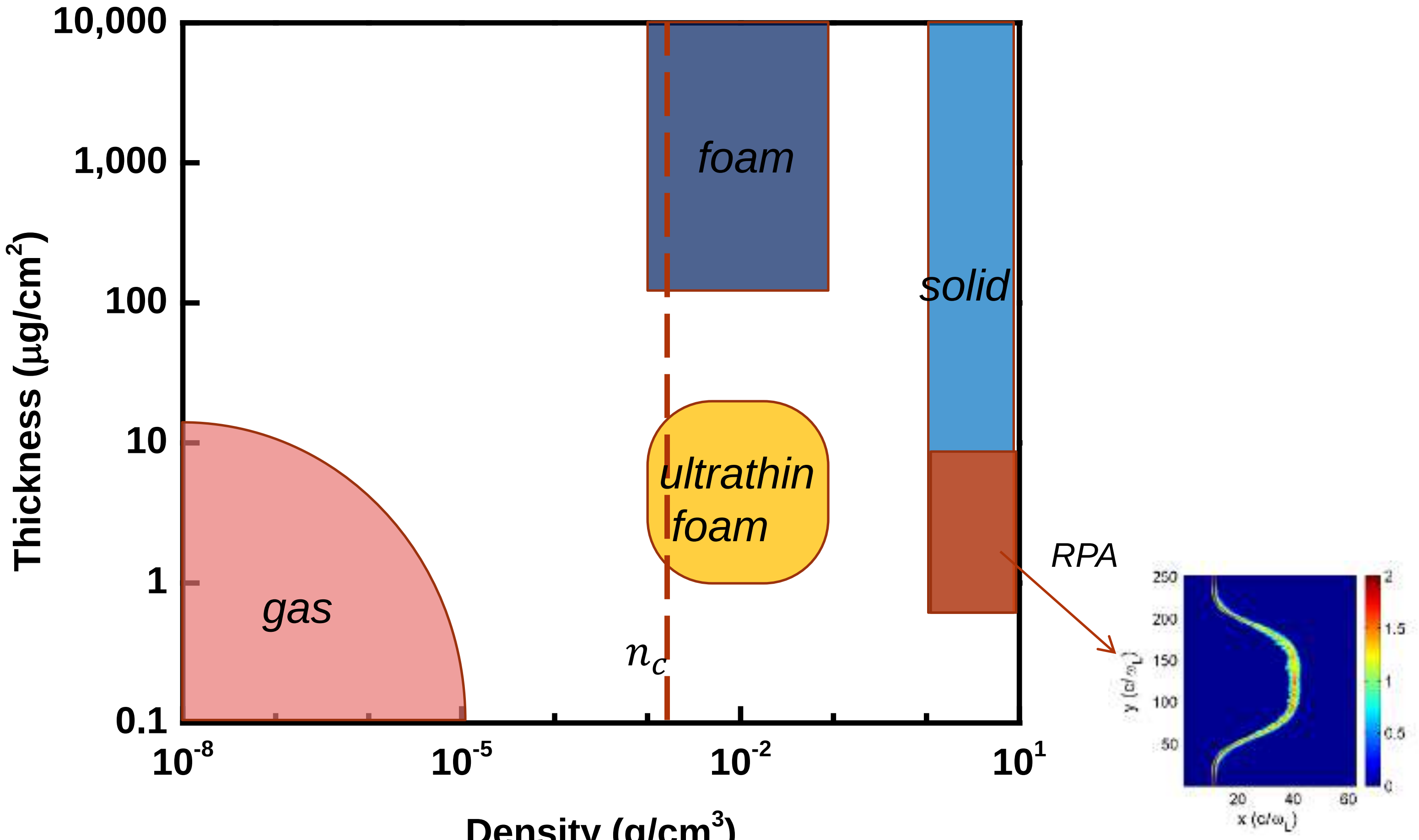
Requirements

- ❑ high homogeneity

  focus spot 3~5 μm, pore size < 200 nm

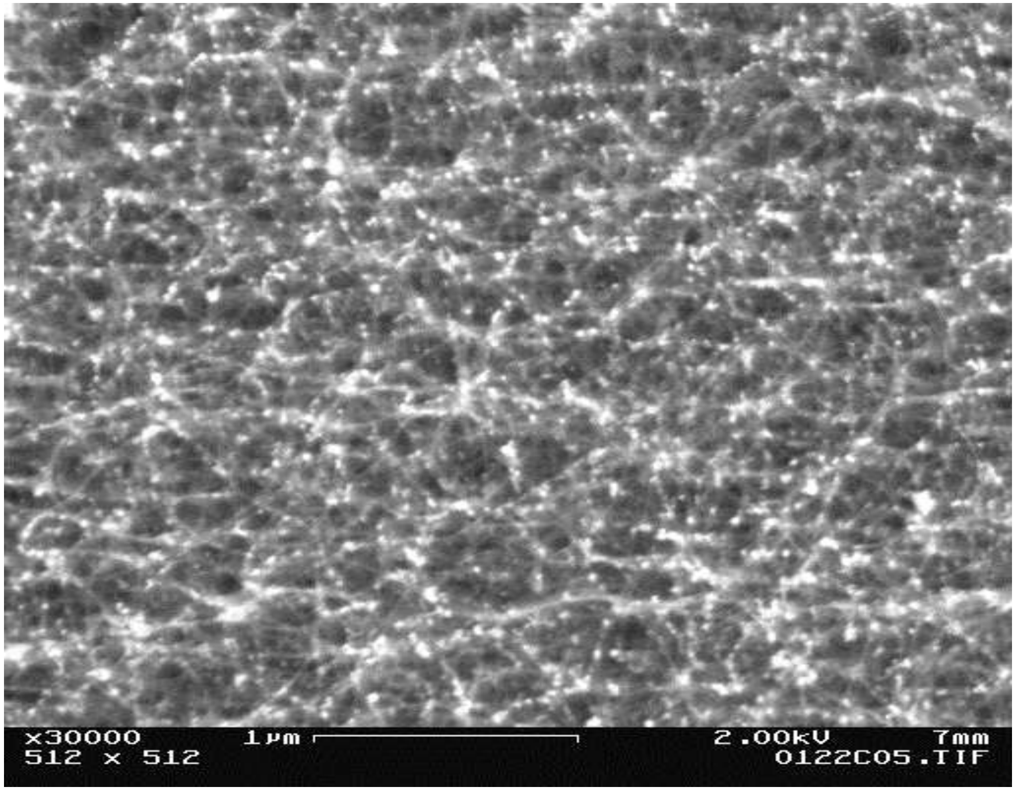
- ❑ ultrathin

  depletion length of high-power femtosecond laser: 2~10 μm



A. Henig et al. Phys. Rev. Lett. **103**, 245009 (2009).

Ultra-low density, ultra-thin carbon nanotube films

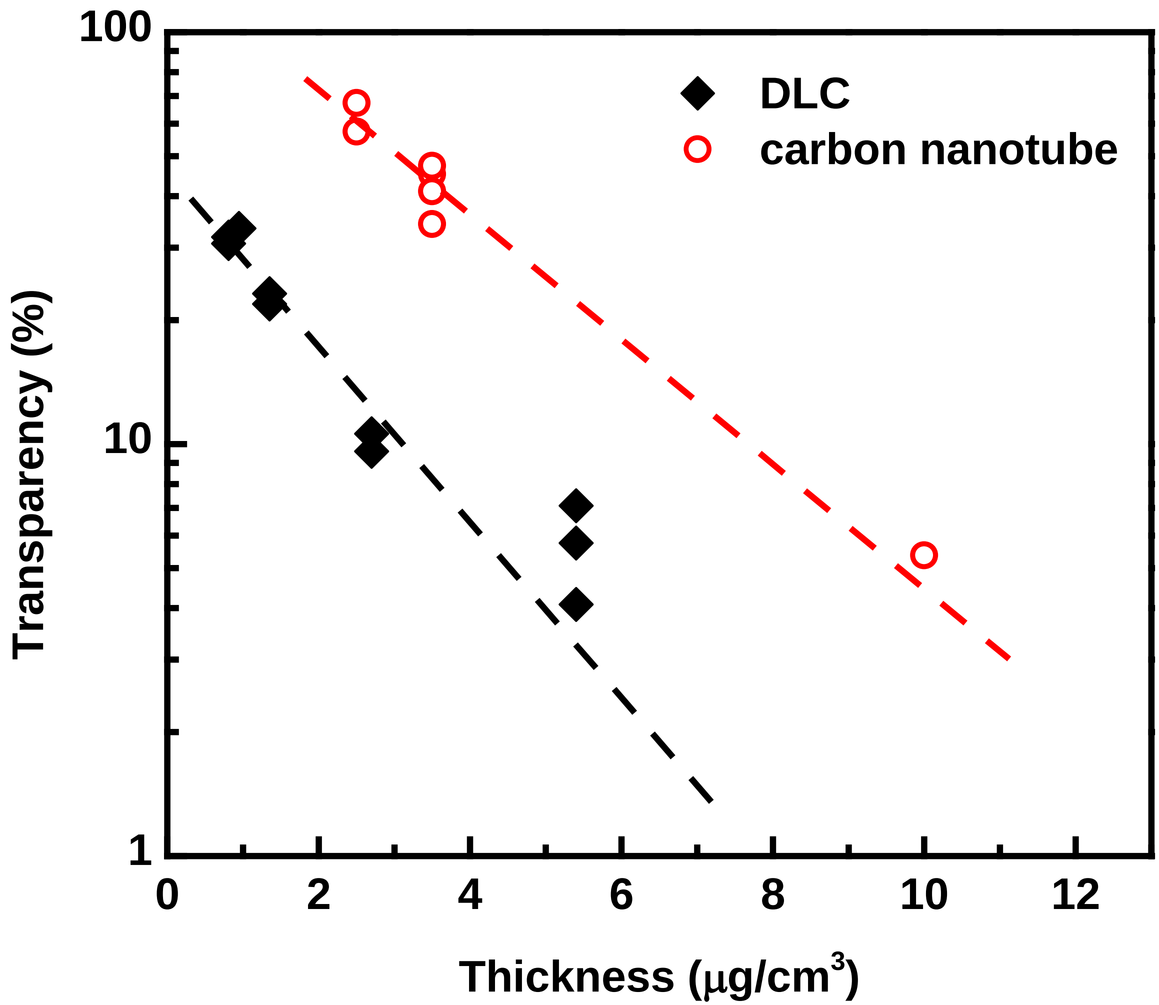


