ISTITUTO NAZIONALE di FISICA NUCLEARE

UNIVERSITY of PADUA in the framework of the MASTER in “Surface Treatments for Industrial Applications”

and the TESLA Technology Collaboration

The International Workshop on:

THIN FILMS AND NEW IDEAS FOR PUSHING THE LIMITS OF RF SUPERCONDUCTIVITY

October 9 – 12, 2006

Legnaro National Laboratories (Padua) ITALY

Bejing 2004: the Choice of Cold Technology

Evaluation Matrix

Matrix parameters which turned out to be more important:

Scientific issues

Technical issues

Physics operation issues

Schedule issues

Social impact of ILC

It was agreed that cost of either machine could not be reliably assessed. Cost was removed from the matrix.

Giorgio Bellettini

Beijing 2004 - International Conference on High Energy Physics

***International Technology Recommendation Panel** of the*
International Committee for Future Accelerators (ICFA)

Front line from left to right:
Akira Masaike, George Kalmus, Volker Soergel, Barry Barish, Giorgio Bellettini, Hirotaka Sugawara,Paul Grannis
Back line from left to right:
Gyung-Su Lee, Jean-Eude Augustin, David Plane, Jonathan Bagger, Norbert Holtkamp, Katsunobu Oide

“…On the basis of that assessment, we recommend that the linear collider be based on superconducting rf technology… ”

“…Both the 'warm' technology and the 'cold' superconducting technology would work for a linear collider…

Barry Barish

“…We based our decision on a set of criteria that address the scientific, technical, cost, schedule, operability issues for each technology, as well as their wider impacts on the field and beyond…”

Each offers its own advantages, and each represents many years of R&D by teams of extremely talented and dedicated scientists and engineers. At this stage it would be too costly and time consuming to develop both technologies toward construction. …”

Then …at SCRF Cornell 2005

…”This cavity design is already 10 years old! In next 10 years it will become obsolete. Therefore R&D is MANDATORY!”

Barry Barish

Workshop Aim

The present superconducting RF accelerator technology is based on solid Nb. Thin film technology offers considerable savings in fabrication costs and what is even more important it opens the way to use alternative superconducting material with enhanced intrinsic properties such as critical temperature and critical field. Intensive and coordinated R&D effort is of decisive importance to explore the realization of this promise and to make the benefits available to the next generation of SC accelerators. The aim of this workshop is to bundle the expertise from industry, research laboratories and accelerator technology in order to launch a new initiative in thin film and innovative related technology for superconducting RF accelerator application. **The immediate infusion of industrial expertise and specialists from cross-disciplinary fields, as for instance superconductivity, plasma physics, material science, nanotechnology and rf engineering**, is of crucial importance

- **Superconductivity**
- **Plasma Physics,**
- **Material Science**
- **Nanotechnology**
- **Rf Engineering**

TESLA

INFN

- 47 talks over 3 ½ days
- 68 participants
- International workshop → 3 regions represented

INFN / CNR / Univ. - DESY / Max Plank Inst. / Nurnberg Univ.

- CNRS / CEA – CERN - Andrzej Soltan Inst. - Tel Aviv Univ.

JLab – Los Alamos - Argonne - Fermi Lab - Cornell / California / Florida Univ.

- SLAC

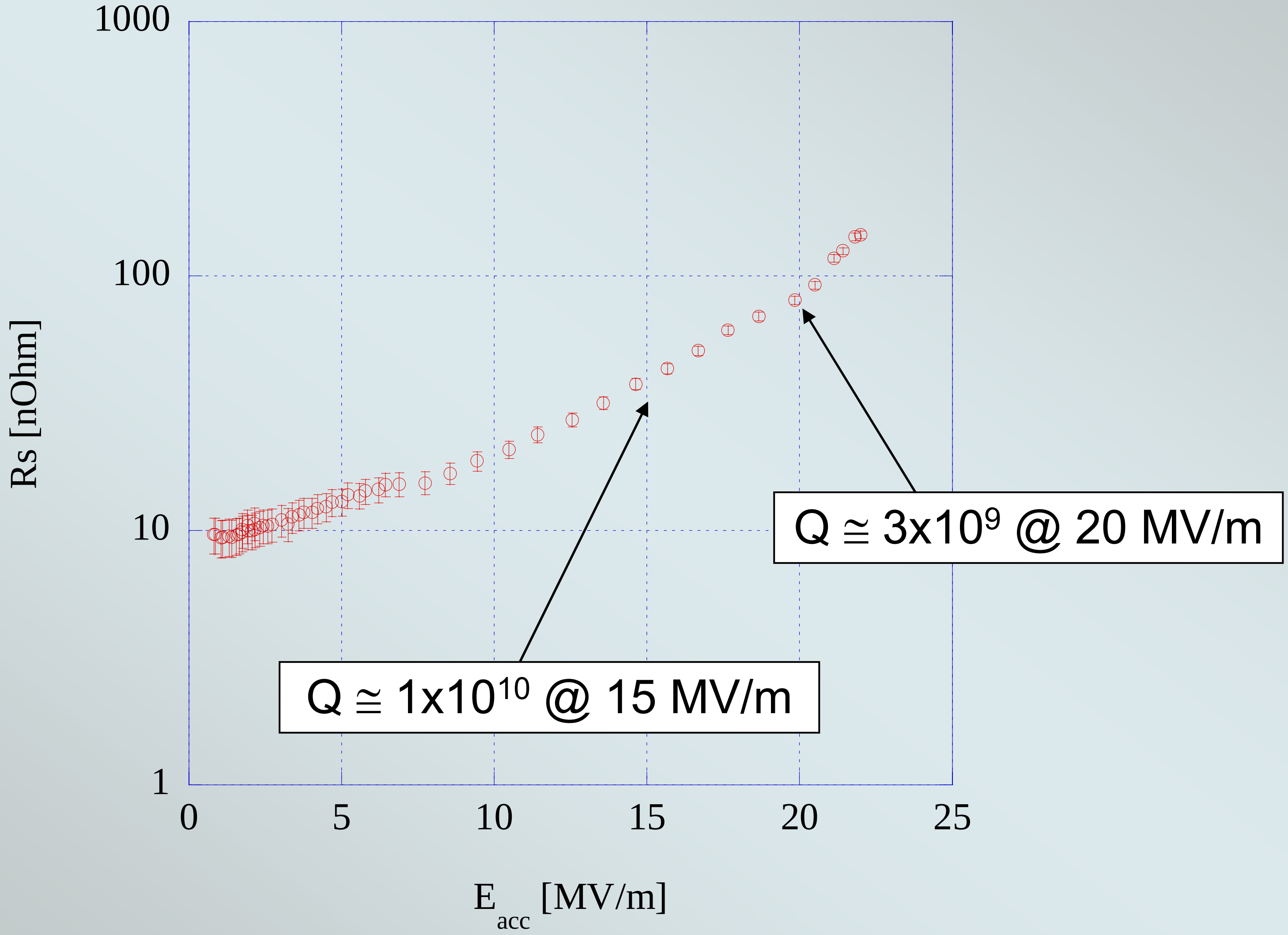
KEK – China Institute of Atomic Energy

Workshop Items

- Niobium Coatings
- Characterization Techniques
- SRF Theory
- A15 Materials
- Magnesium Diboride
- Power Couplers and Subsidiaries
- Advanced Cavity Cleaning
- Arc Deposition

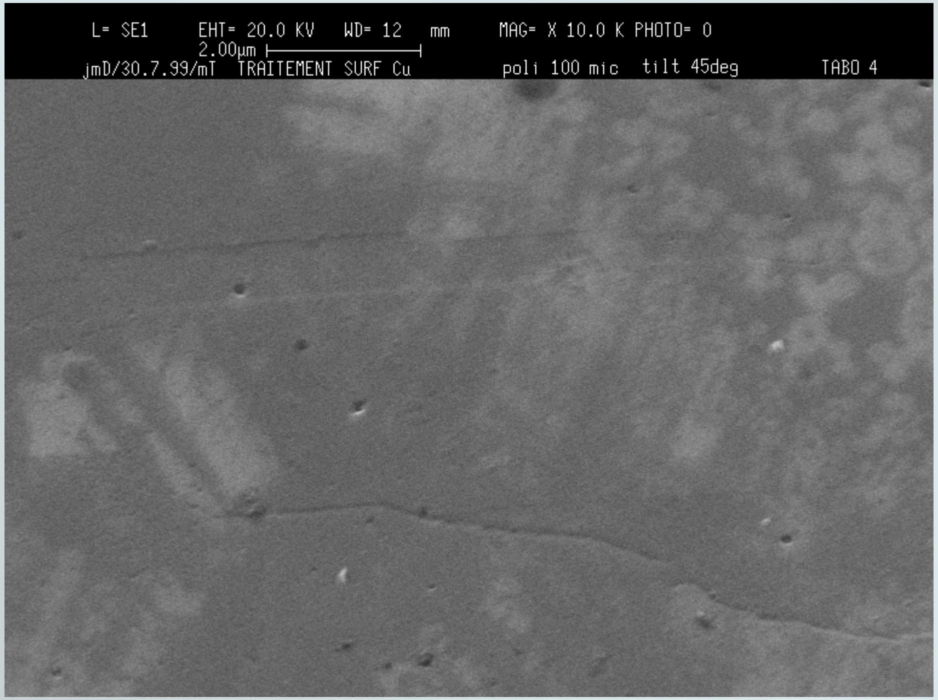
Nïobium thin films

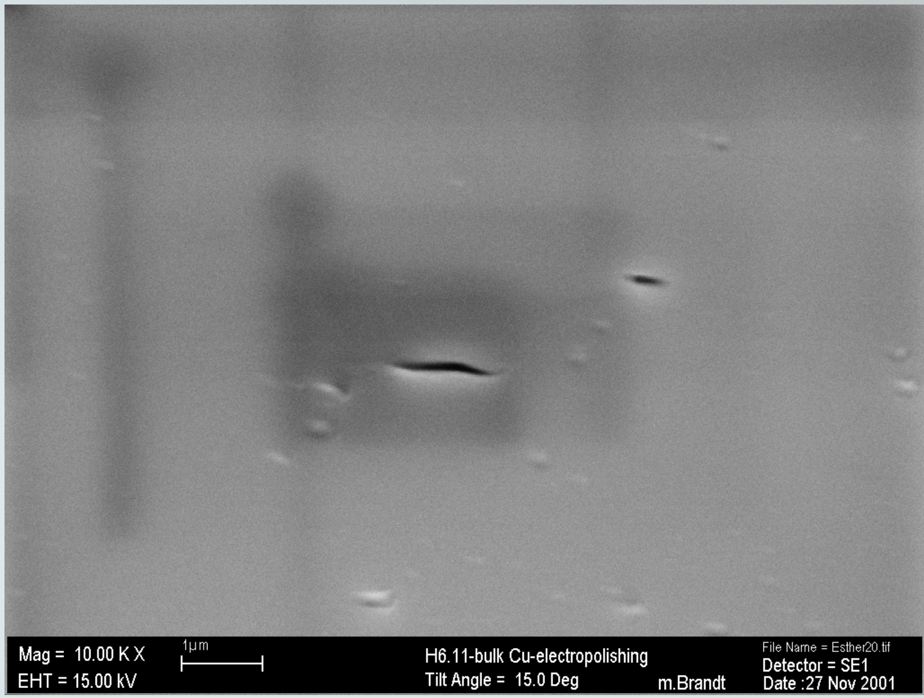
State-of-the-art at 1500 MHz – 1.7 K – single cell



28 MV/m reached in a large LEP cryostat (He evaporation at large power)

Defects in Cu substrate





Electropolished copper surface

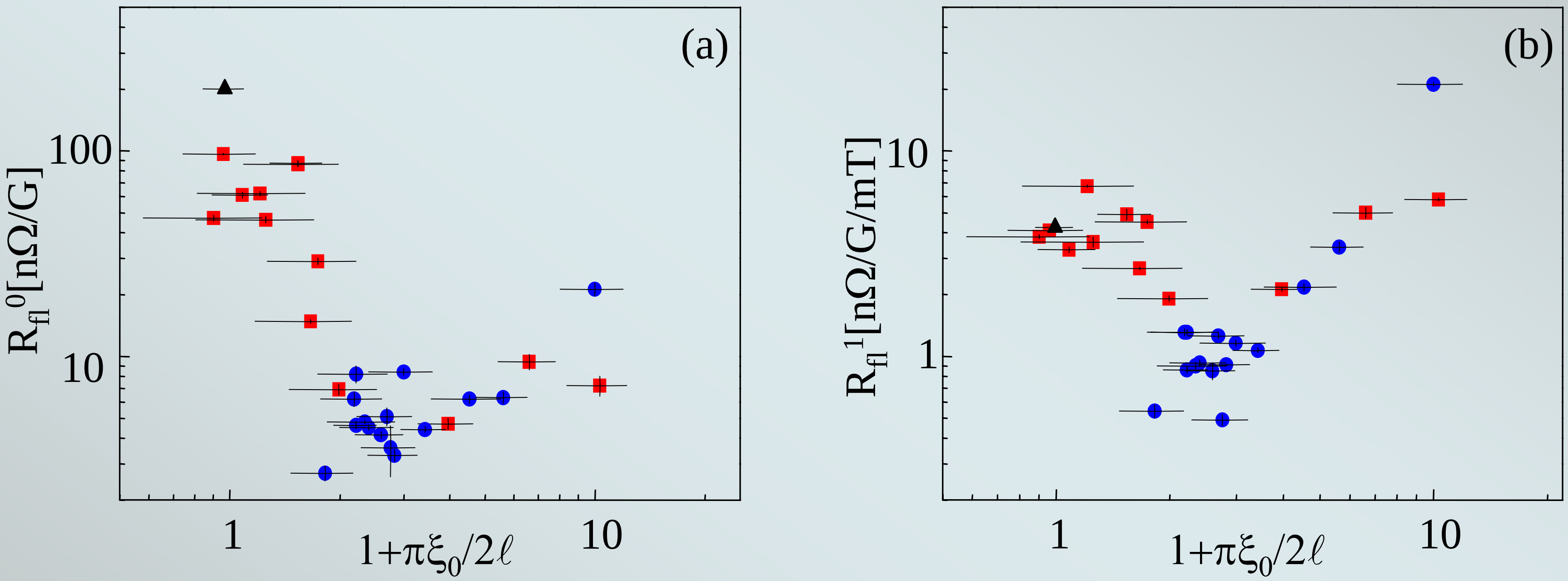
- average roughness: 0.02 µm
- A few defects still appearing

Cross section of a copper cavity

- Defects are present inside !
- Not an artifact of the preparation

Thanks to: G. Arnau-Izquierdo

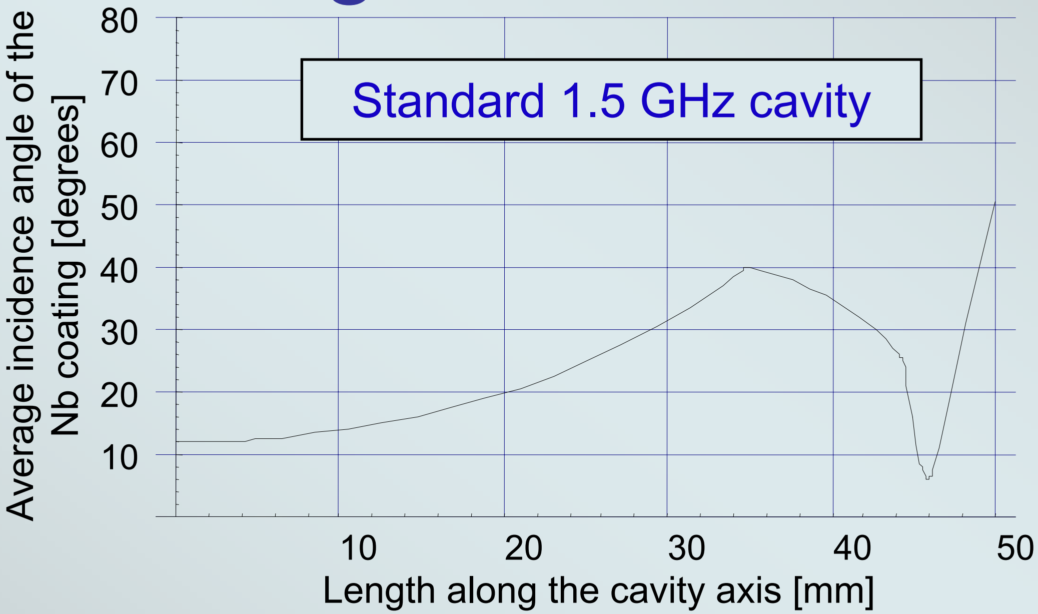
Surface resistance at zero RF field

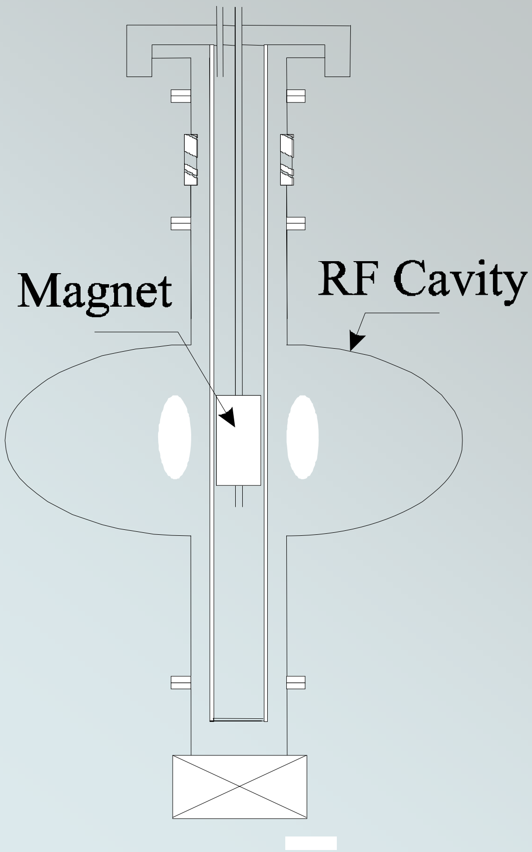


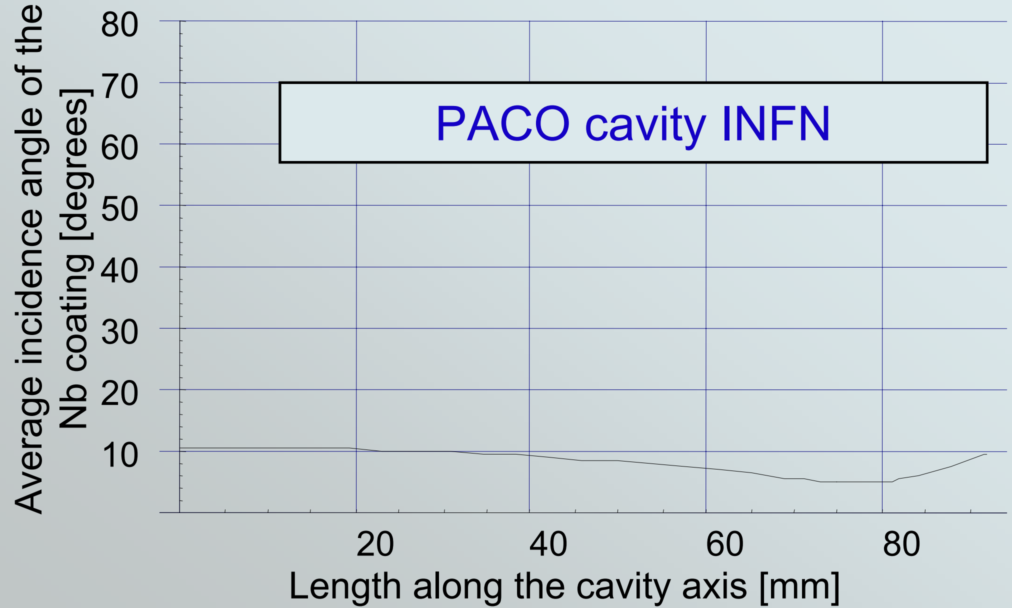
Squares: coatings on oxide-free copper

Circles: coatings on oxidized copper

Angle of incidence in spherical cavity



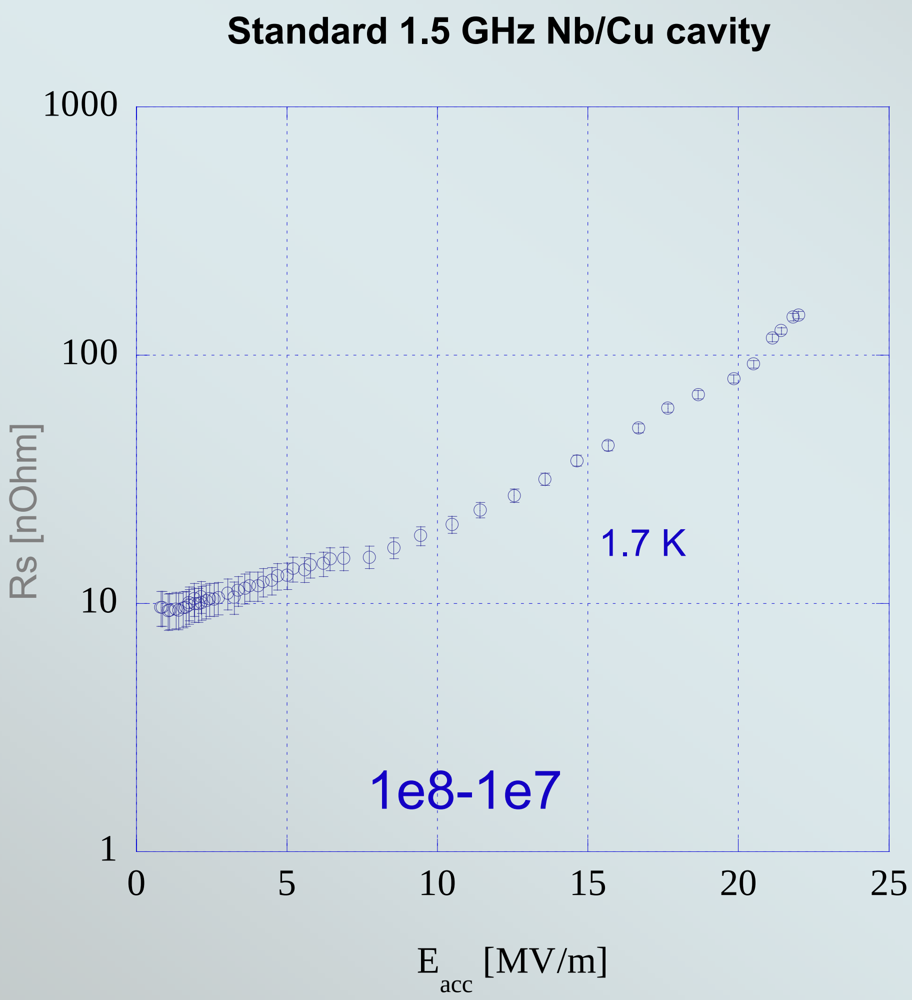




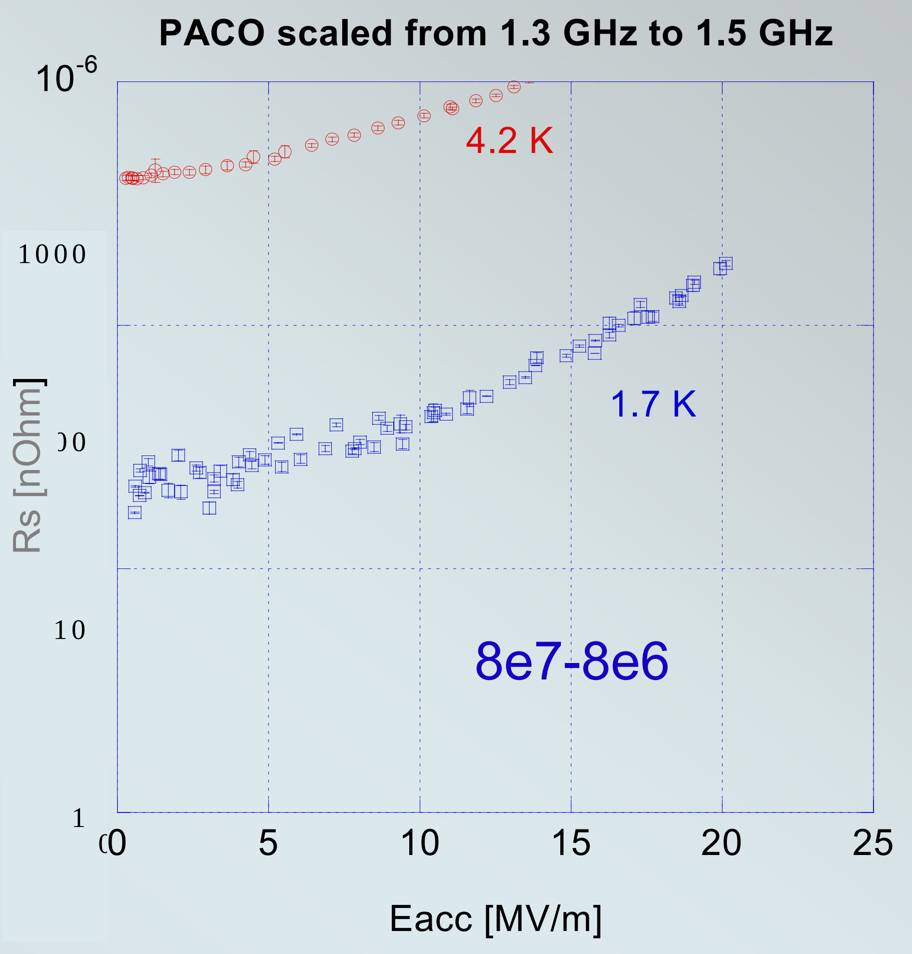
The cathode is not point-like

$\Rightarrow$

The incidence angle is always >0



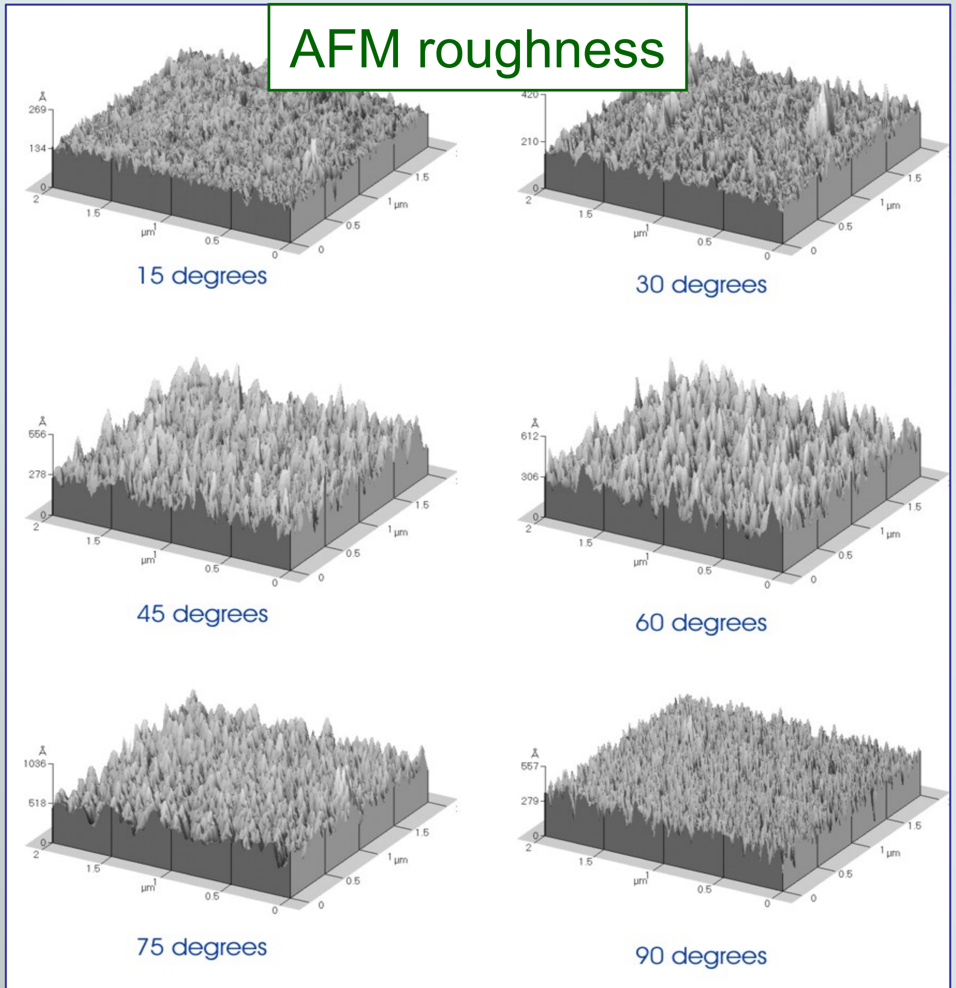
Standard 1.5 GHz Nb/Cu cavity
1000
100
10
1
Rs [nOhm]
1.7 K
1e8-1e7
0
5
10
15
20
25
E acc [MV/m]



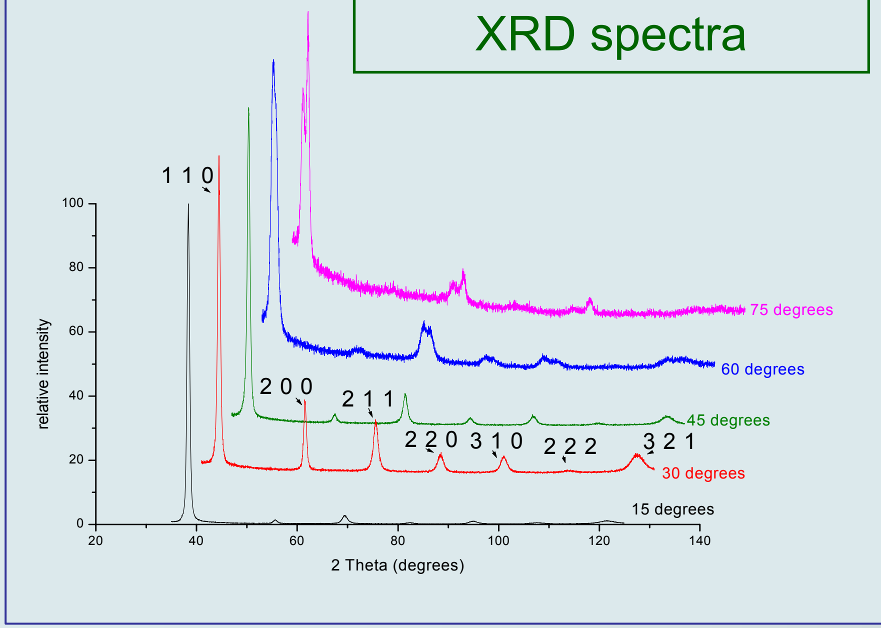
PACO scaled from 1.3 GHz to 1.5 GHz
10^-6
4.2 K
1000
Rs [nOhm]
1.7 K
10
8e7-8e6
1
0
5
10
15
20
25
Eacc [MV/m]

Variation of target-substrate incidence angle

AFM roughness

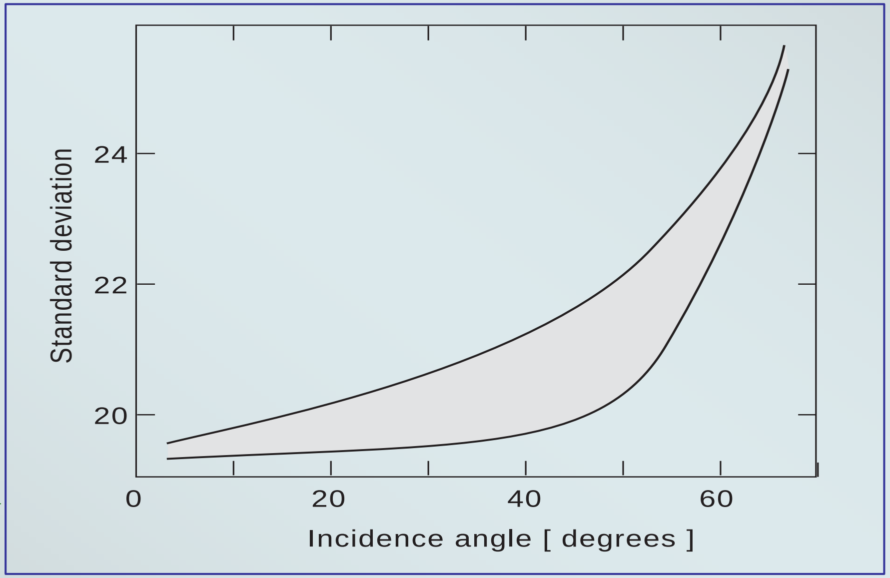


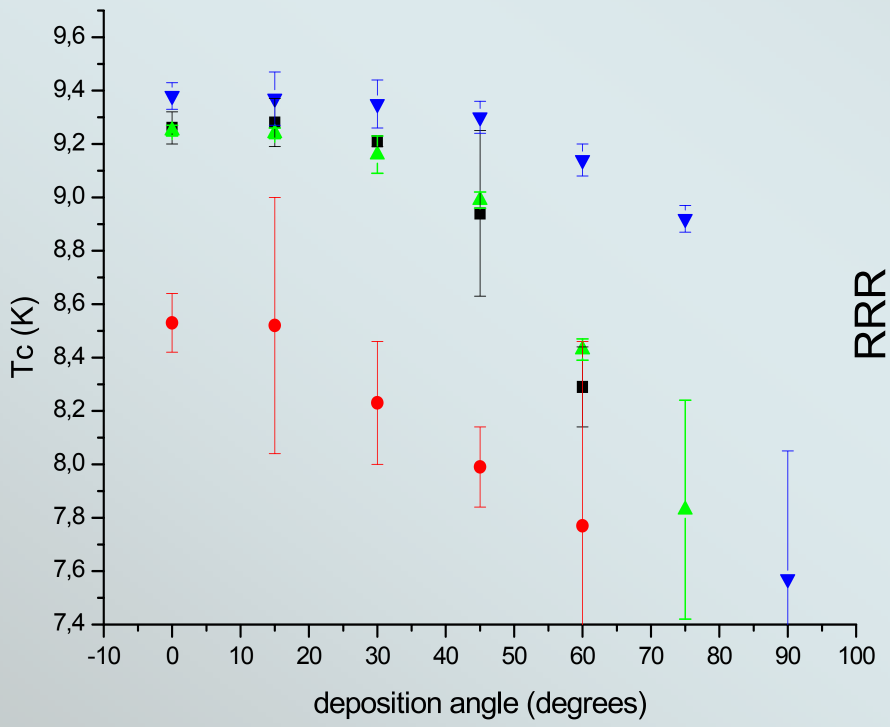
XRD spectra



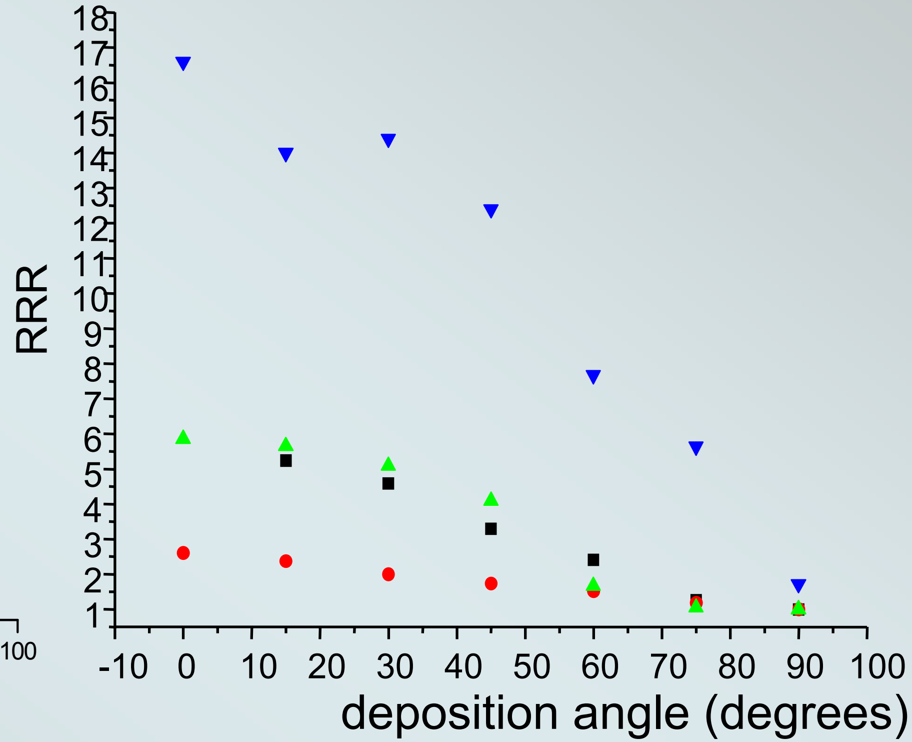
From: V. Palmieri, D. Tonini – INFN-LNL

Std.Dev. of grey levels of SEM images
(CERN 1999)





Tc (K)
9,6
9,4
9,2
9,0
8,8
8,6
8,4
8,2
8,0
7,8
7,6
7,4
-10 0 10 20 30 40 50 60 70 80 90 100
deposition angle (degrees)