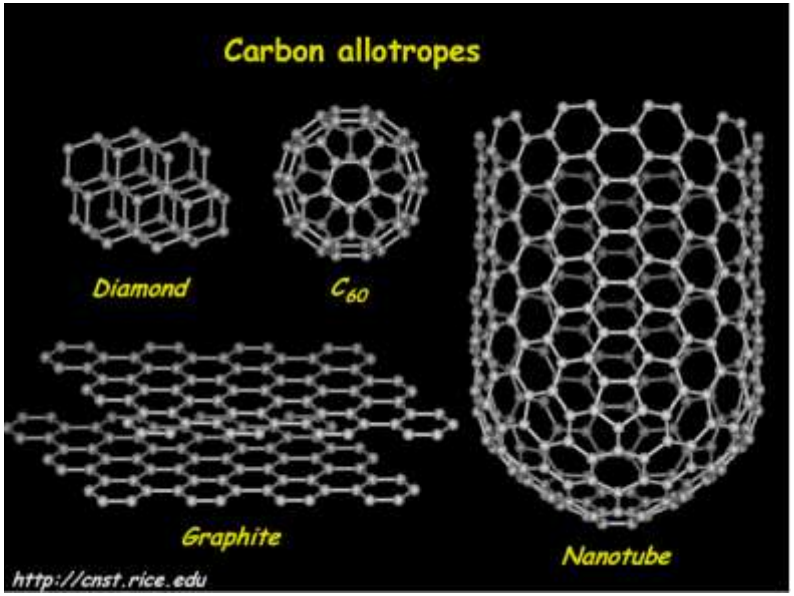
ρ= 25~50 mg/cm^3

d= 2.5~100 ug/cm^2

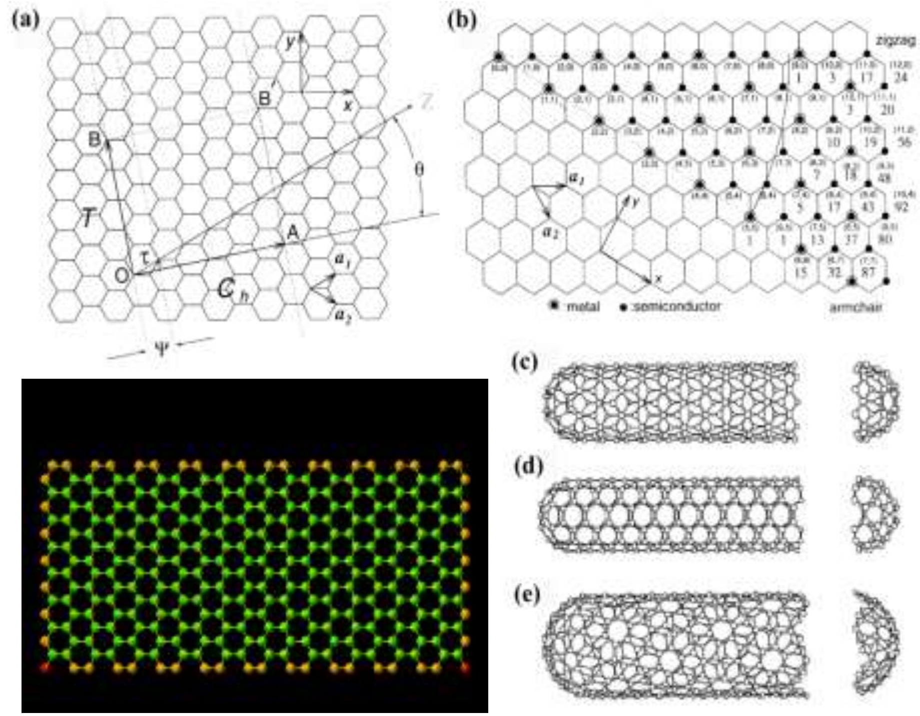
n_e/n_c =5~10

Transparency *vs* targets thickness (from Astra Gemini 500TW laser)





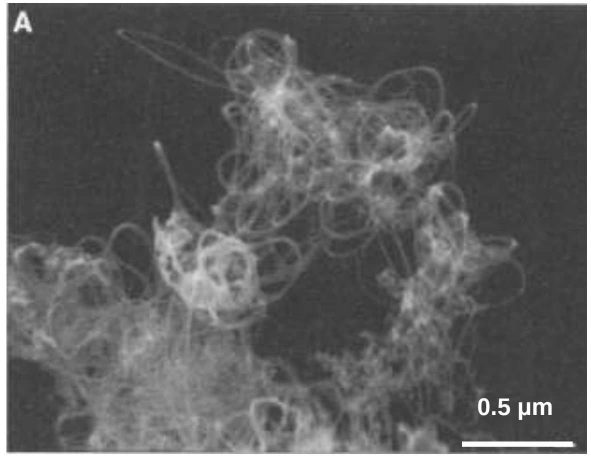
allotropes of carbon

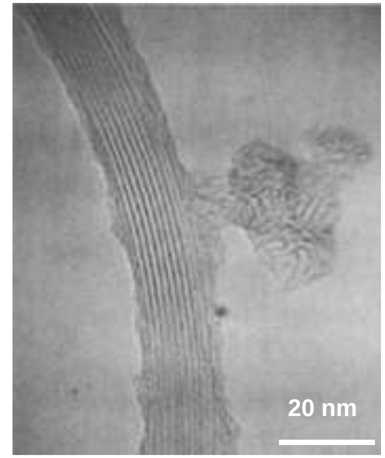


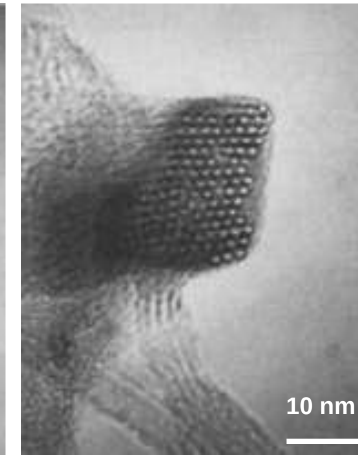
a SWNT can be viewed as scrolled from a single lay of graphite