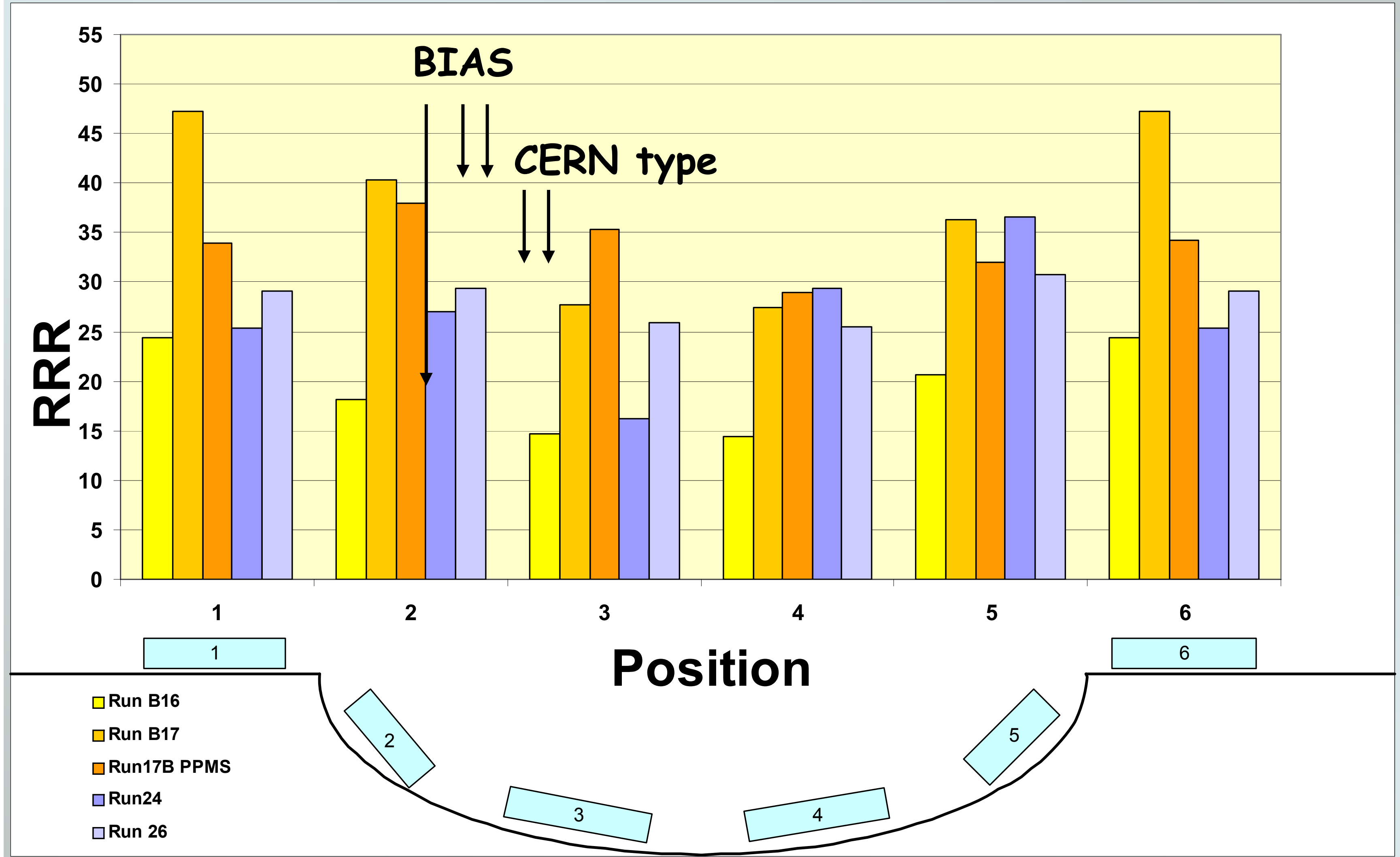


RRR
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
-10 0 10 20 30 40 50 60 70 80 90 100
deposition angle (degrees)

Biased Magnetron Sputtering:the construction

G. Lanza

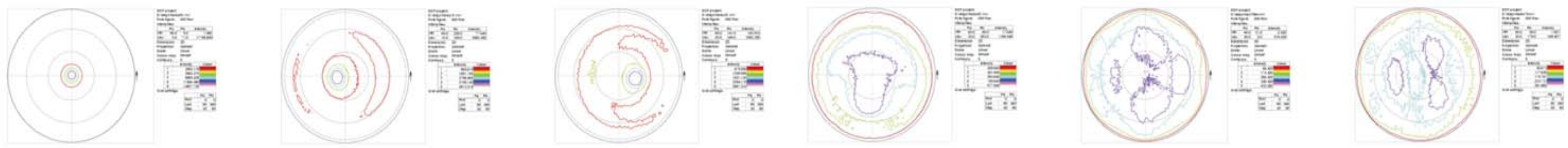
Biased Magnetron Sputtering: RRR results



The grid still doesn't affect much the equator part

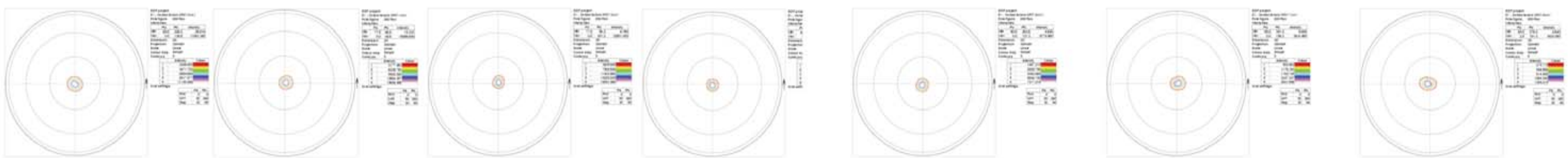
X-Ray Textures

MAGNETRON SPUTTERING



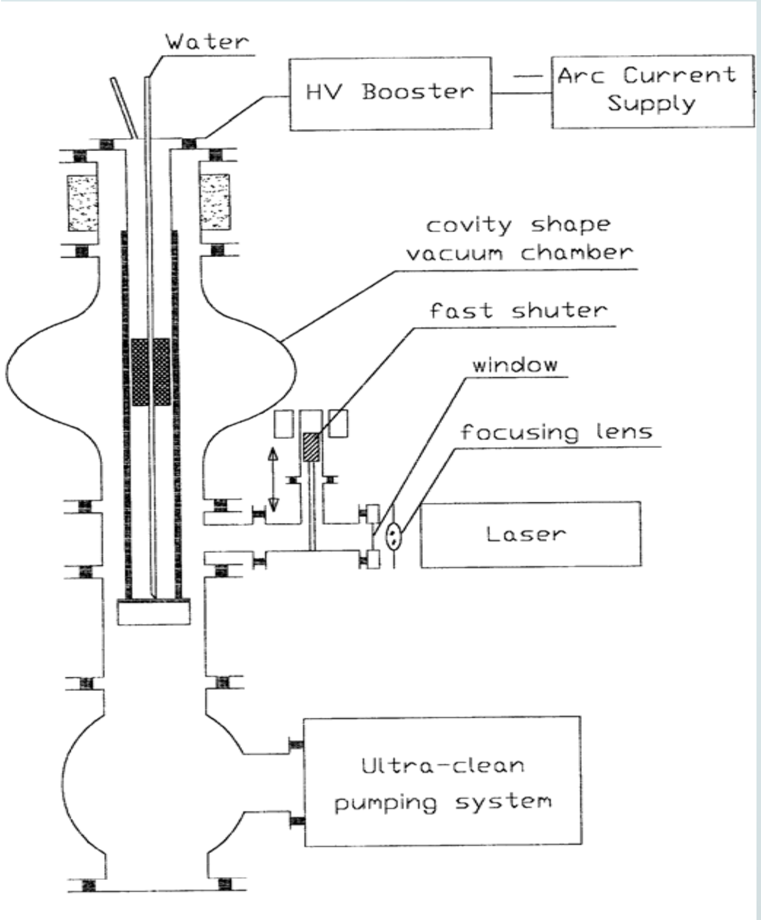
0 degrees 15 degrees 30 degrees 45 degrees 60 degrees 75 degrees

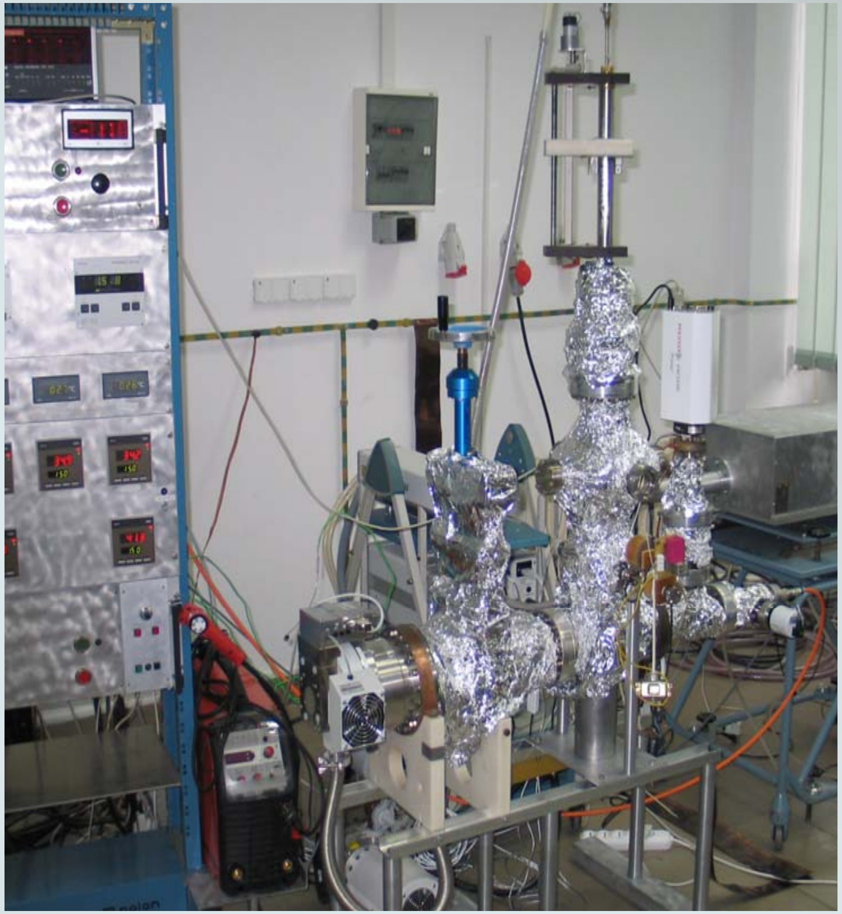
CATHODIC VACUUM ARC



0 degrees 15 degrees 30 degrees 45 degrees 60 degrees 75 degrees 90 degrees

UHV arc systems with a linear cathode



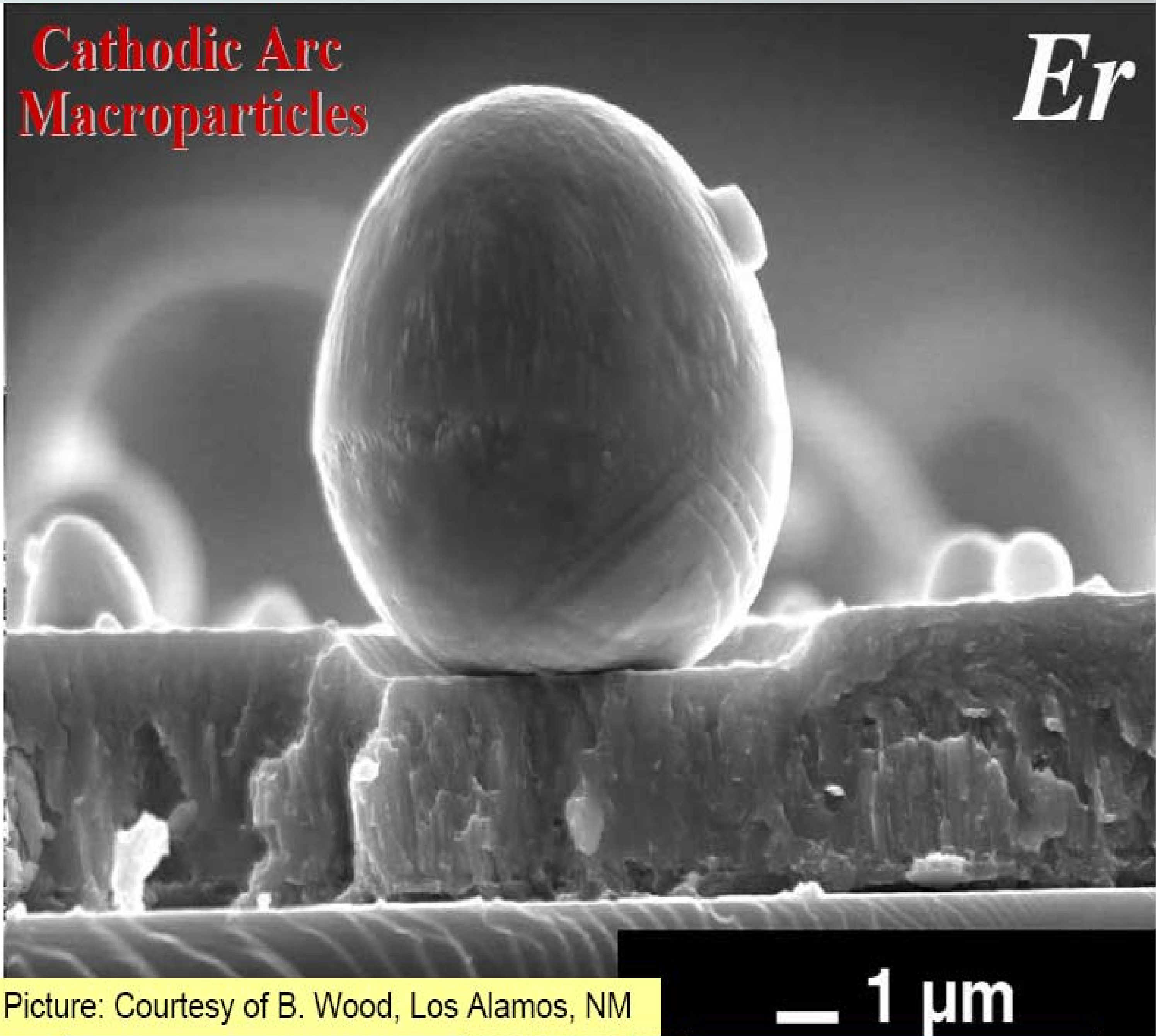


Scheme of the UHV system with a linear (cylindrical) arc and the first linear-arc facility constructed at IPJ in Swierk, Poland, in 2005.

Preliminary test for cavity coating

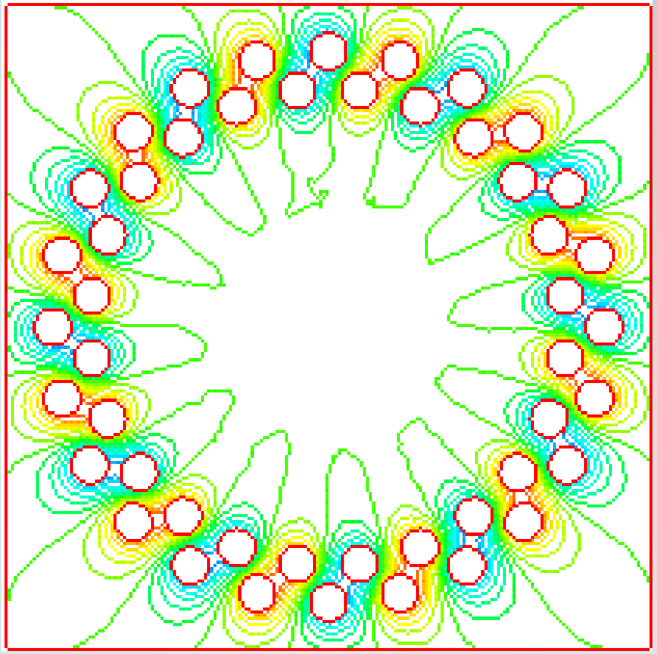
The first single-cavity taken of the real accelerator unit, after its preparation, has been coated without micro-droplet filtering.

The coated single-cell has been cut along its symmetry axis in order to perform an analysis of the inner surfaces.



Picture: Courtesy of B. Wood, Los Alamos, NM

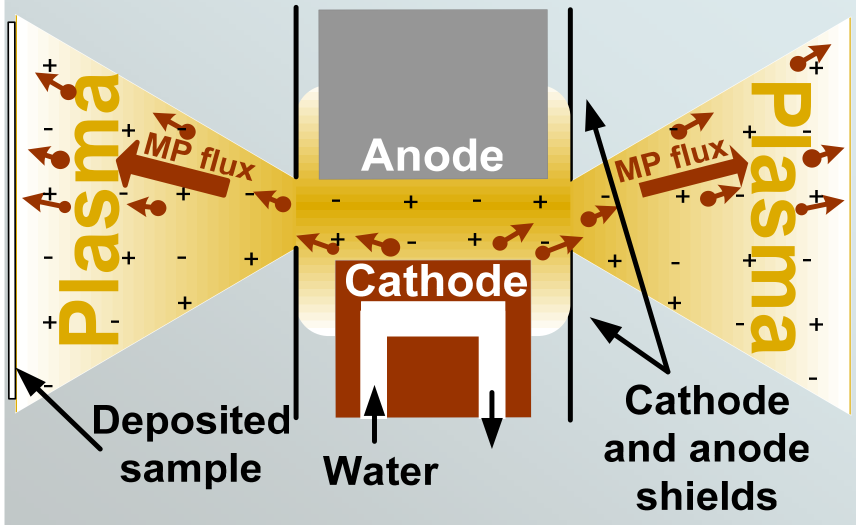
New cylindrical filters for elimination of micro-droplets

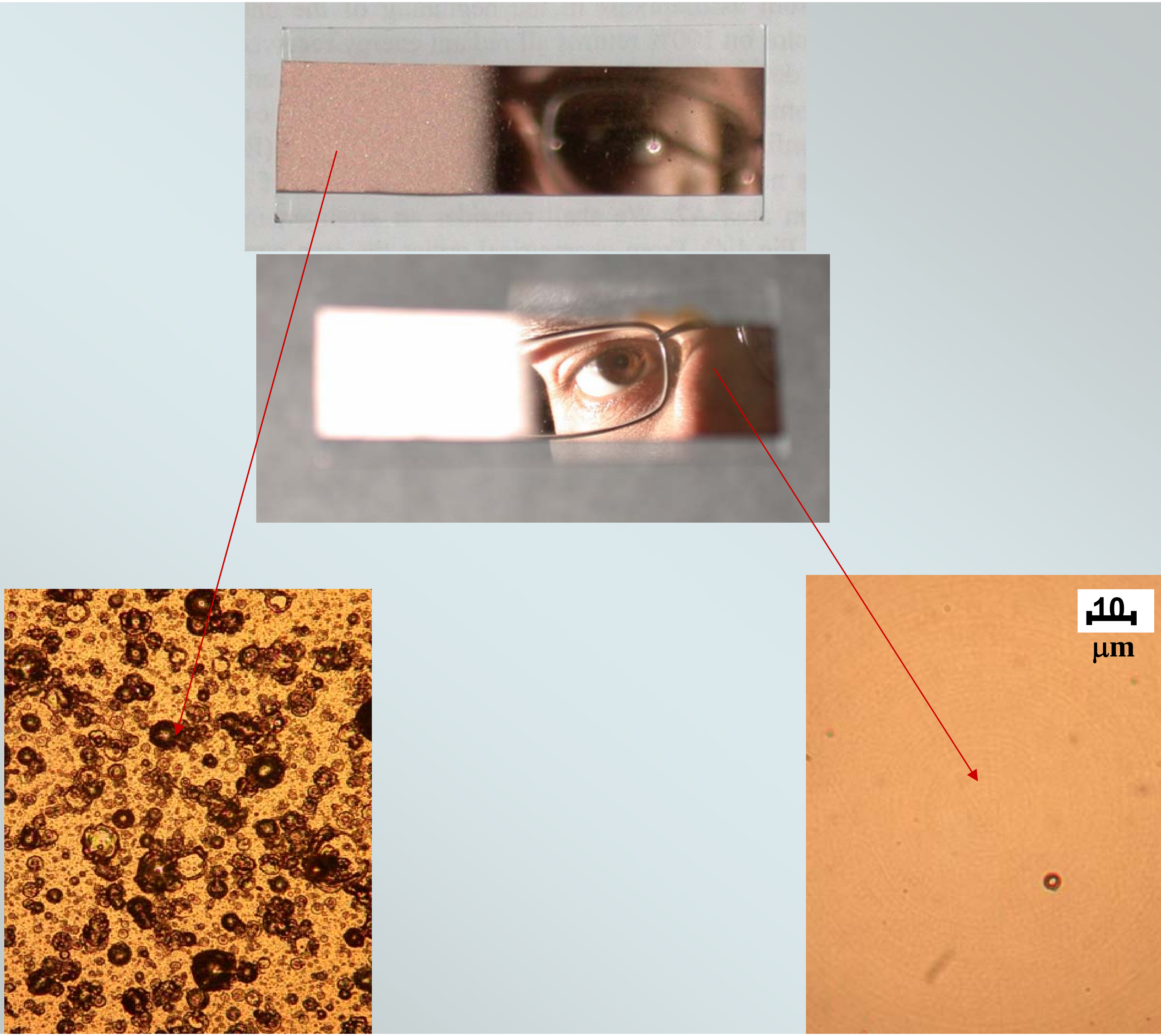


A cylindrical magnetic filter consisting of current-carrying tubes (left) and the distribution of magnetic field lines in its cross-section (right).