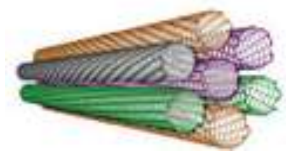
Individual SWNT

SWNT bundle



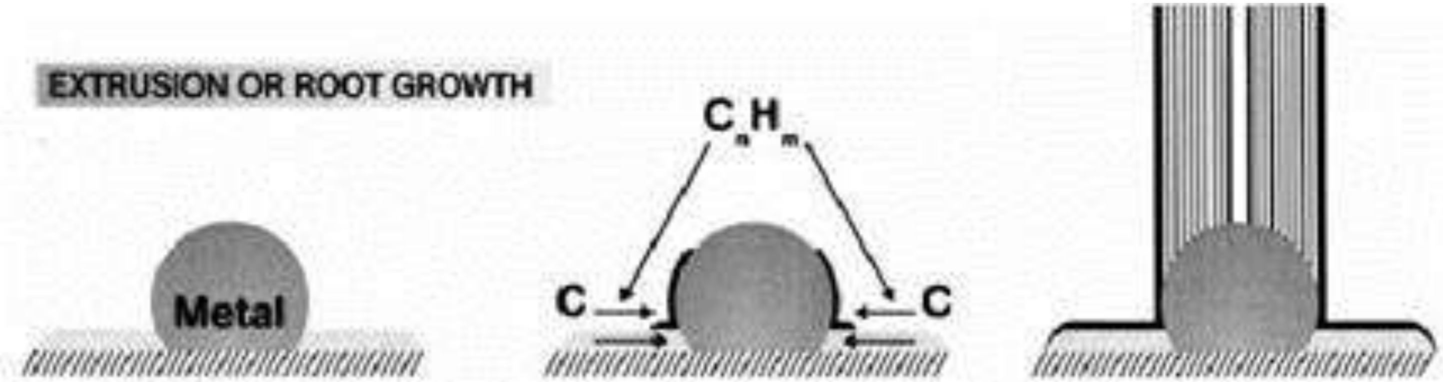






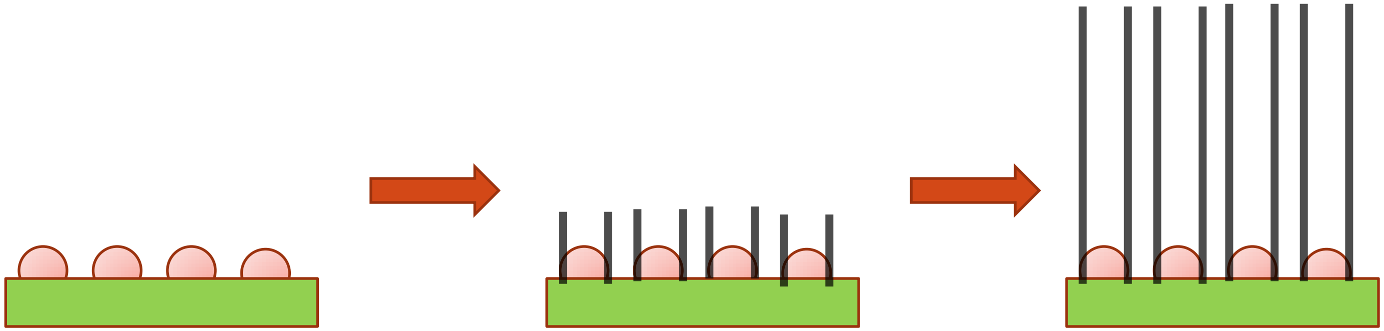
➢ Diameter	0.4~2 nm	2~40 nm
➢ Length	1µm~1cm	1µm~1cm
➢ Metallicity	Metallic or Semiconducting	Metallic
➢ Conductivity	/	~20,000 Scm^{-1}
➢ Tensile Strength	30~40 GPa	<20 GPa

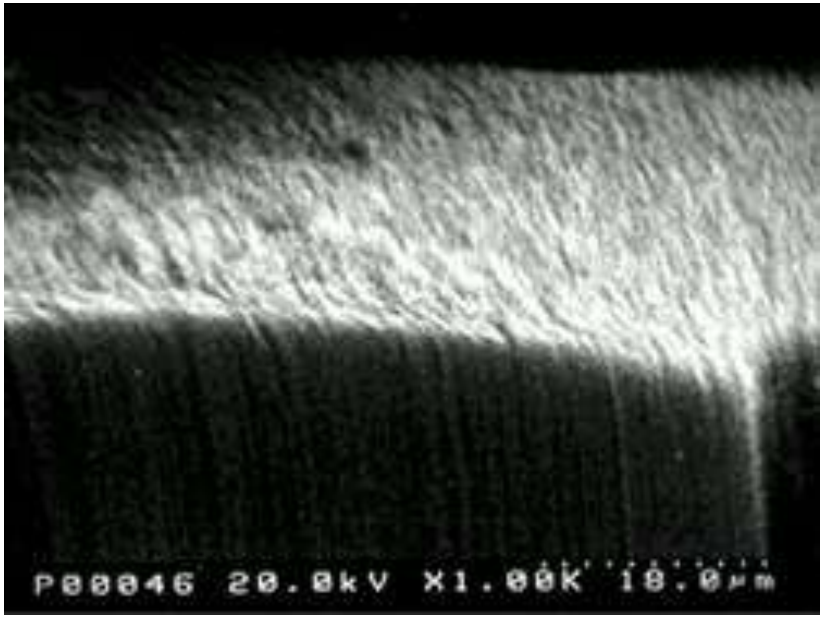
Growth mechanism of Carbon Nanotubes

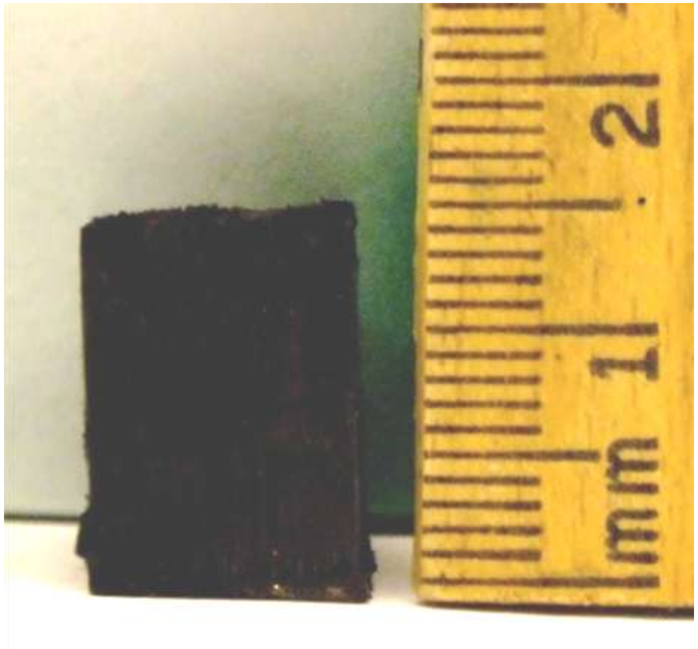


nanoparticle formation → carbon aggregation → nanotube growth

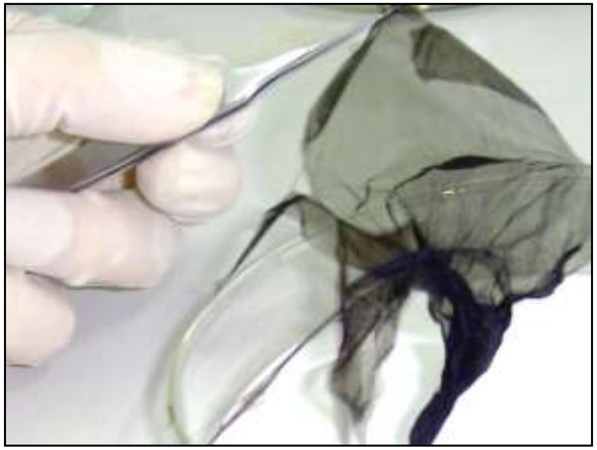
Carbon Nanotube Arrays

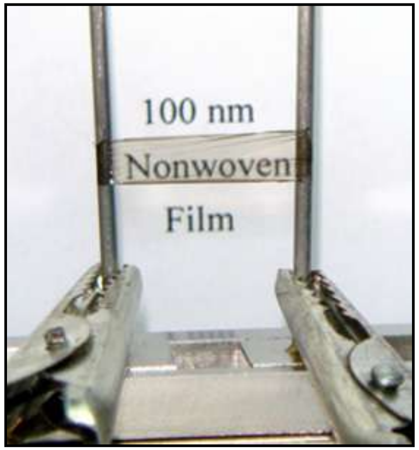


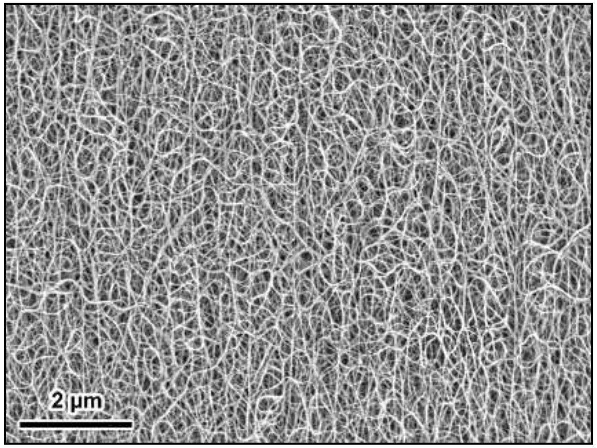


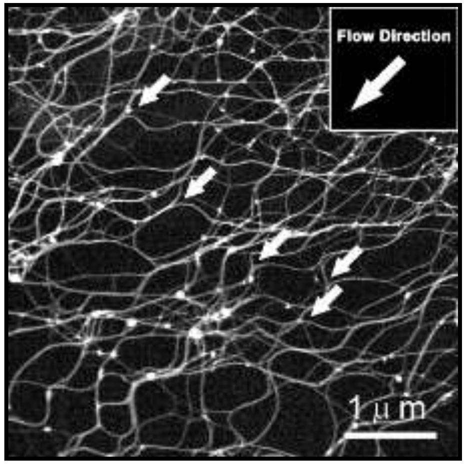


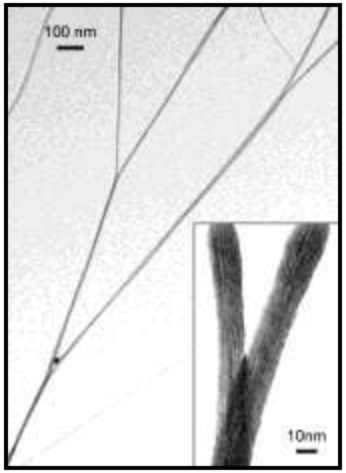
Strong, Highly Conducting, Transparent SWNT Films











block inter-bundle slippage under load

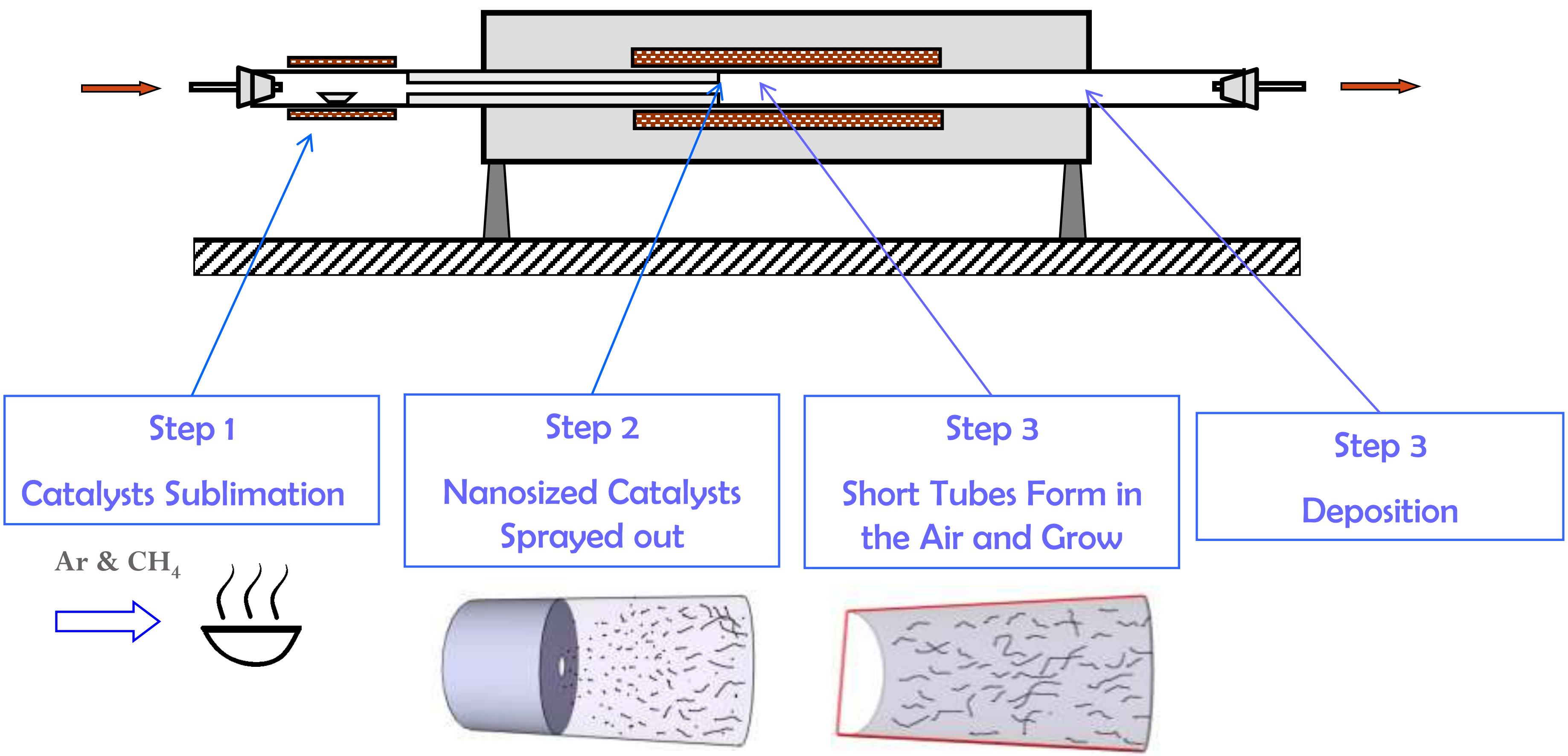
→ tensile strength > aluminum sheet

lower tunneling barriers & higher electron transition efficiency between SWNT bundles