Other Arc Modes proposed by Ray Boxman

- Hot Anode Vacuum Arc
  - Crucible anode
- Hot Refractory Anode Vacuum




10
µm

Sputtering:

The film Microstructure is affected by the non-zero cathode - substrate angle

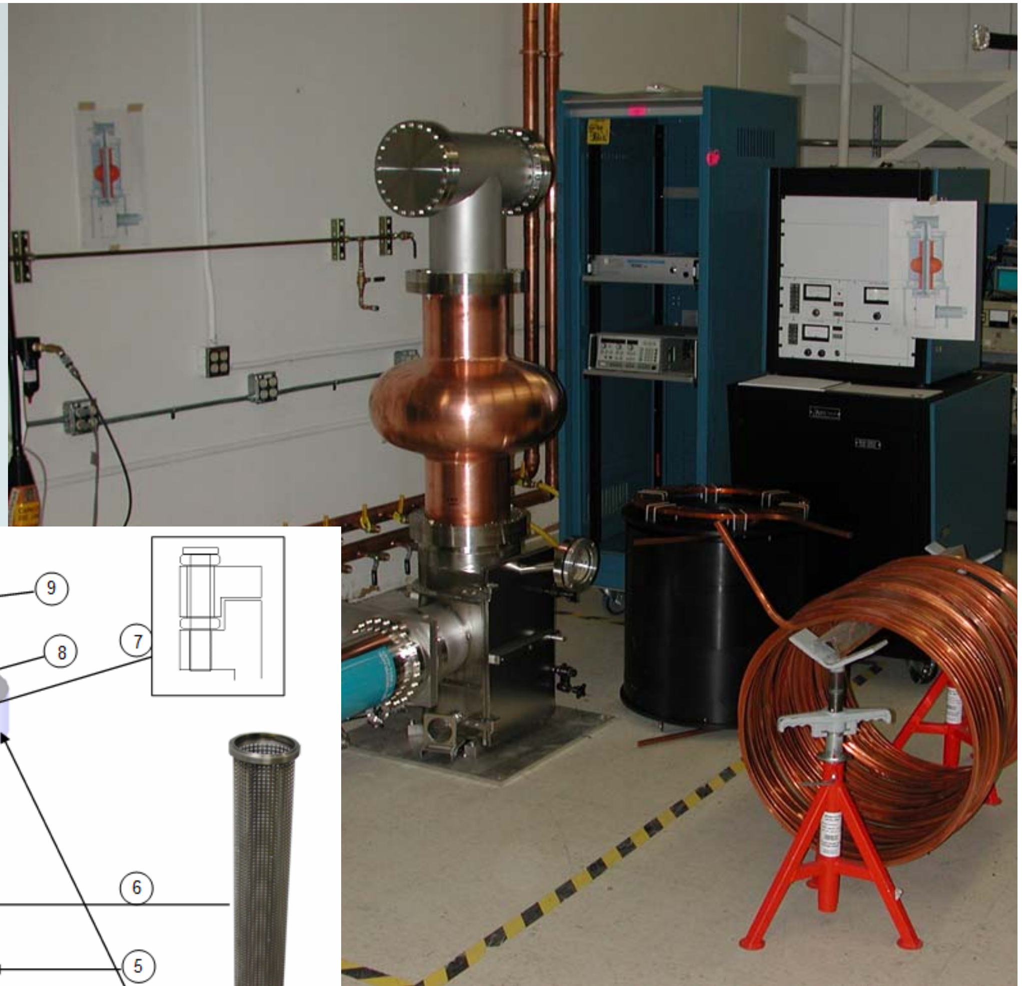
Cathodic Arc:

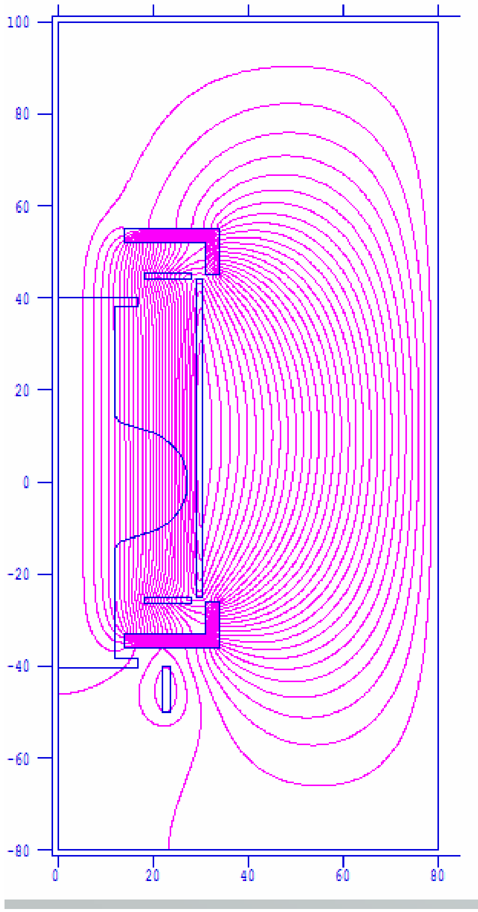
The film Morphology suffers of the presence of microparticles

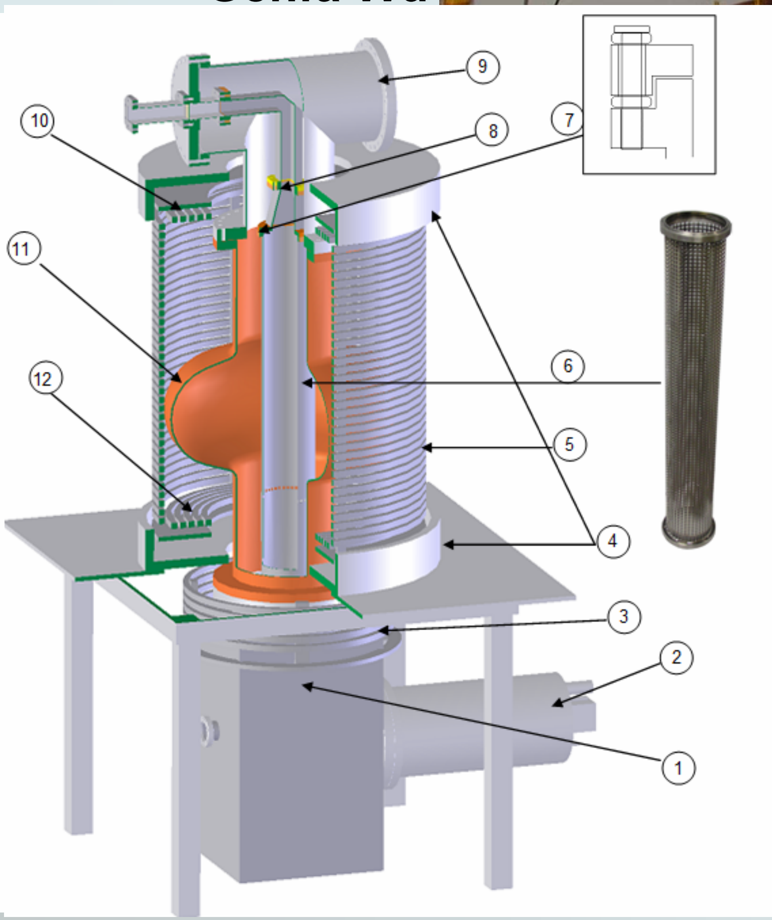
But there is something without the limits of both these techniques ….

ECR cavity deposition system

Genfa Wu





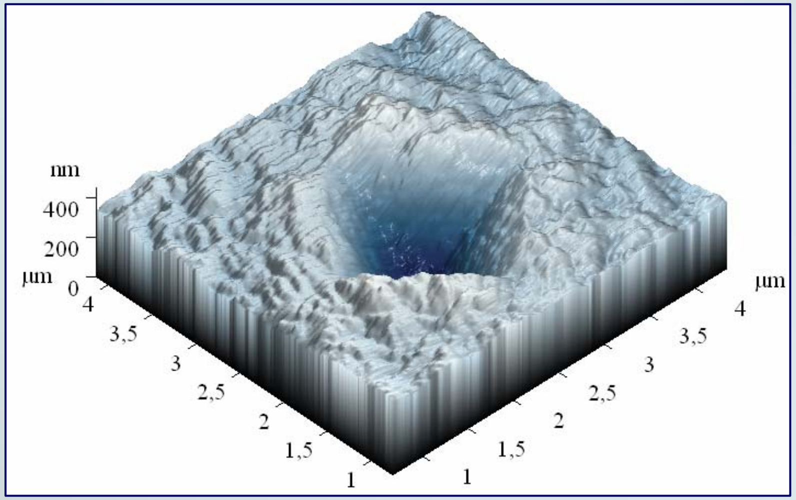


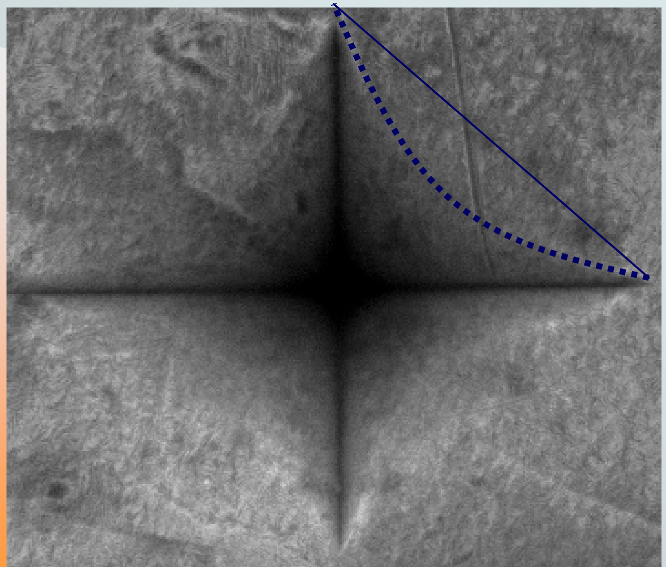
(1) 14kW rod-fed E-gun
(2) 9000 l/s cryopump system
(3) bucking coil for E-gun
(4) top and bottom iron yokes (outer iron shield is removed for illustration)
(5) center coils
(6) Nb grid tube
(7) bias insulator
(8) WR284 waveguide E-bend and horn to the grid tube
(9) “T” vacuum chamber
(10) top pancake coil
(11) Cu cavity
(12) bottom pancake coil.

Characterization Techniques

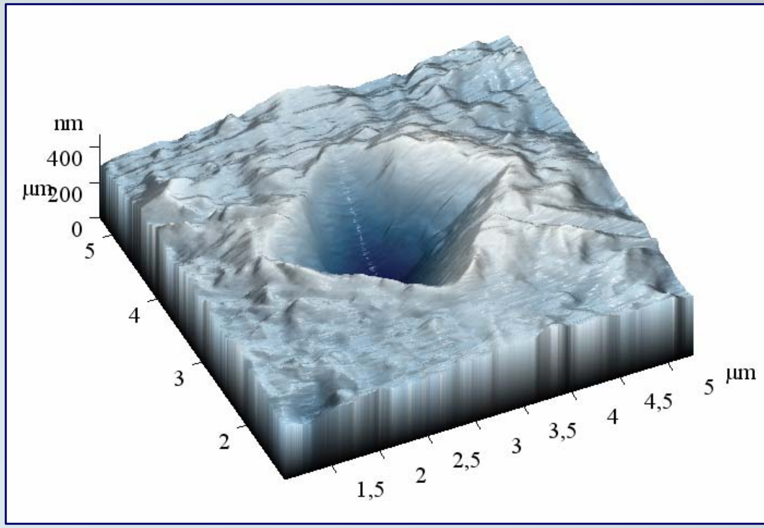
Elastic modulus and ISE

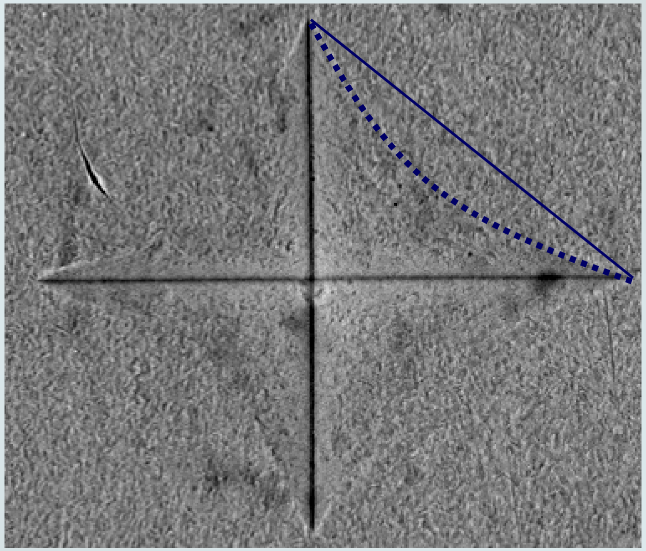
Biased MS E = 88,95 GPa





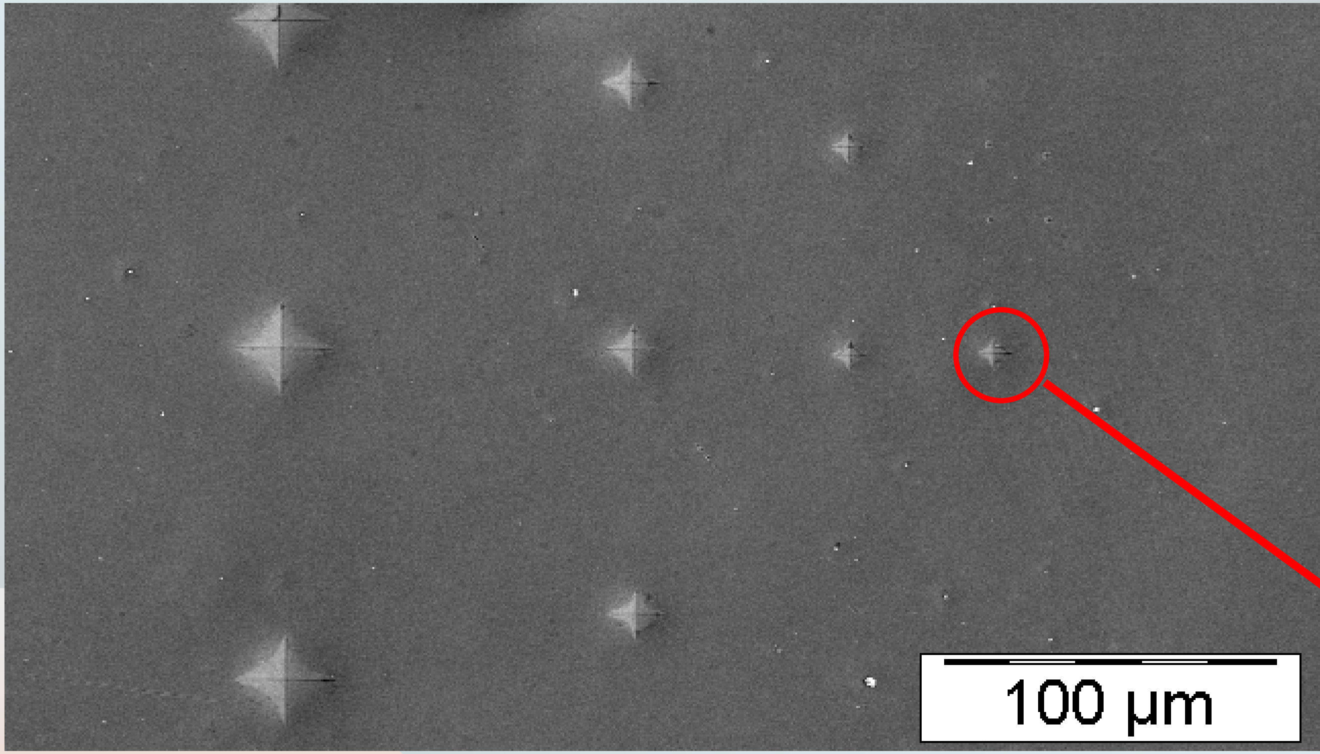
unbiased MS E = 54,33 GPa

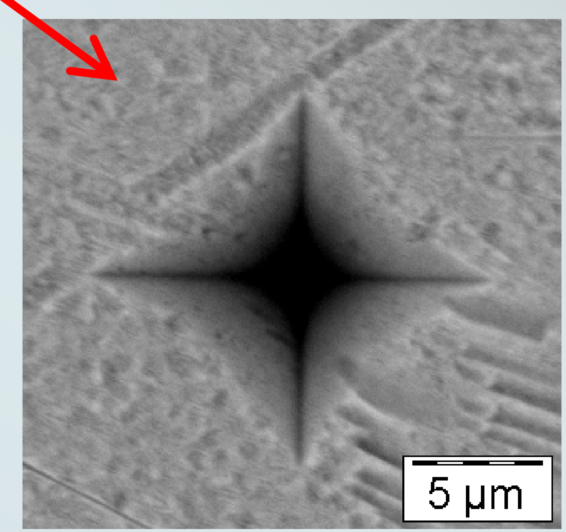




Bemporad et al.: High resolution morphological and mechanical characterization of niobium films obtained by MS and Bias-MS PVD

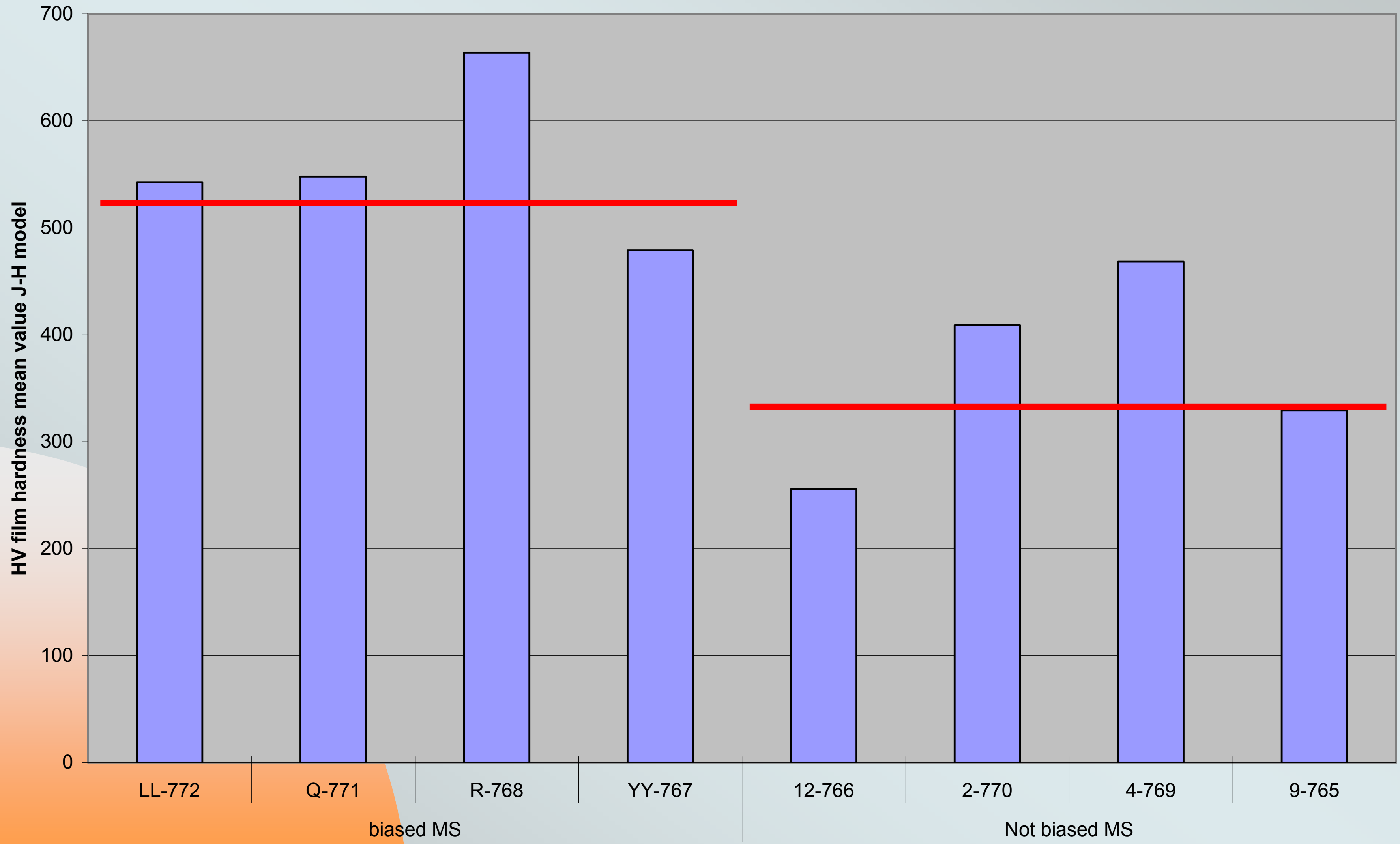
Vickers indentation at different loads





Bemporad et al.: High resolution morphological and mechanical characterization of niobium films obtained by MS and Bias-MS PVD