→ $\sigma \sim 2000$ S/cm

Ma *et. al.*Nano Letters 2007, 7 (8), 2307

Floating Catalyst Synthesis Method



Chemical Vapor Deposition System

High Temperature Tube Furnace

Heated Length: 1 m

Highest Working Temperature: 1300°C

Gas Flow System

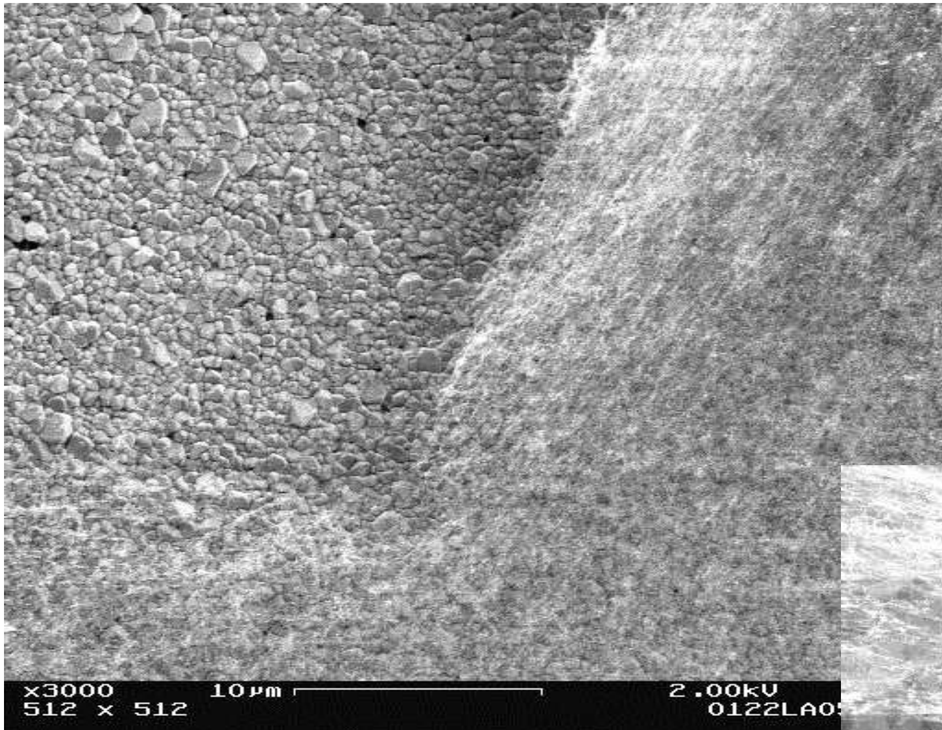
Gas type: Ar, CH_4, O_2, H_2

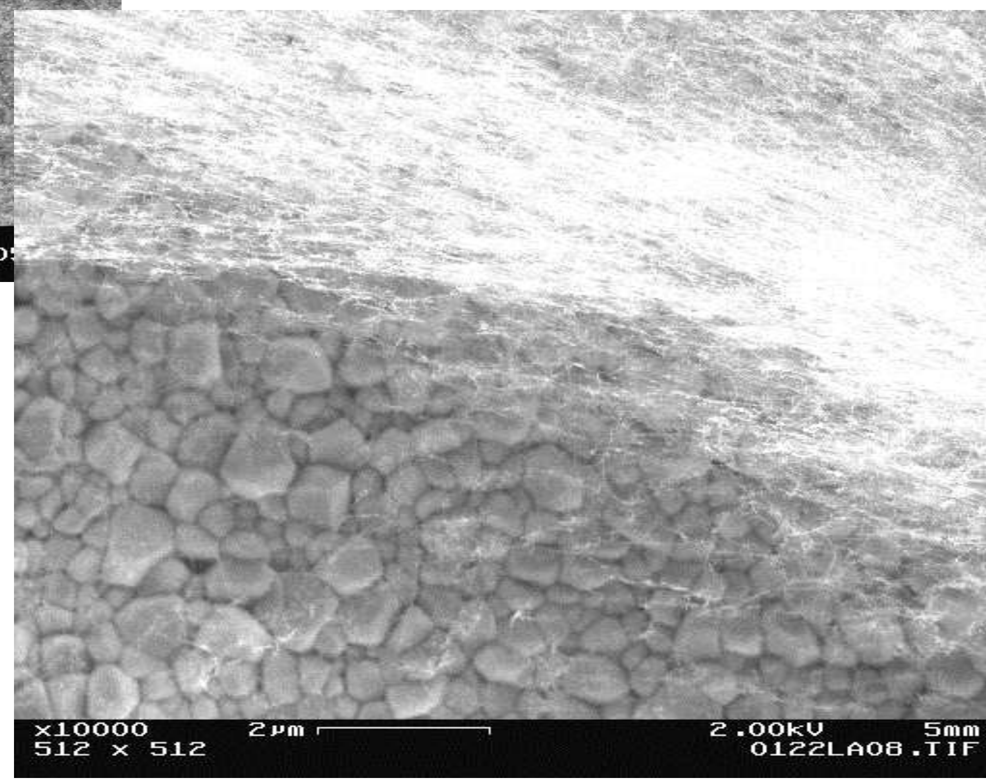
Maximum Flow rate: 10,000 sccm

CH_4 Flow Precision: 0.01 sccm

System sealing: HV standard

DLC & CNT double-layer targets





THANK YOU

Novel Micro-Focusing Cone Indent Target Fabrication

D.Haddock[1], C Spindloe[1], M. Tolley[1], M Beardsley[2], E Barber[2], G Scott[3], and D Neely[1]

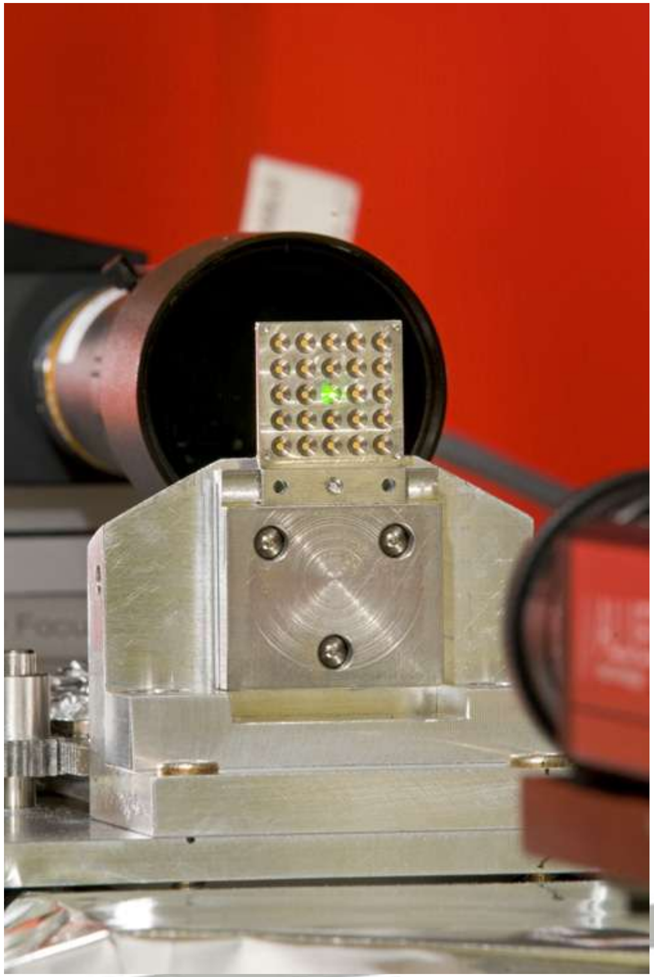
[1]Central Laser Facility, Rutherford Appleton Laboratory, Science and Technology Facilities Council, Harwell Oxford, Didcot, Oxon, OX11 0QX.

[2]RAL Space, Rutherford Appleton Laboratory, Science and Technology Facilities Council, Harwell Oxford, Didcot, Oxon, OX11 0QX.

[3]Department of Physics, University of Strathclyde, Glasgow UK.

High-repetition rate targetry

~2m



• World's first high repetition rate, dual beam Petawatt user facility
• Medium energy (15J per beam) but ultra-short pulses (30 fs), 1 shot every 20 seconds

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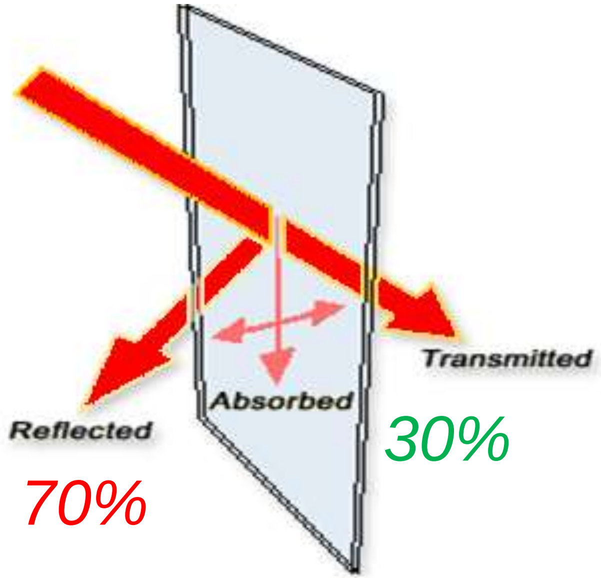
Slide courtesy of C.Spindloe[1]

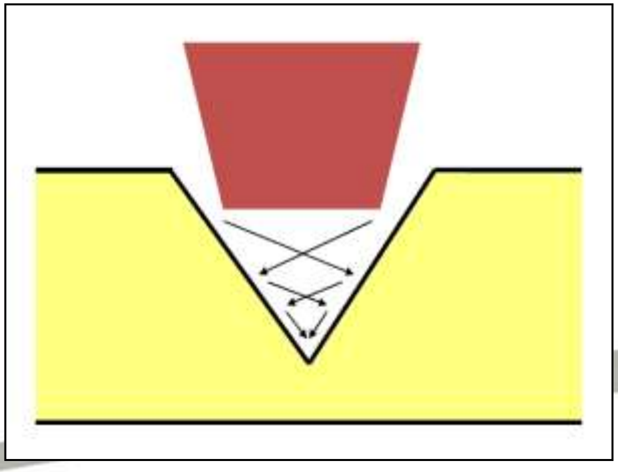
Background



Increase in laser power is expensive and tricky

- Approximately 70% laser light is specularly reflected from flat targets
- This energy is usually lost from the system!

“Light trap” Proposed



Multiple internal reflections increase chance of absorption

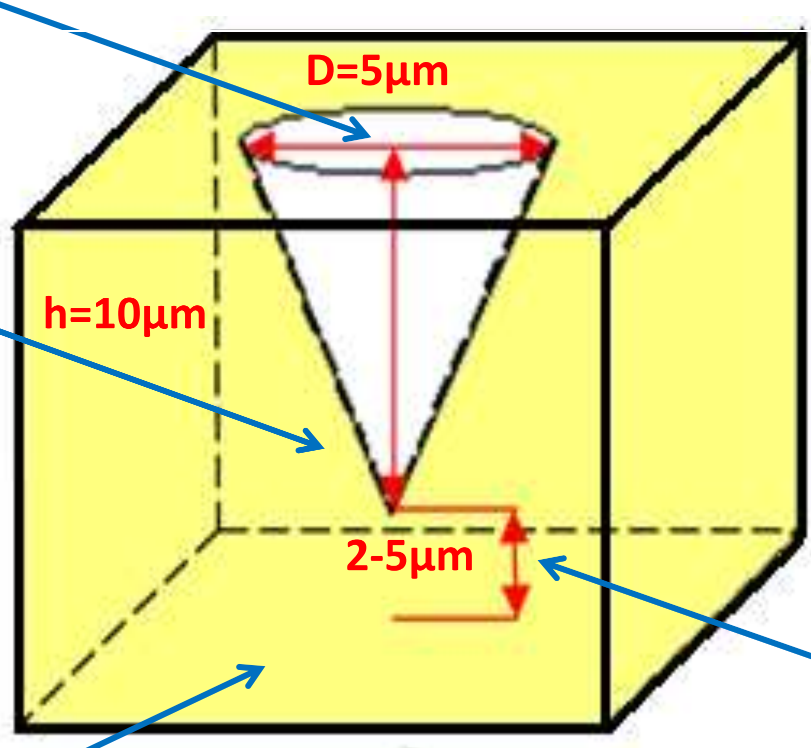
Estimates at an increase to 60-70% laser absorption; double the energy previously available.

Science & Technology Facilities Council

Design

Opening diameter ~ focal limit Laser system. (Astra = 2µm full width half maximum)

30º opening angle



Array of targets for high repetition rate, 500µm spacing to avoid neighbour damage

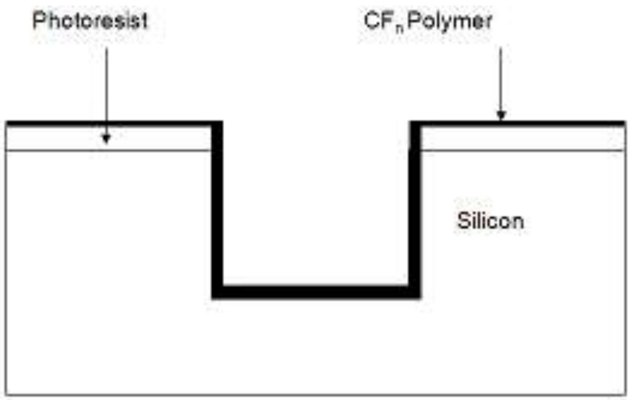
Small exit distance allows ion acceleration

Polished rear surface <1µm Ra

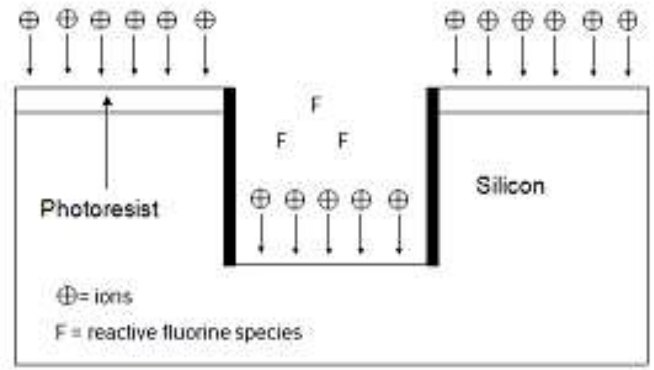
Production of cone shape

<u>Deep Reactive Ion Etching of Silicon substrates:</u>

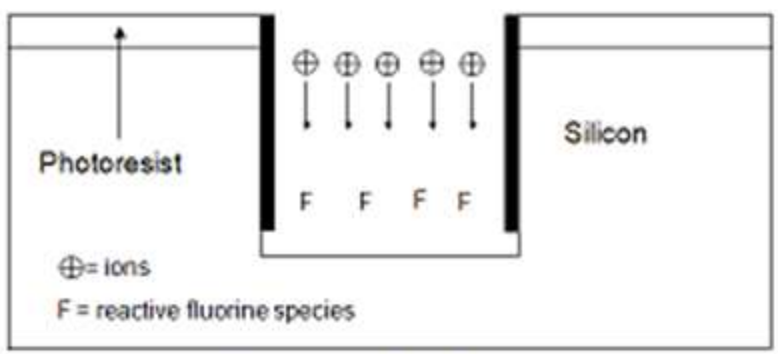
A ratio of the etching gas **SF_6** to a sidewall passivation polymer **C_4F_8** determines the extent of the etch.



a)A thin polymer layer is deposited on the wafer by the decomposition of C_4F_8 gas in the plasma.



b)The passivation layer is removed by ion bombardment only from the horizontal surfaces.

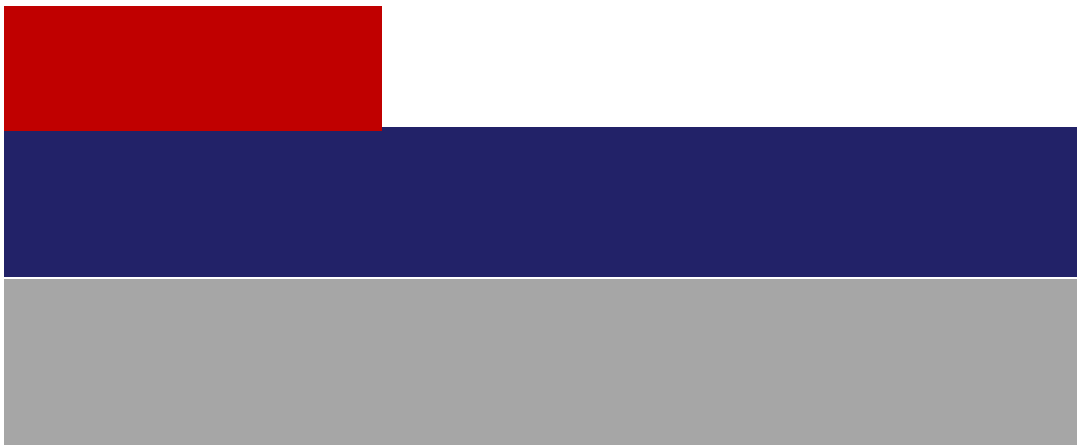


c)Silicon is etched by the flourine species.

Illustrations courtesy of A.Malik[2]

Cone Creation

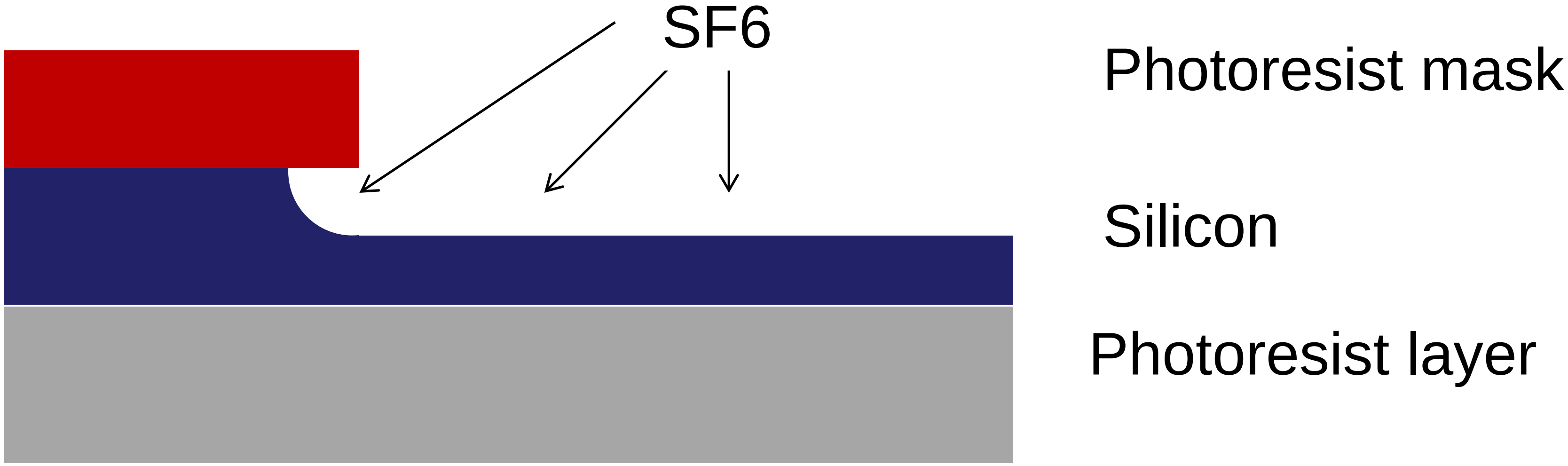
Step 1: Mask silicon area with photoresist