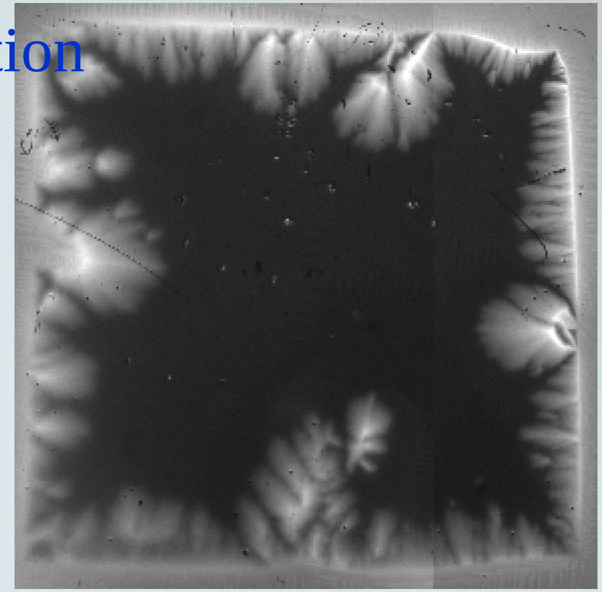
Hardness comparison



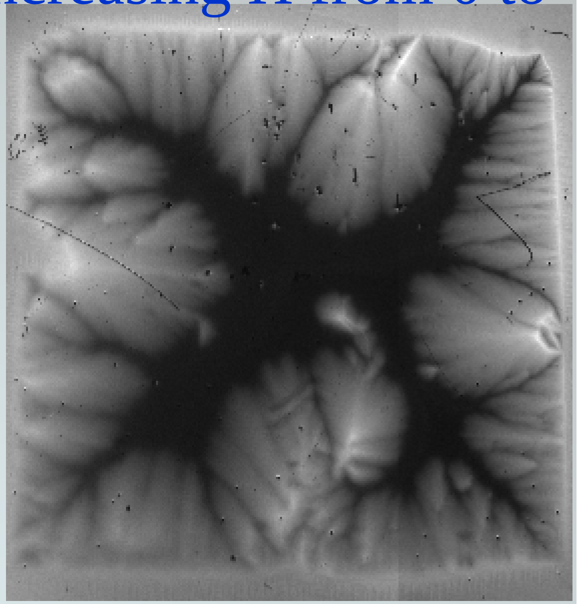
Bemporad et al.: High resolution morphological and mechanical characterization of niobium films obtained by MS and Bias-MS PVD

MgB2 thin film on STOCBS 33-1-5 ZFC T=16K increasing H from 0 to 120mT Bean flux penetration

#1 H=8mT

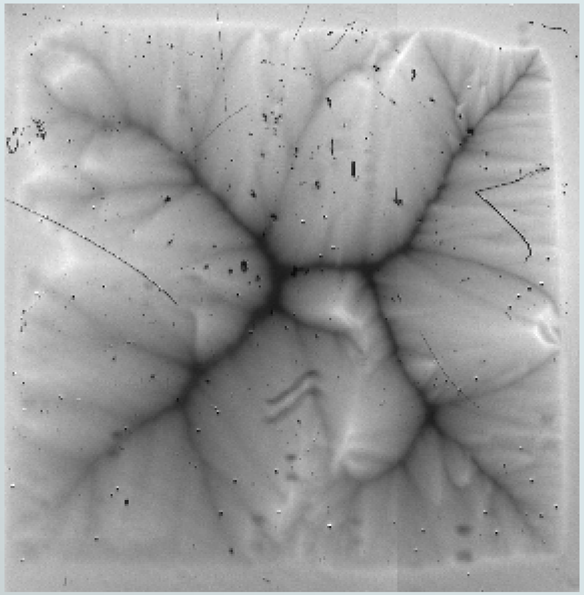


#5 H=20mT

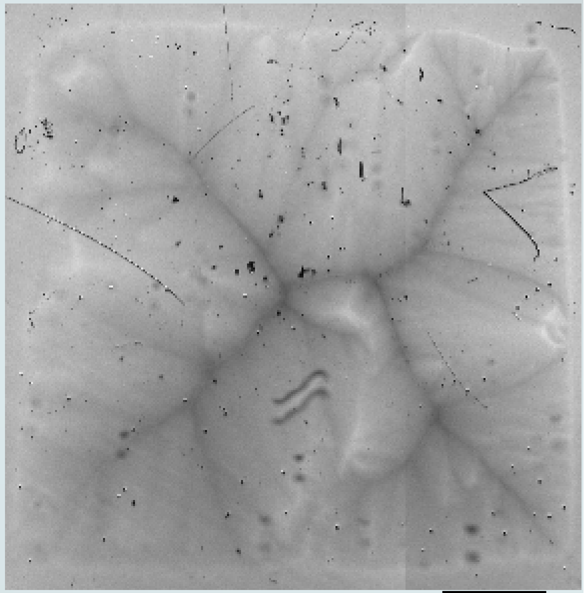


#9 H=40mT

#11 H=60mT



#13 H=80mT

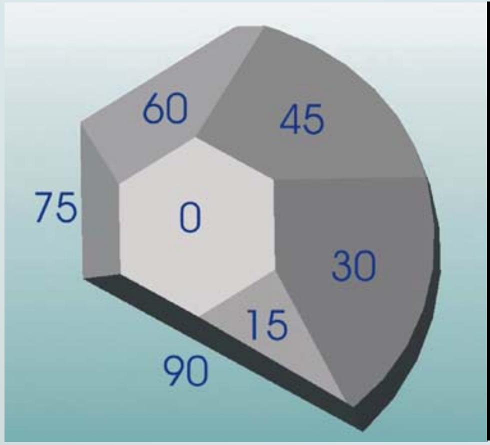


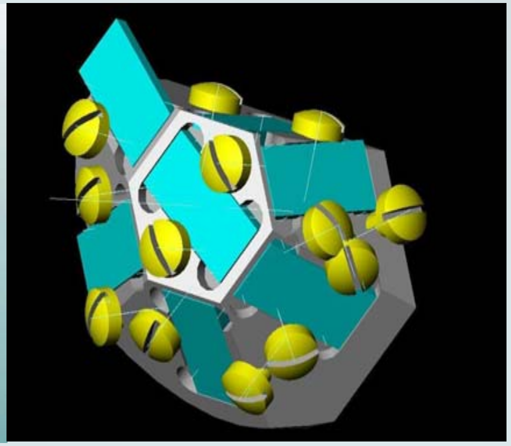
#17 H=120mT

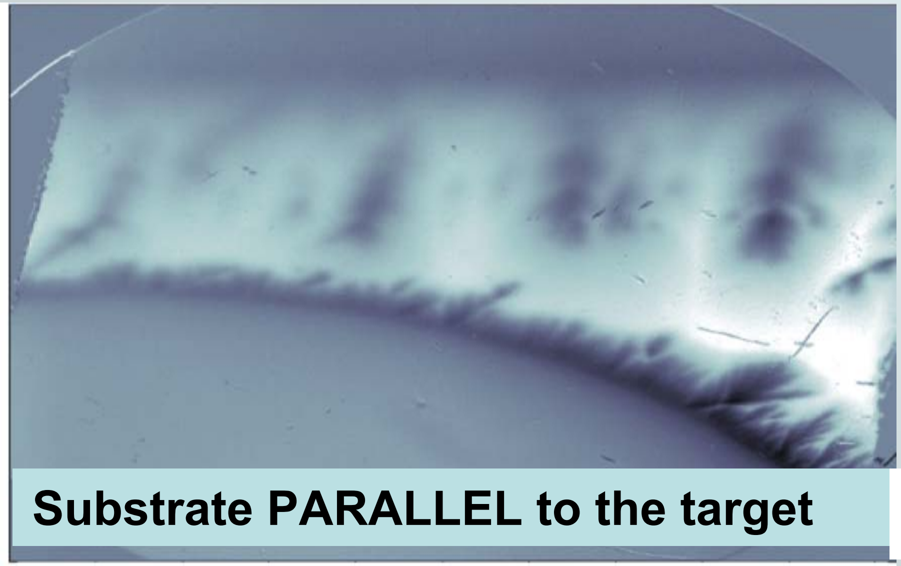
1 mm

MORPHOLOGY OF NIOBIUM FILMS SPUTTERED AT DIFFERENT TARGET – SUBSTRATE ANGLE

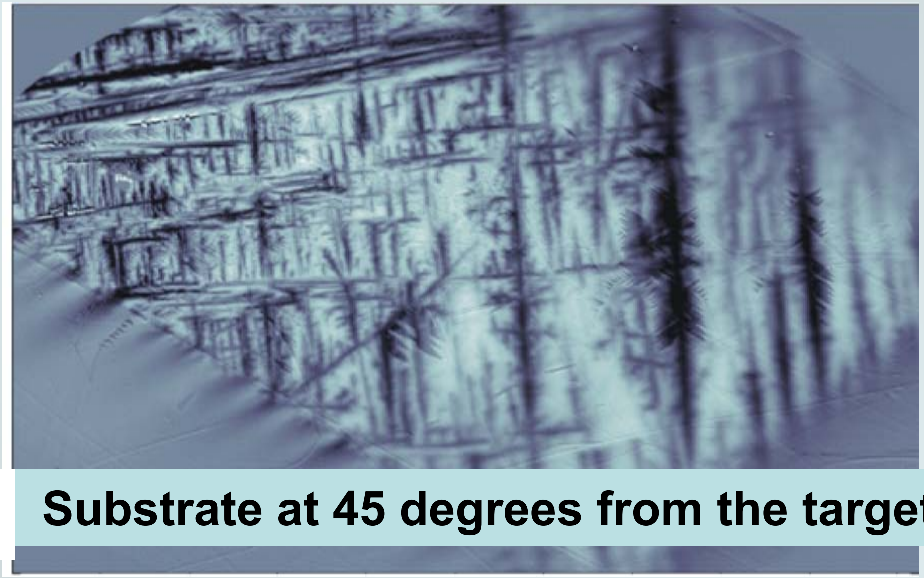
D. Tonini, C. Greggio, G. Keppel, F. Laviano, M. Musiani, G. Torzo, V. Palmieri



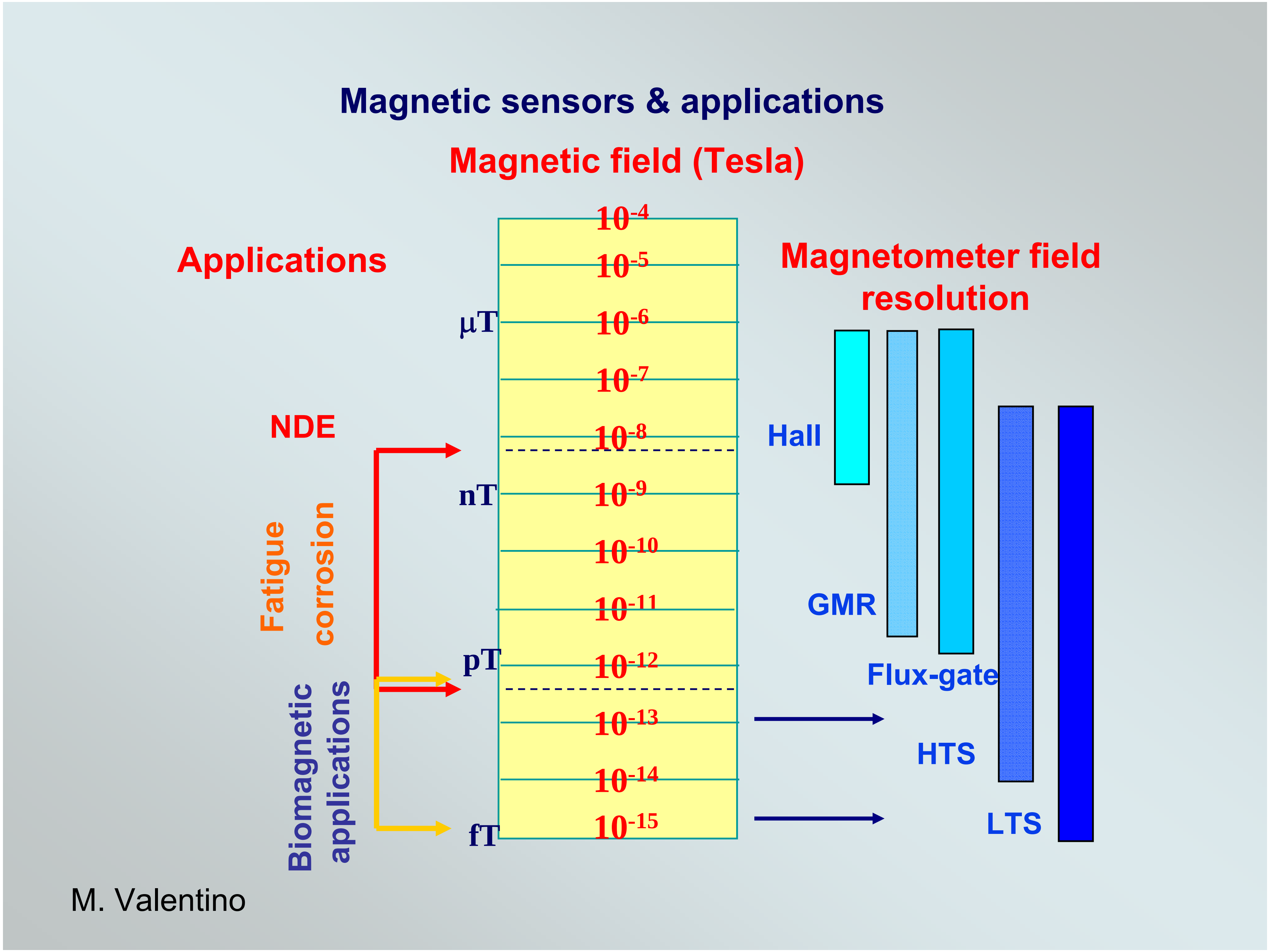




Substrate PARALLEL to the target



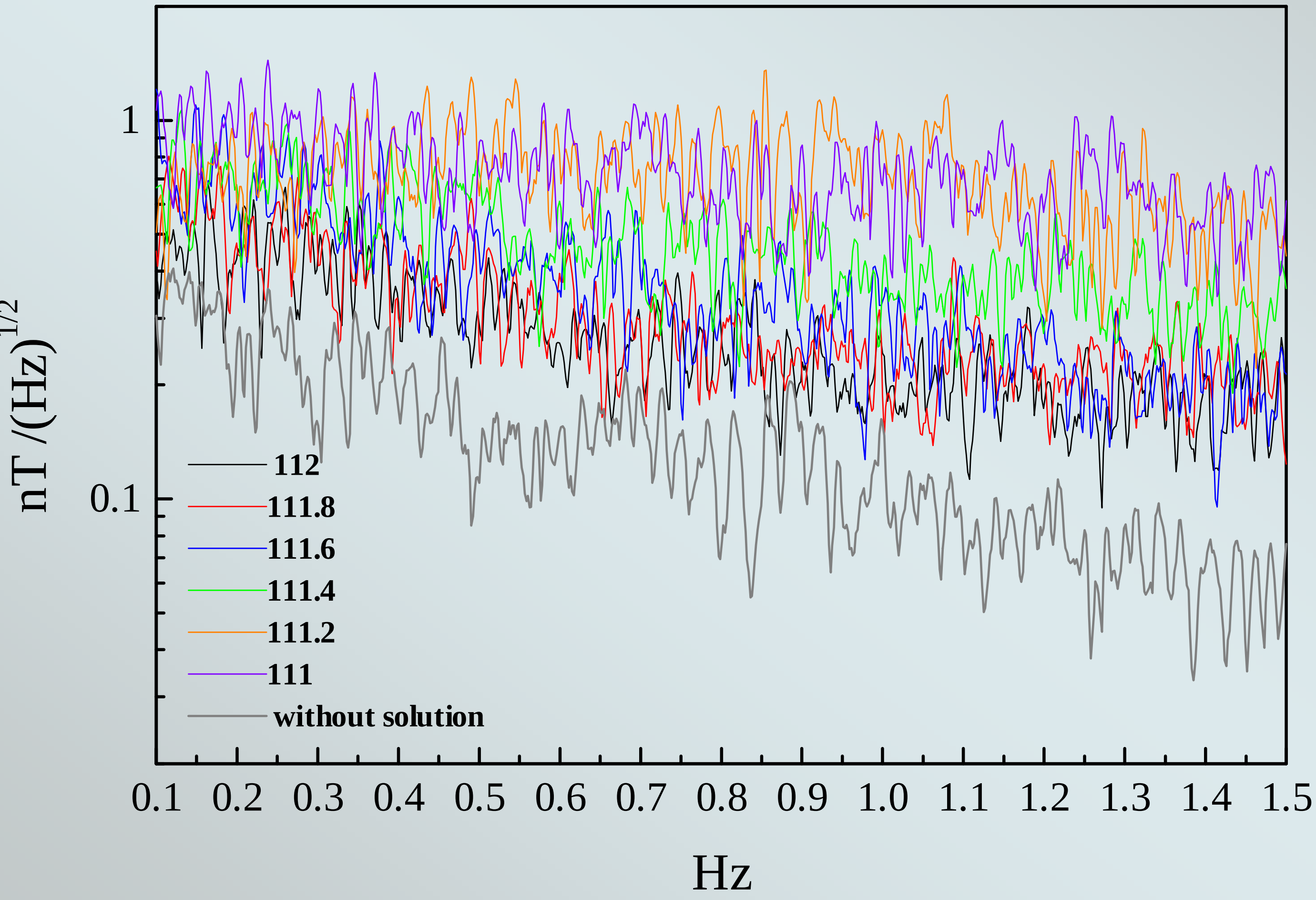
Substrate at 45 degrees from the target



Magnetic sensors & applications
Magnetic field (Tesla)
Applications
Magnetometer field resolution
10-4
10-5
μT
10-6
10-7
NDE
10-8
Hall
nT
10-9
10-10
Fatigue
corrosion
10-11
GMR
pT
10-12
Flux-gate
10-13
HTS
10-14
Biomagnetic applications
fT
10-15
LTS
M. Valentino

Buffered Chemical polishing of Niobium

BCP 1:1:1 to BCP 1:1:2 increasing the H_3PO_4 percentage the magnetic signal Intensity increase



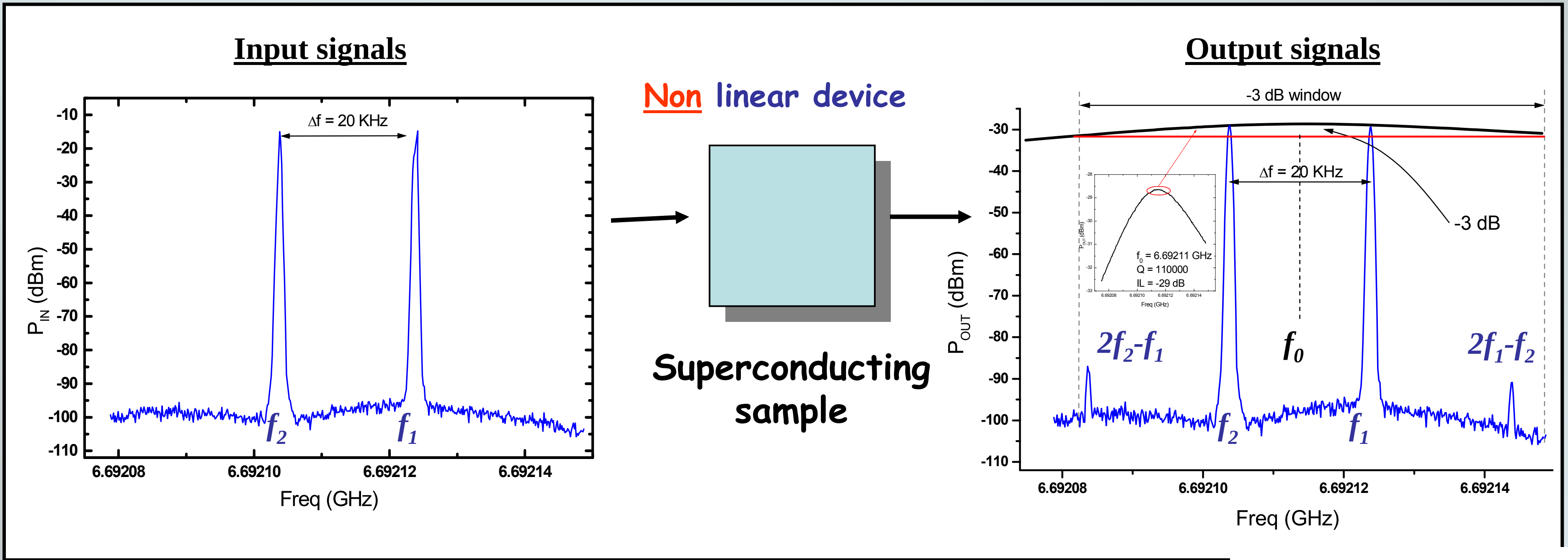
M. Valentino

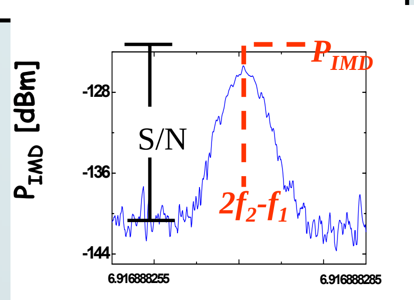
The IMD technique

A. Andreone

Input signal made up of two signals of equal magnitude but different frequencies:

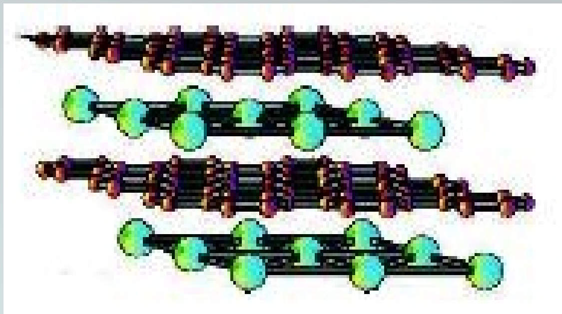
$$V_{in} = V_1 \cos(2\pi f_1 t + a_1) + V_2 \cos(2\pi f_2 t + a_2)$$





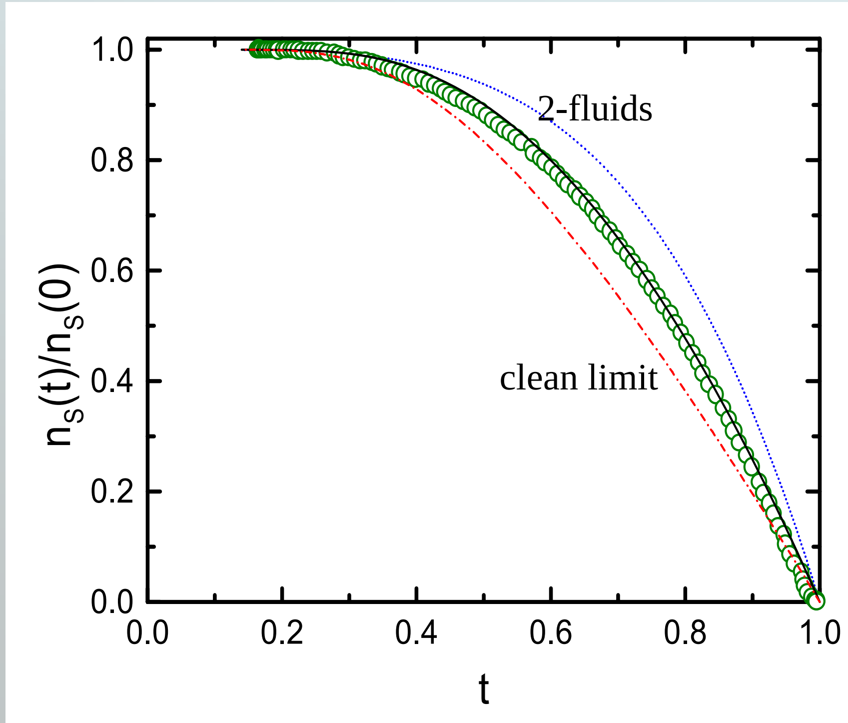
$|V_1 - V_2| < 0.1$ dBm, $f_1 - f_2 = 20$kHz << 3 dB bandwidth

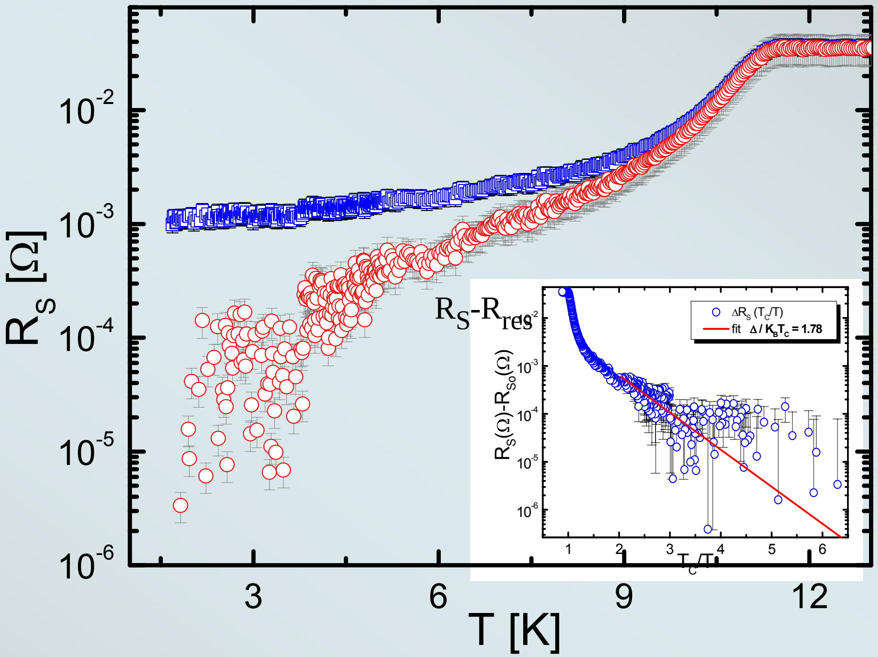
CaC_6: a graphite intercalated superconductor



$T_C = 11.2$ K

Both superfluid density and microwave losses give evidence of conventional, weak-coupled, superconductivity ($2\Delta/K_B T_C \sim 3.6$)





G. Lamura *al*, Phys. Rev. Lett. **96**, 107008 (2006); G. Cifariello *et al.*, M^2S 2006

SRF Theory

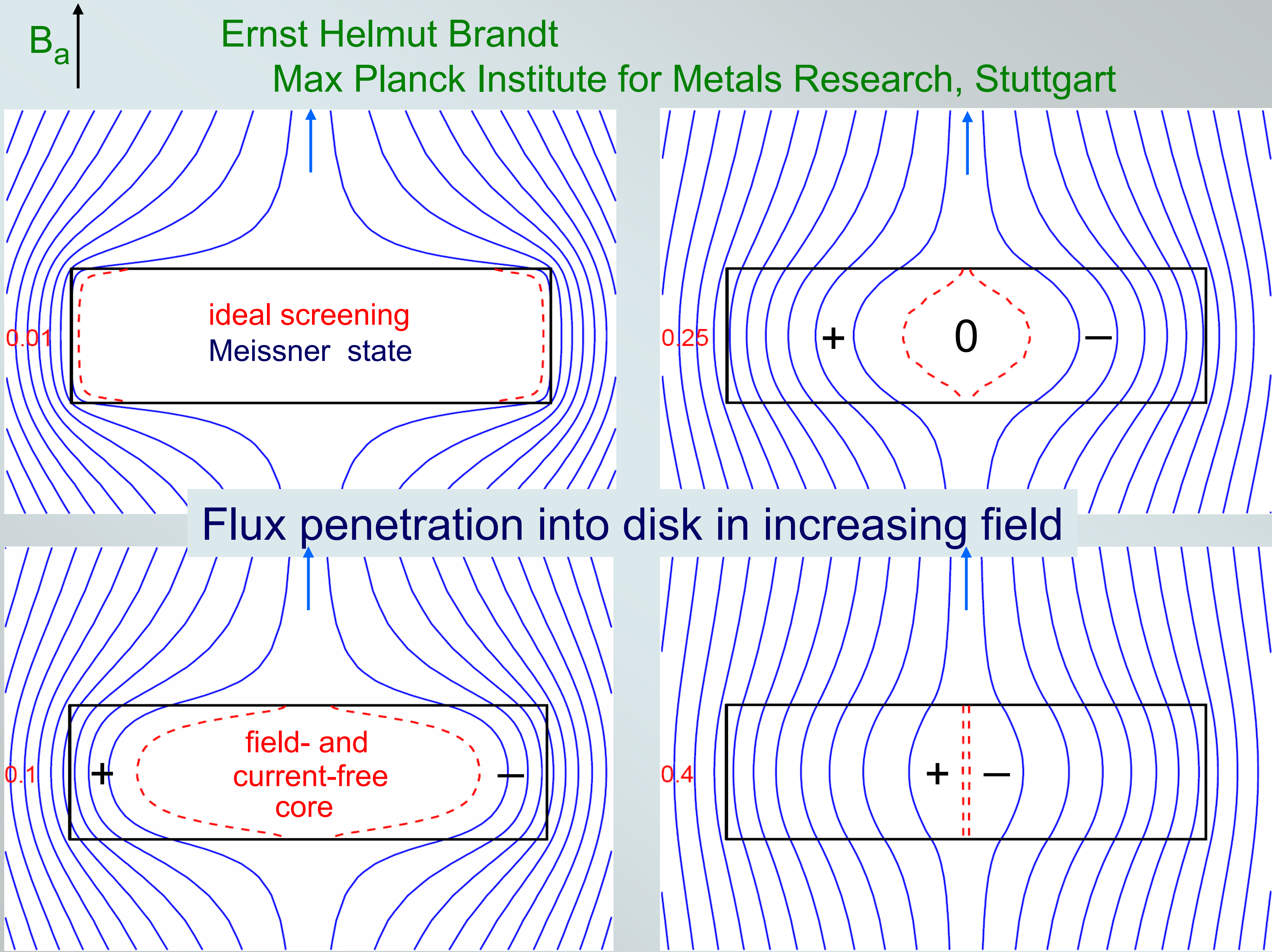
Electrodynamics of Superconductors exposed to high frequency fields

- Superconductivity
- Radio frequency response of ideal superconductors

  two-fluid model, microscopic theory
- Abrikosov vortices
- Dissipation by moving vortices
- Penetration of vortices

"Thin films applied to Superconducting RF:Pushing the limits of RF Superconductivity"
Legnaro National Laboratories of the ISTITUTO NAZIONALE DI FISICA NUCLEARE
in Legnaro (Padova) ITALY, **October 9-12, 2006**

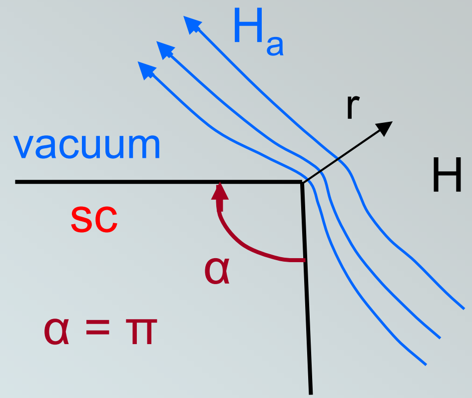
Ernst Helmut Brandt
Max Planck Institute for Metals Research, Stuttgart



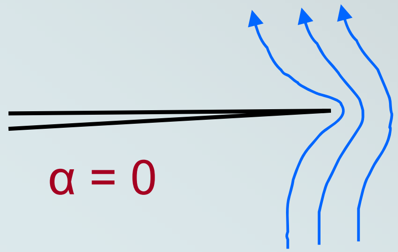
Flux penetration into disk in increasing field

5. Ideal diamagnet, corner with angle α :

Near corner of angle α the magnetic field diverges as $H \sim 1/\, r^{\beta}$, $\beta = (\pi - \alpha)/(2\pi - \alpha)$



$H \sim 1/\, r^{1/3}$

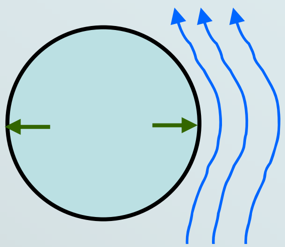


$H \sim 1/\, r^{1/2}$

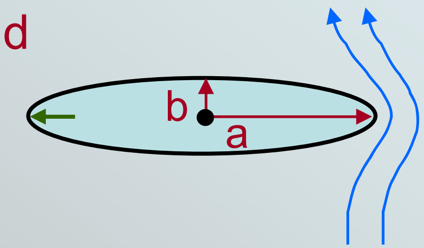
Magnetic field H at the equator of:

cylinder $H/H_a = 2$

sphere $H/H_a = 3$



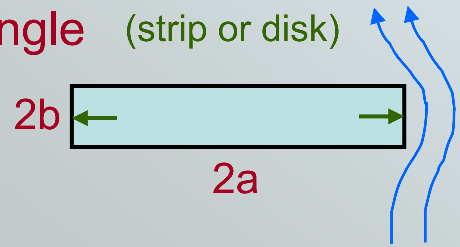
ellipsoid



$H/H_a = a/b$

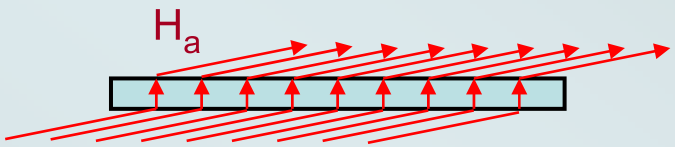
$b << a$

rectangle (strip or disk)



$H/H_a \approx (a/b)^{1/2}$

$b << a$



Large thin film in tilted mag. field: perpendicular component penetrates in form of a vortex lattice