Illustrations courtesy of G.Arthur

Cone Creation

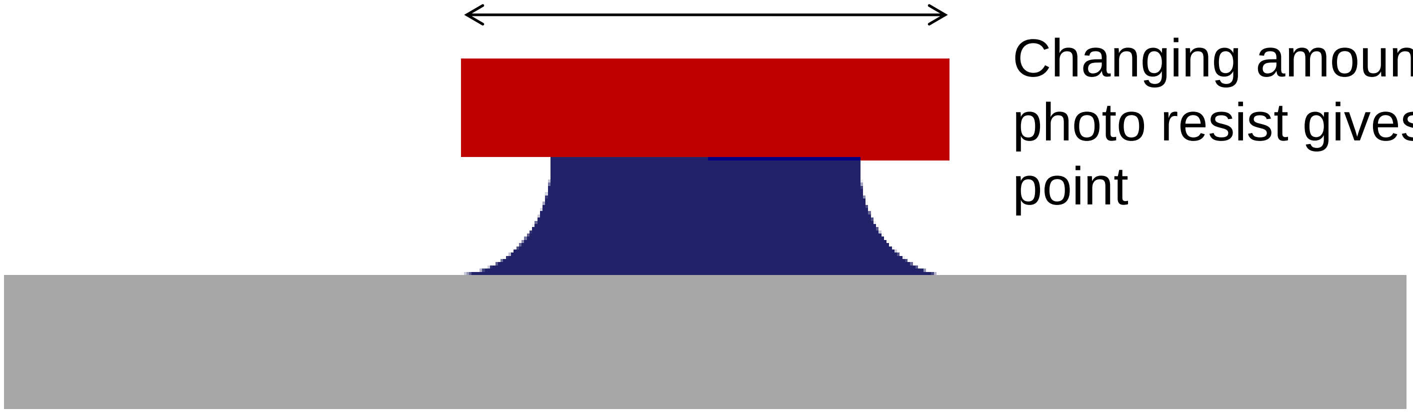
Step 2: SF6 Ions attack silicon. Extent of attack dependant on SF_6/C_4F_8 ratio



Illustrations courtesy of G.Arthur

Cone Creation

Step 3: Etch simultaneously on the other side.
Continue to reach desired shape



Changing amount of photo resist gives sharper point

Photoresist mask made into to repeated pattern allowing dozens of cones to be mass produced.

Illustrations courtesy of G.Arthur

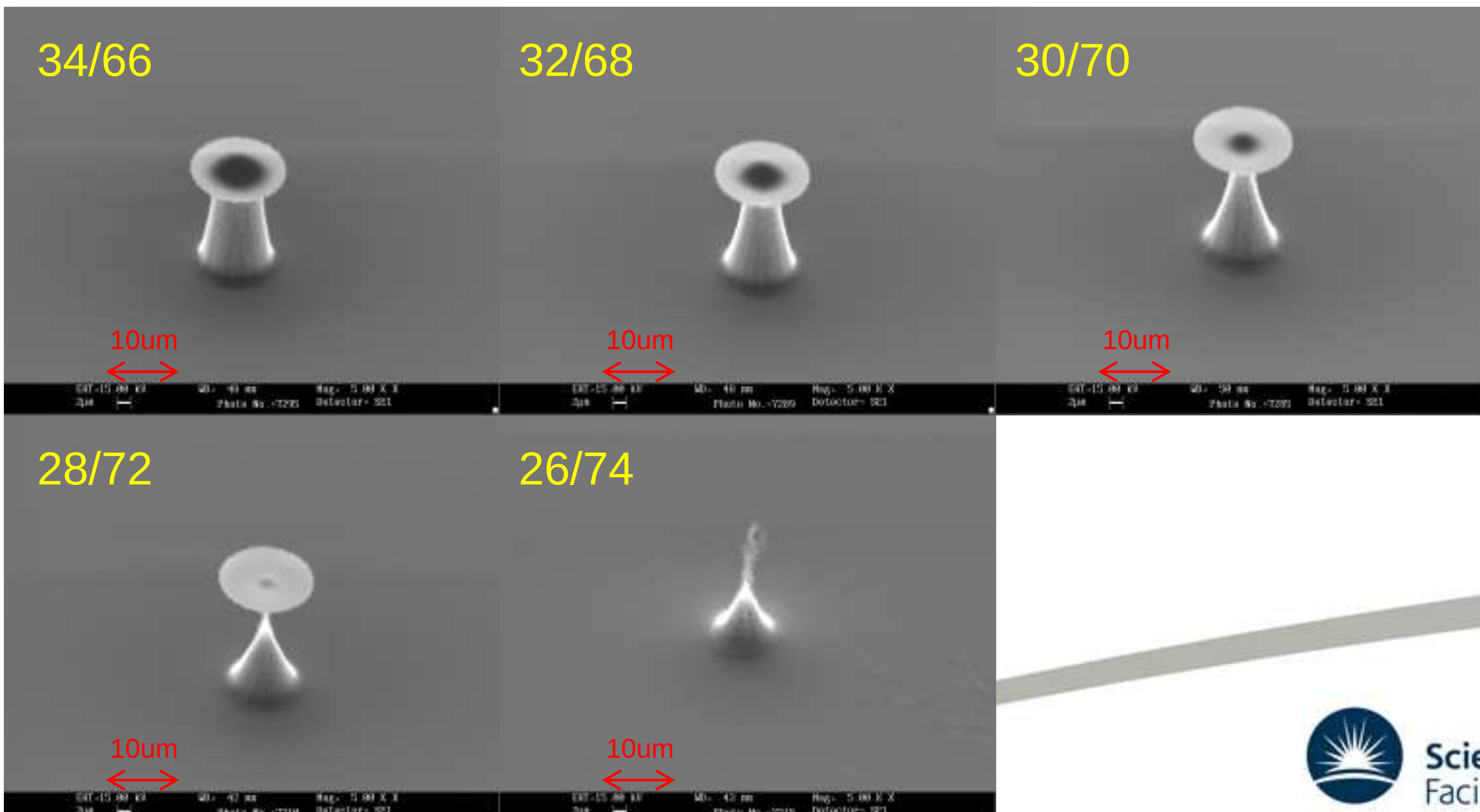
Cone Creation

Step 4: Remove photoresist using solvent

Illustrations courtesy of G.Arthur

Characterization

- Micro-cones flash coated with gold. Plasma Deposition
- Scanning Electron Microscope for dimension analysis
- Gas Ratio of Passivation/Etch
- Increase in relative amount of etching gas to passivation gas gives differing shapes



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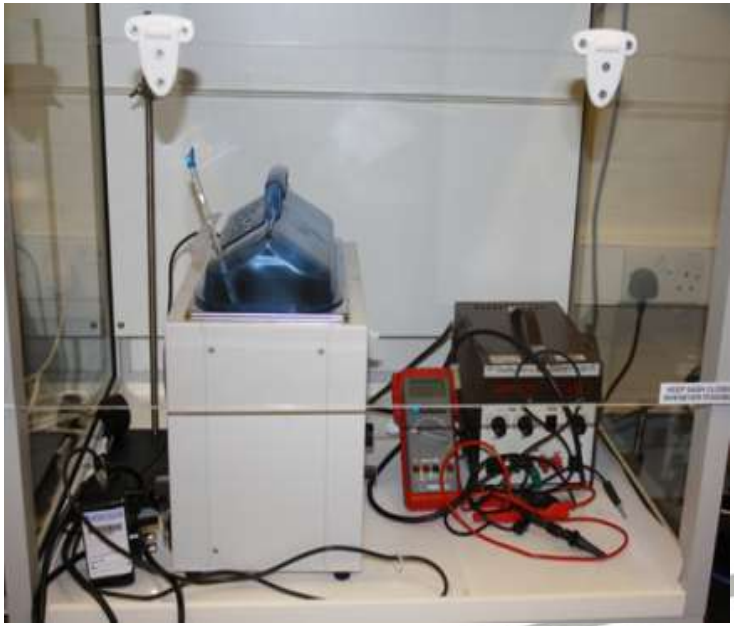
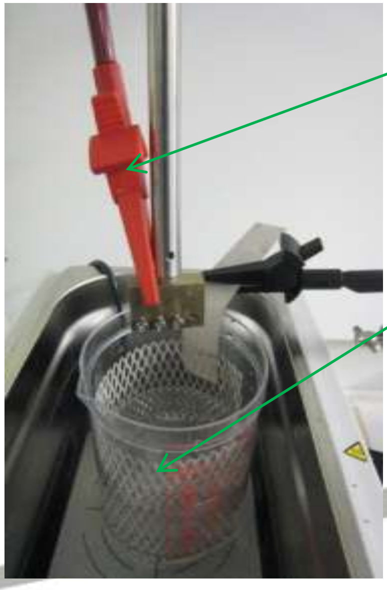
Electroplating