Theories / Experiments Confrontation

dapnia

cea

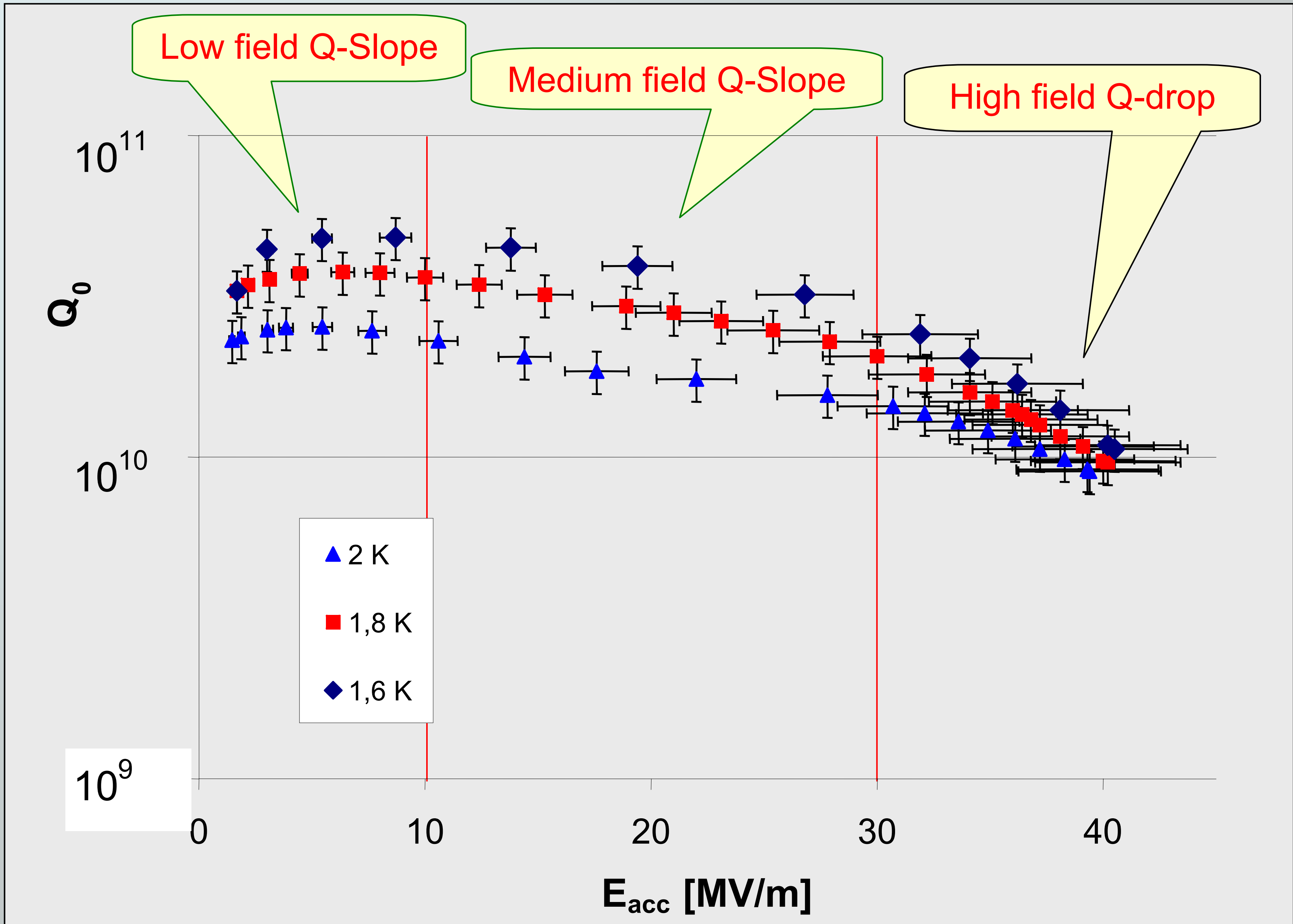
saclay

B. Visentin - SRF (2003) – updated at Argonne Workshop (2004)

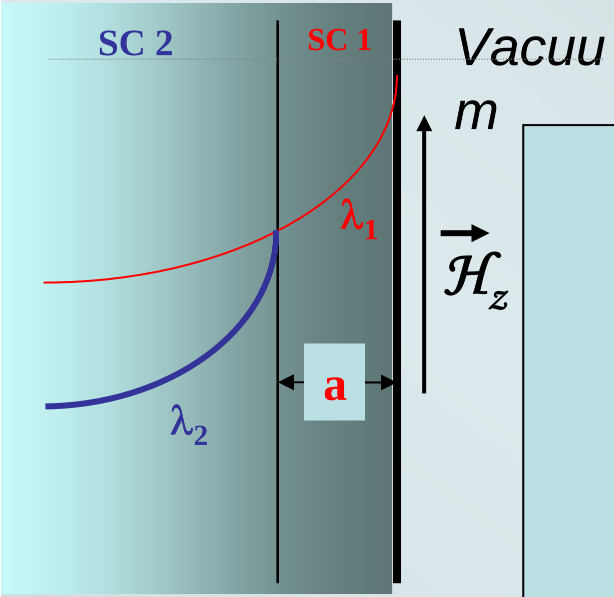
	Q-Slope Fit	Q-Slope before baking (EP = BCP)	Q-Slope Improvem^t after baking	Q-Slope after baking (EP < BCP)	No change after 4 y. air exposure	Exceptional Results (BCP)	Q-Slope unchanged after HF chemistry	TE_{011} Q-slope after baking	Quench EP > BCP	BCP Quench unchanged after baking	Argum^t Validity	Fund^al Disagreem^t Exper. ≠ Theory
Magnetic Field Enhancem^t	**Y** simulat. code	~~**N**~~ $\beta_m \neq B_{C2}^S \neq$	**Y** $B_{C2}^S \uparrow$	**Y** lower β_m	-	**N** high β_m	-	-	**Y** lower β_m	**N** $B_{C2}^S \uparrow$	**Y**	D_1
Interface Tunnel Exchange	**Y** E^8	**N** $\beta* \neq$	**Y** $Nb_2O_{5-y} \downarrow$	**Y** lower $\beta*$	**N** $Nb_2O_{5-y} \uparrow$	**N** high $\beta*$	~~**N**~~ new Nb_2O_{5-y}	~~**N**~~ improv^t	-	-	**Y**	D_2
Thermal Feedback	**Y** parabolic	**Y** ≅ thermal properties	**Y** $R_{BCS}\downarrow$ $R_{res}\uparrow$	**N** ≅ therm. propties	-	-	-	-	-	-	**N** C coeff.^t	-
Magnetic Field Dependence of Δ	**Y** expon^tial	**N** $B_{C2}^S \neq$	**Y** $B_{C2}^S \uparrow$	**Y** higher B_{C2}^S	-	-	-	-	-	-	~~**N**~~ thin film	D_1
Segregation of Impurities	?	**N** segregation ≠	**N** only O diffusion	**Y** surface ≠	-	**Y** good cleaning	**N** chemistry	-	-	-	**Y**	-
Bad S.C. Layer Interstitial Oxygen $Nb_{4\text{-}6}O$	?	**Y** NC layer	**Y** O diffusion	**N**	**N** interstitial re-appears	-	~~**N**~~ new bad layer	-	**Y** higher B_{C2}^S	**N** $B_{C2} \downarrow$	**Y**	D_1

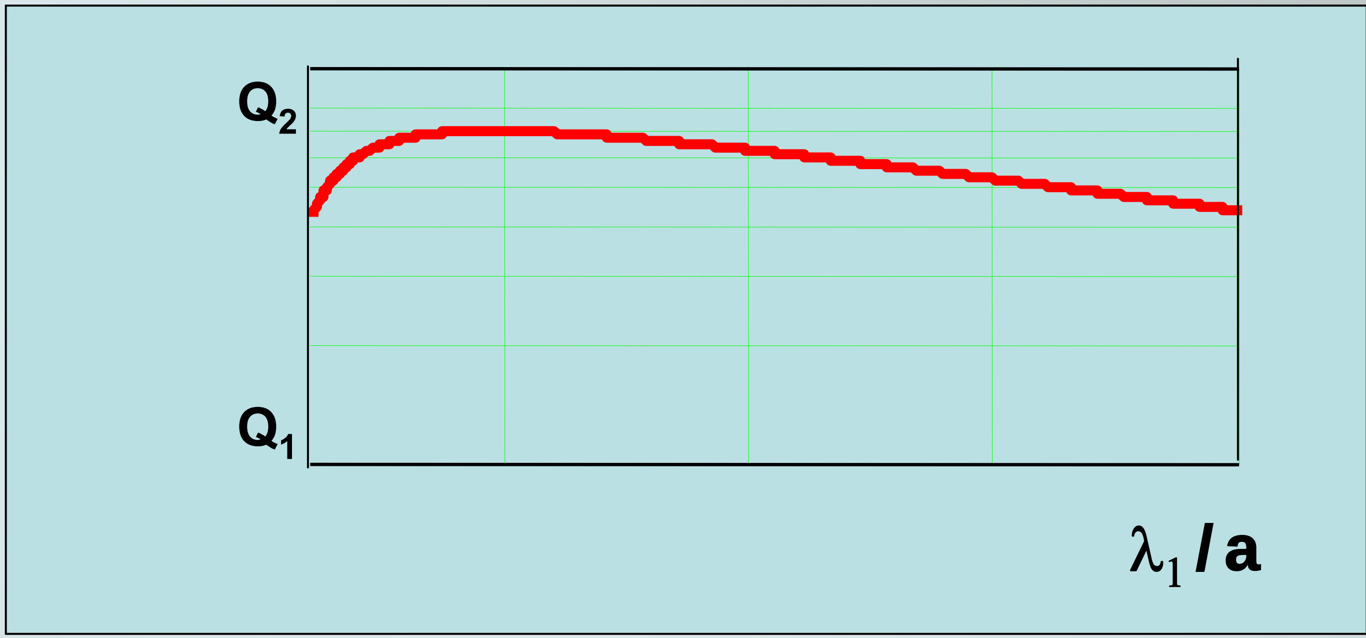
Y / **N** = theory in **agreement** / **contradiction** with experimental observation

N+ / = undisputable disagreement with experiment



Best 9-cell cavity result (after electro-polishing) (Courtesy D. Proch)





$$Q = Q_1 + (Q_2 - Q_1)e^{-a/\lambda 1}$$

$$\cancel{\boxed{\Delta = \Delta_0 \left(1 - H^2/H_C^2\right)}}$$

This formula has done a lot of damage to our community for the understanding of the Q-Slope

This relation goes back to first principles

$$\Delta = \Delta_0 - p_f v_s$$

It means to take into account the supercurrent!

If for Superconducting Magnets the fundamental and <u>indipendent</u> parameters are 3: T_C, H_C and J_C, …..

why for Superconducting cavities, JC disappeared?

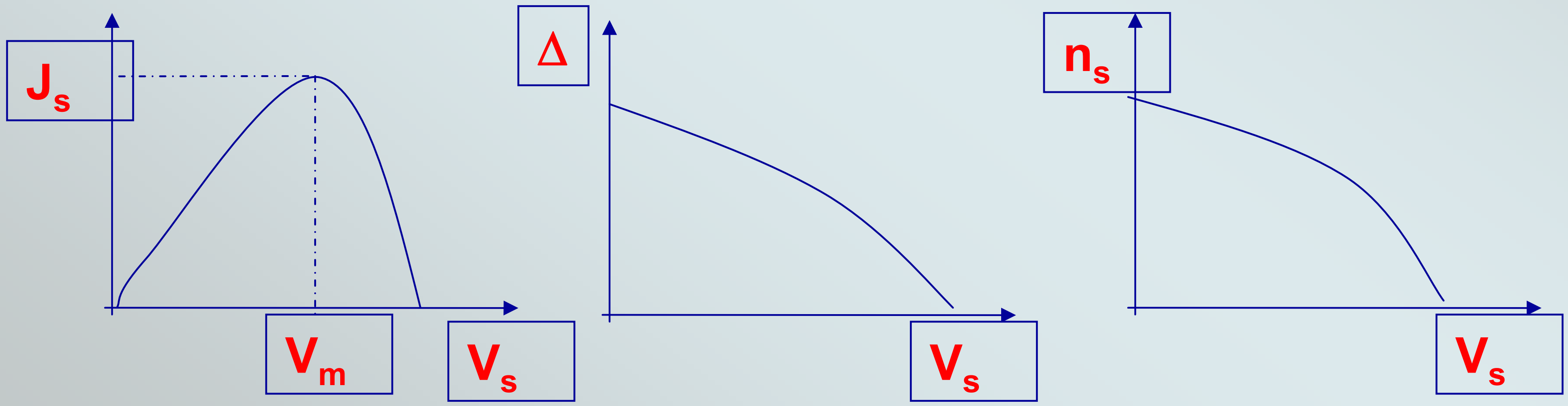
Is 40 MV/m (1600 G) a field not strong enough?

In local electrodynamics of superconductivity, $j = j_1 + j_2$

Where J_1 is the Meissner current $$j_1 = n_s e v_s \left(1 - \frac{v_s^2}{v_c^2}\right)$$

At small supercurrent $$j_1 = n_s e v_s$$

but at larger V_s, GL theory foresees a deparing effect by the current



Over $\mathbf{V_m}$ the superconducting state become unstable

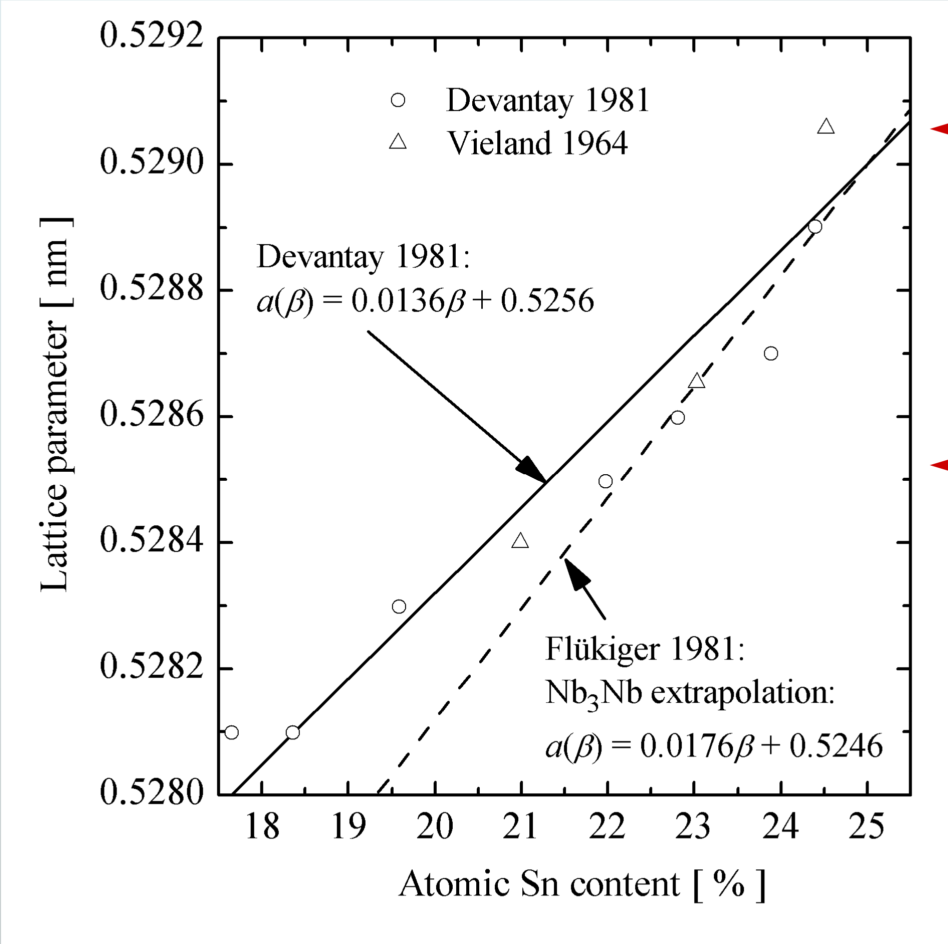
A15 Materials

High Field Superconductors with Technological Potential

Material	Structure Classification	Tc (K)	H_{c2} (T) Obs. 4.2K	Jc (A.cm^{-2}) 4.2 K (T)
Nb-Ti	A-2	10.2	12	5 x 10^5(5 T)
Nb-Zr	A-2	10.8	11	
V_3Ga	A-15	15.5	23.6	2 x 10^6(10T)
V_3Si	A-15	17.0	23	
Nb_3Sn	A-15	18.3	26	3 x 10^5(10T)
Nb_3Al	A-15	18.9	29.5	10^5(22T)
Nb_3(Al,B,Be)	A-15	20.0		3 x 10^4(8T)
Nb_3Ga	A-15	20.3	33	
Nb_3(Al,Ge)	A-15	20.5	41	1 x 10^4(12T)
Nb_3Ge	A-15	23.2	37	
NbCN	B-1	17.8	12	1 x 10^3(7T)
V_2(Hf,Zr)Lave	C-15	10.1	23	3 x 10^5(6T)
$PbMo_6S_8$	C-15	14.0	65	

Sn content: Lattice parameter

a increases with Sn content (as does T_c (below))

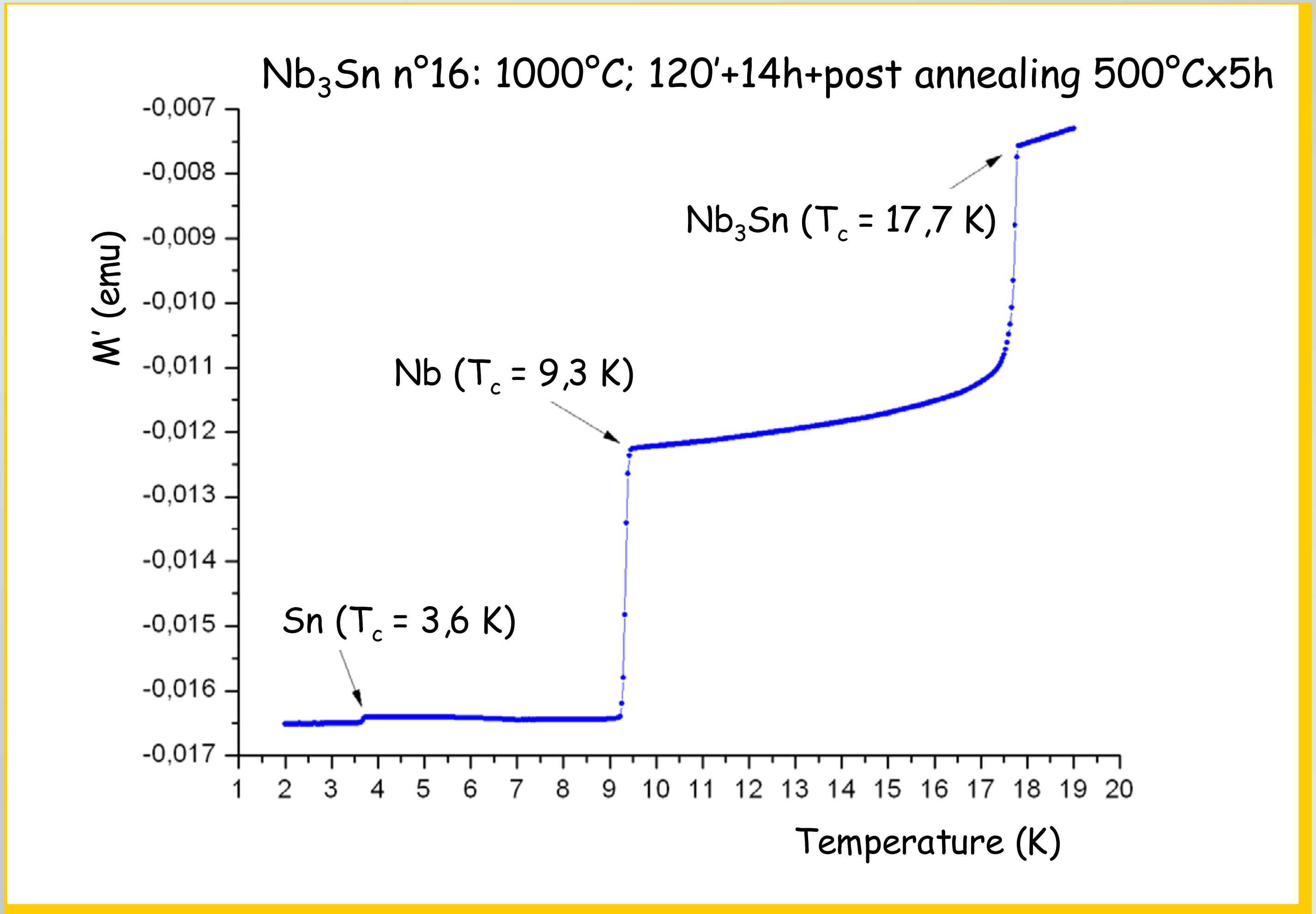


Maximum T_c

Reduced T_c (from Sn deficiency though Nb spacing is smaller)