- Deposition of thick metal layers (up to 30μm) allows the coating of complex intricate forms
- The deposition of a metallic coating onto an object is achieved by putting a negative charge on the object to be coated and immersing it into a solution which contains a salt of the metal to be deposited. The object to be plated is made the cathode of an electrolytic cell





Negative Cathode

Ammonium Gold Sulphite Solution

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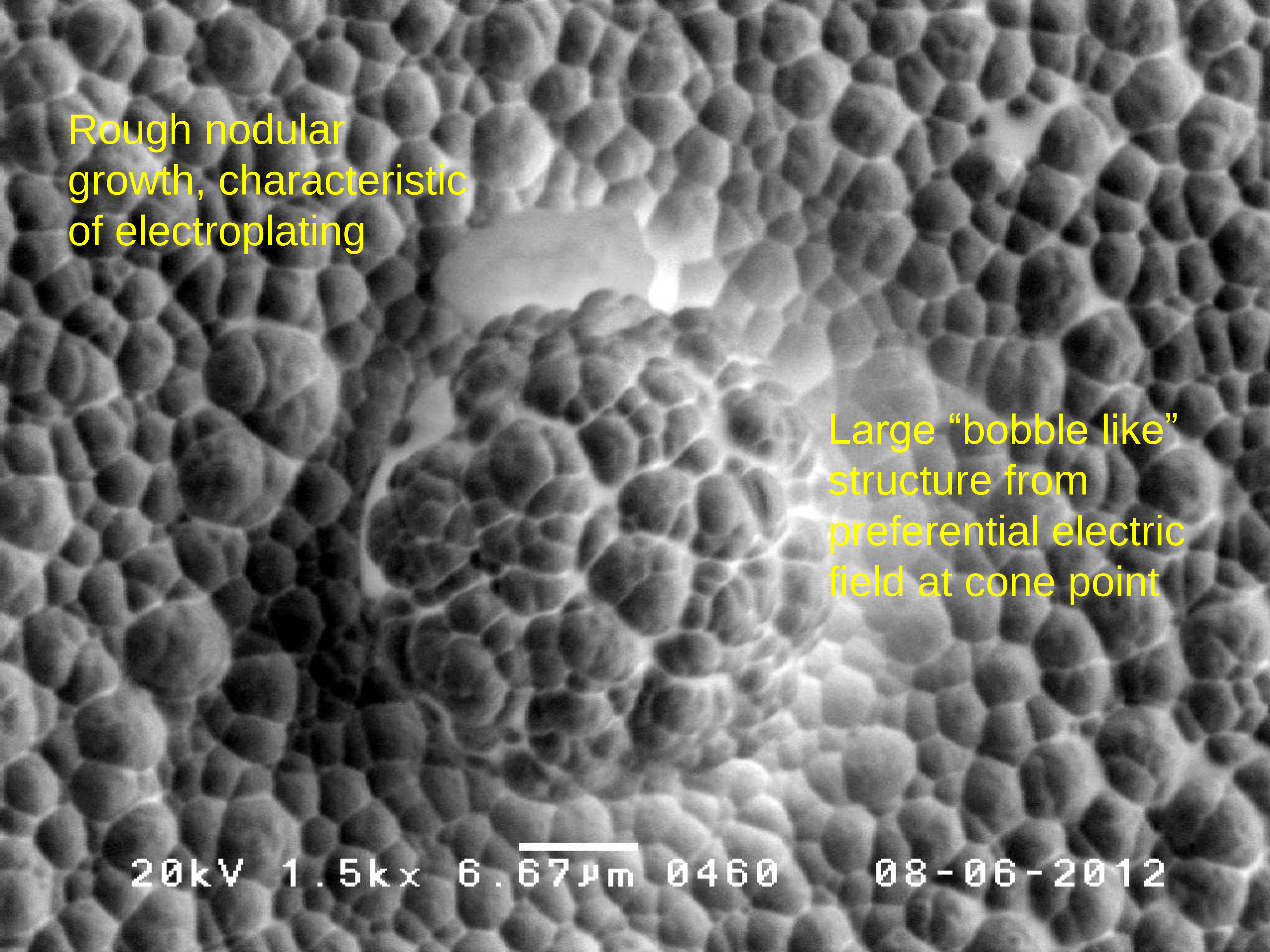
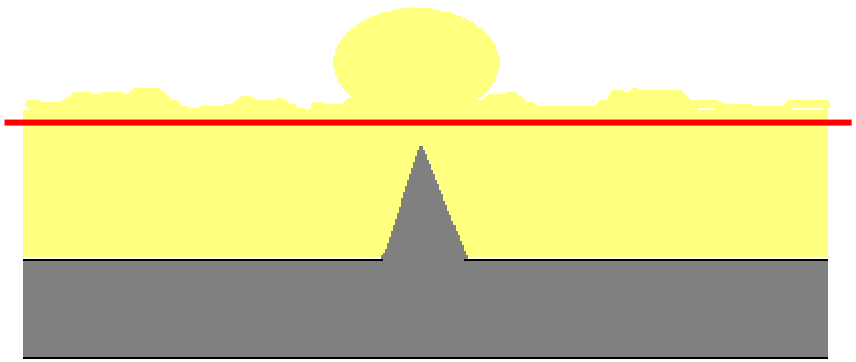
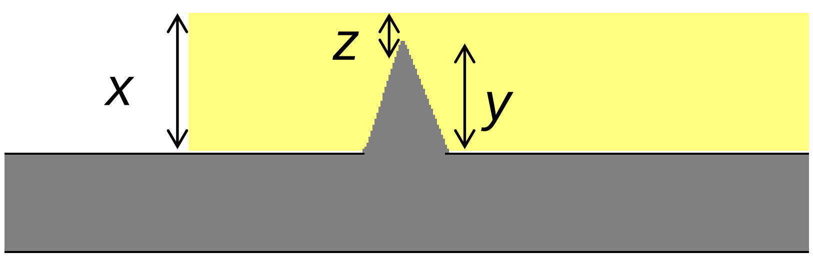

Rough nodular
growth, characteristic
of electroplating
Large “bobble like”
structure from
preferential electric
field at cone point
20kV 1.5kx 6.67µm 0460 08-06-2012

Precision Machining

- **Need to remove nodular structure and leave a polished exit surface**



•High precision machining tool strips rough surface layer
•Leaves polished flat surface <1um Ra



•*x* dimension known from step height measurement
•*y* dimension known from SEM
•Therefore *z* characterized with accuracy equal to that of the x and y measurements

Final Stage: Etch Silicon with Potassium Hydroxide!

Conclusion

•Concept: Improve Laser interaction efficiency by cone-indent geometry

Order of magnitude ~ Focal spot

•Create cone mould by DRIE of Silicon. Ratio of Passivation and etching gas important

•Characterization at mould stage

•Electroplate to above cone height

•Precision Machine rear surface form. Etch Silicon

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Thank you!

Dave Neely – *Concept*

Eleanor Barber – *DRIE*

Sam Serra - *Electroplating*

Matt Beardsley – *Precision Machining*

Chris Spindloe – *Supervision*

QUESTIONS?

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References

- [1] *Fabrication and Experimental Delivery of Targets for High Power Laser Systems*

  C.Spindloe – Target Fabrication CLF

- [2] **Micron & nano scale targets for high power laser experiments.**

  A.Malik - MNTC

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