- Devantay, JMS 1981; Vieland, RCA Rev. 1964; Flükiger, 1981

S.Deambrosis et al



Method: "1 step" process

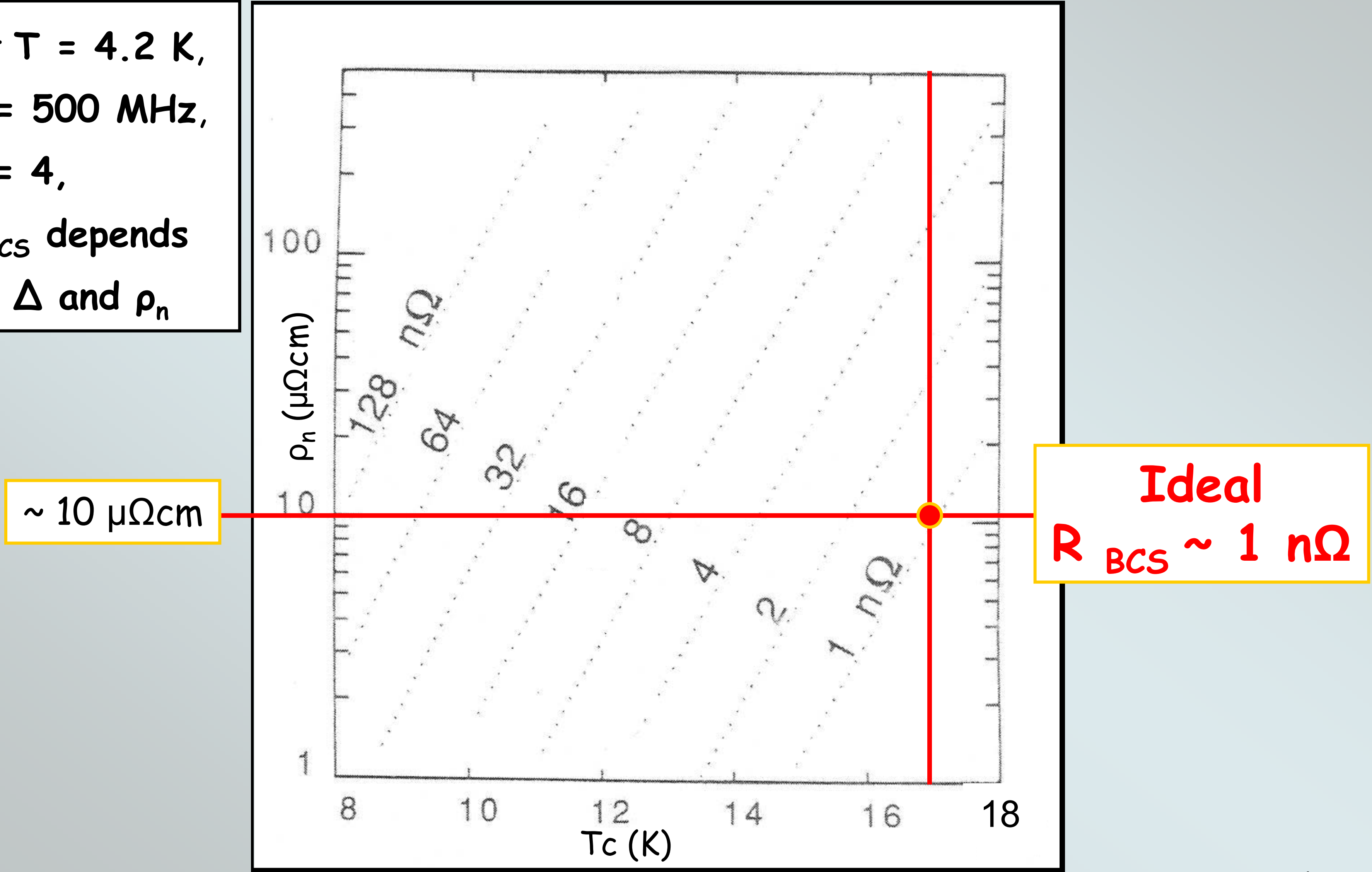
V3Si

At T = 4.2 K,

f = 500 MHz,

s = 4,

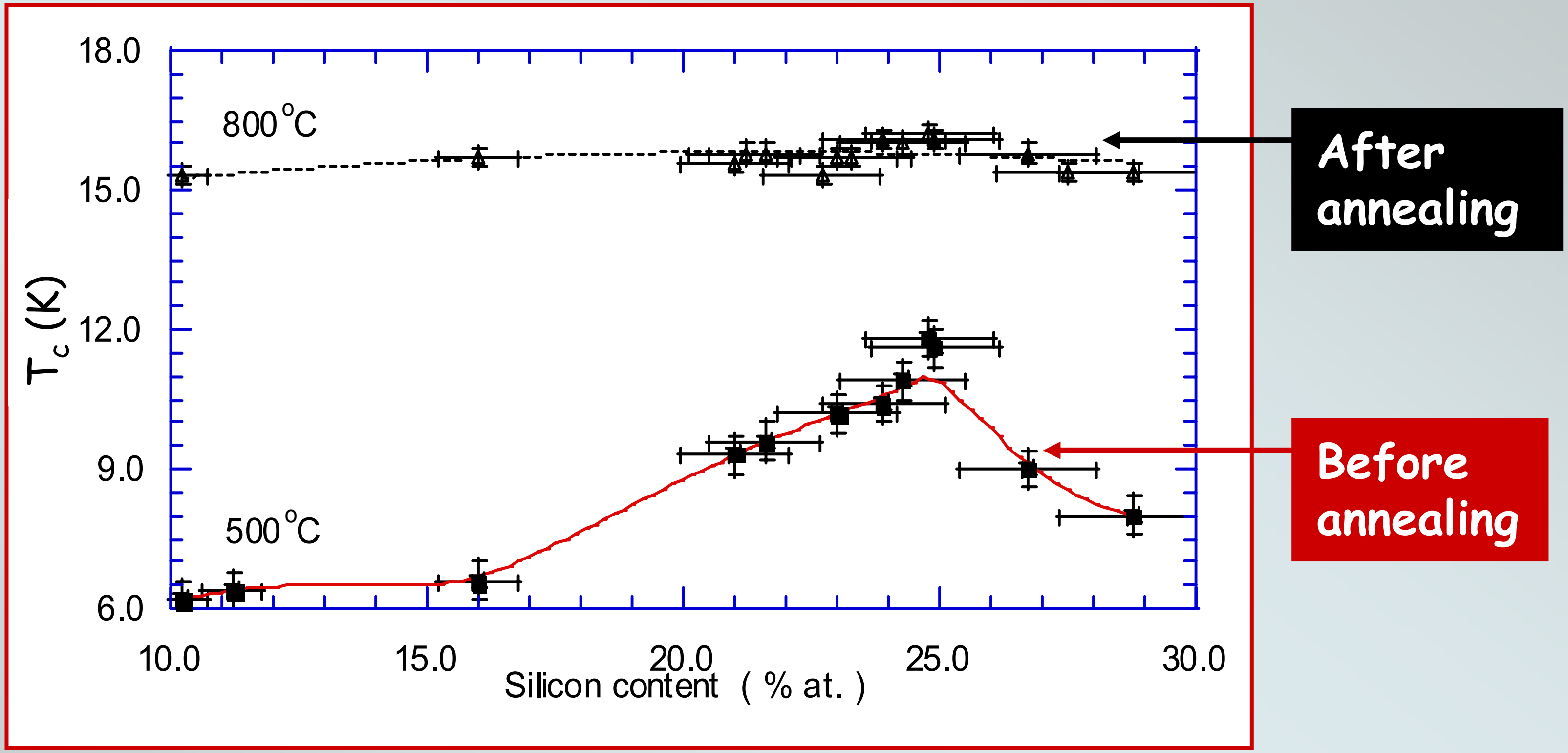
R_{BCS} depends on Δ and ρ_n



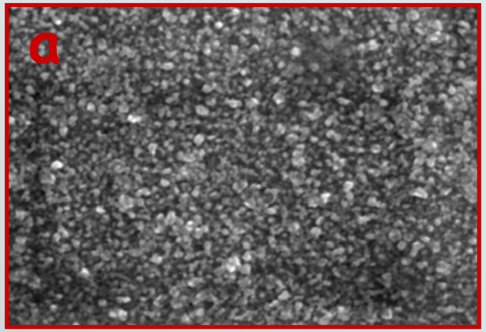
Theory

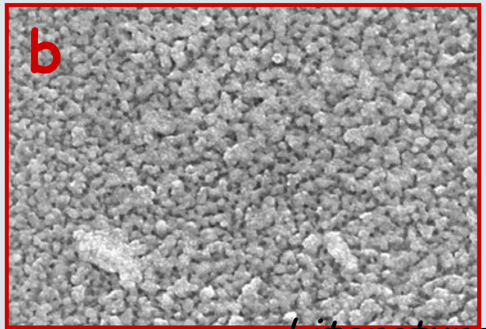
Reactive sputtered V_3Si films

Y. Zhang, V. Palmieri, W. Venturini, R. Preciso, Legnaro National Laboratory - INFN, Italy



Surface of two annealed samples under SEM: Grain size, (a) 0.2μm, (b) 0.5μm





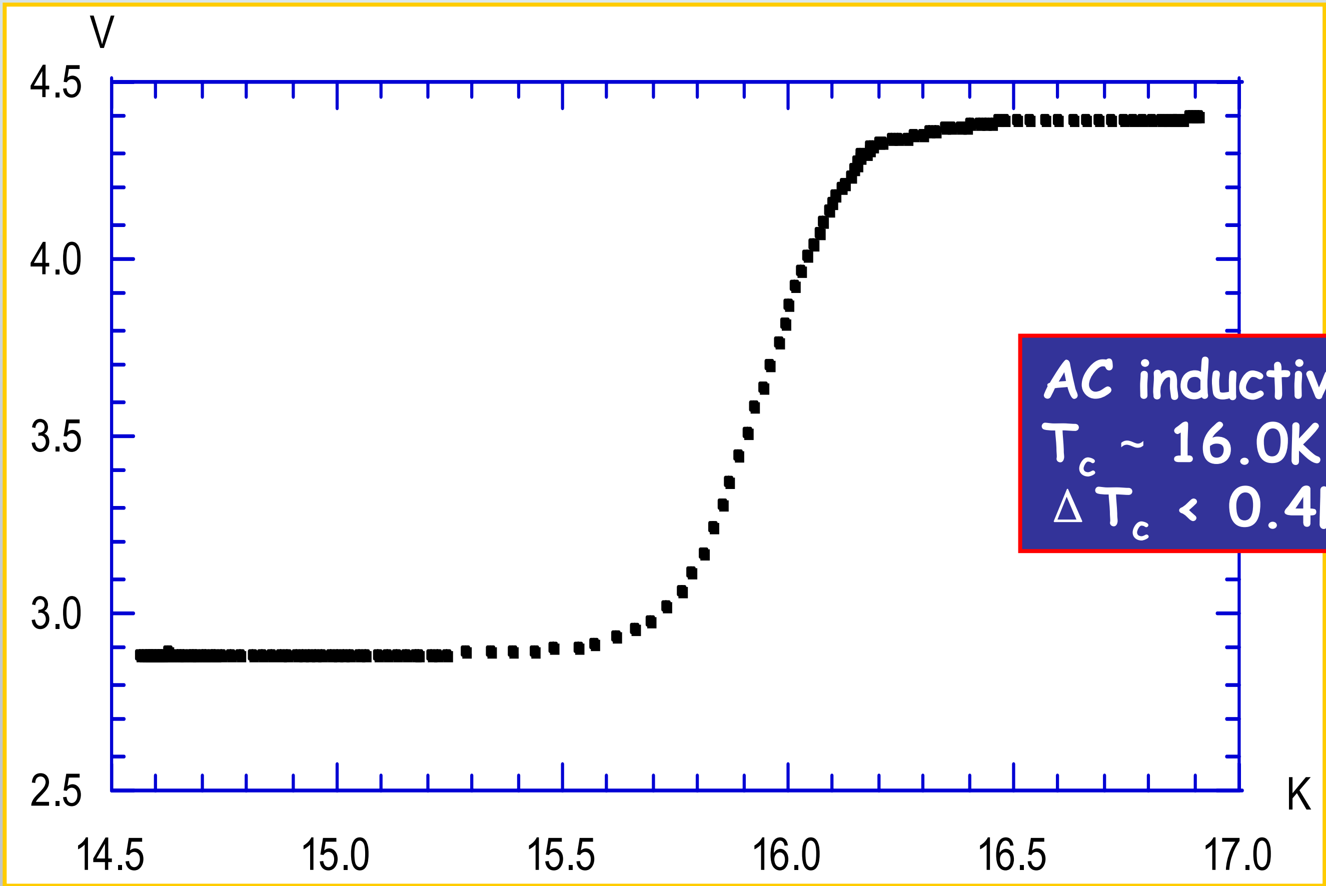
Literature

Thermal diffusion of V_3Si films

Y. Zhang, V. Palmieri, W. Venturini, F. Stivanello, R. Preciso, Legnaro National Laboratory, ITALY

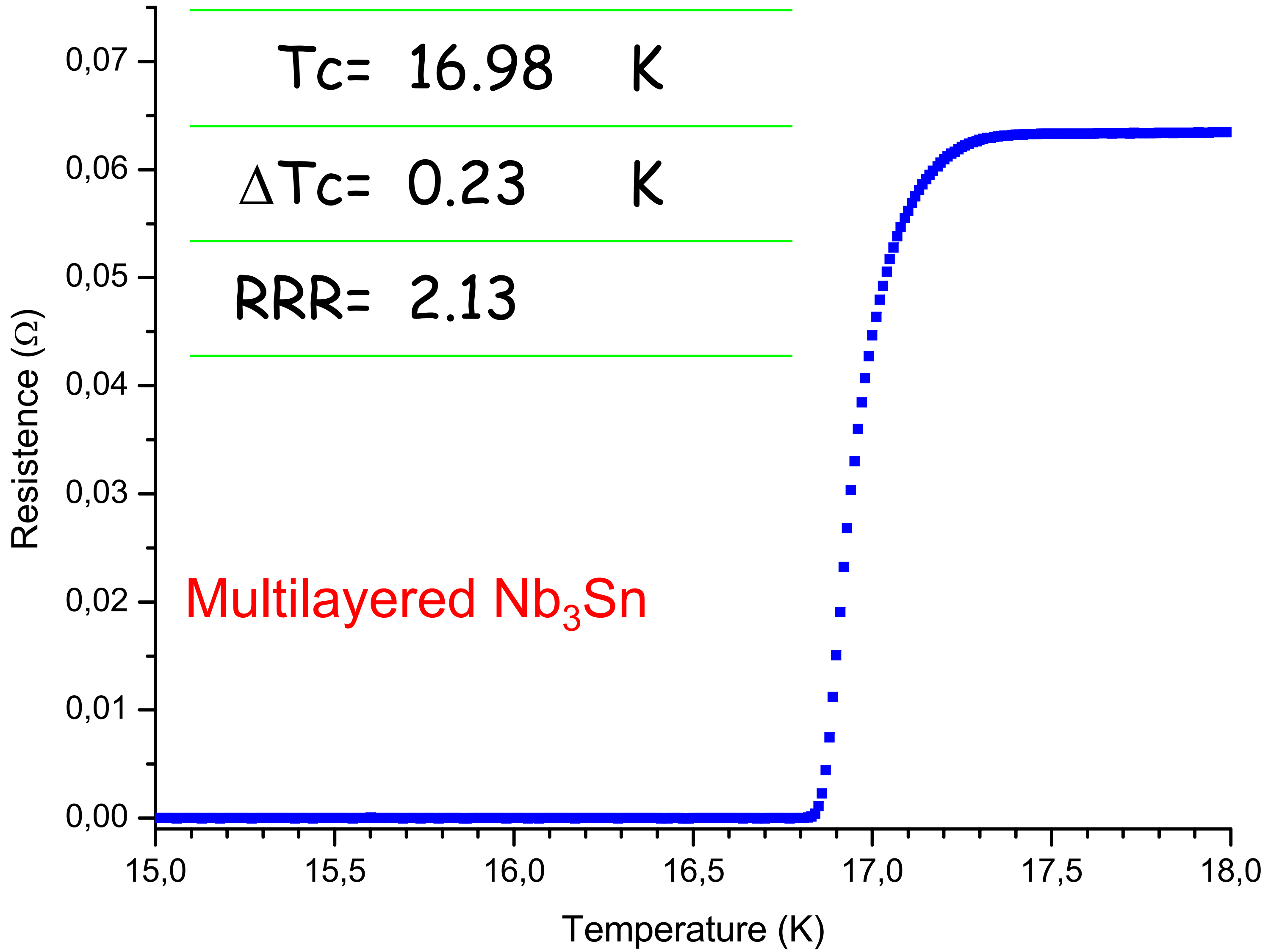
Diffusion Parameters:

Silane pressure	Heat power	Temperature	Diffuse in silane	Anneal in vacuum
$1.2 \cdot 10^{-4}$mbar	300W	900°C	20h	40h



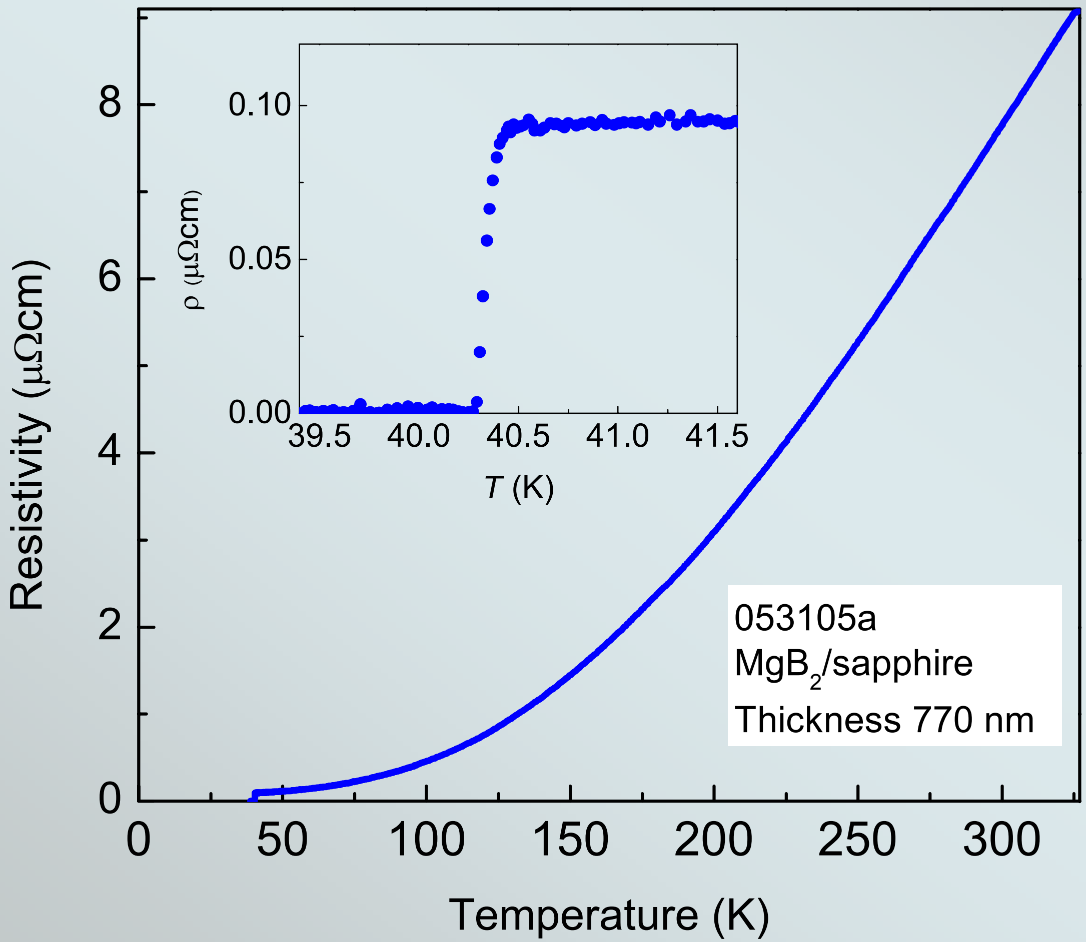
AC inductive measurement:
$T_c \sim 16.0$K
$\Delta T_c < 0.4$K

Literature

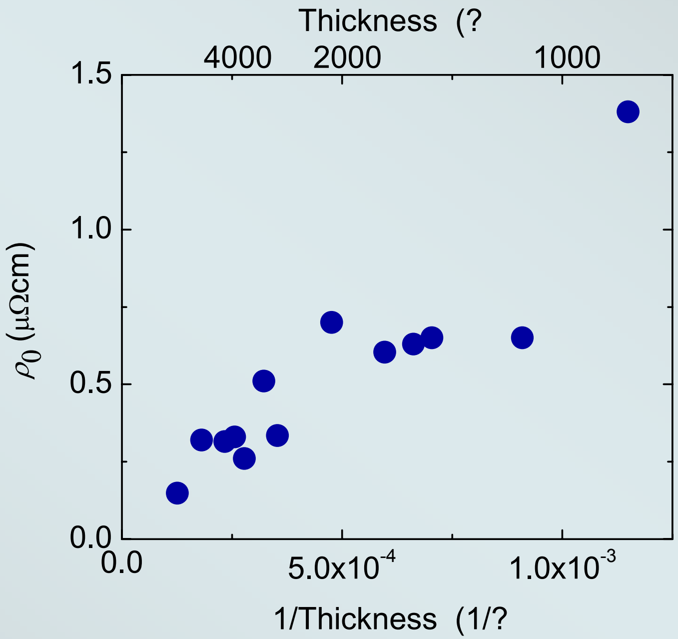


Tc= 16.98 K
ΔTc= 0.23 K
RRR= 2.13
Multilayered Nb_3Sn
Resistence (Ω)
0,00
0,01
0,02
0,03
0,04
0,05
0,06
0,07
15,0
15,5
16,0
16,5
17,0
17,5
18,0
Temperature (K)

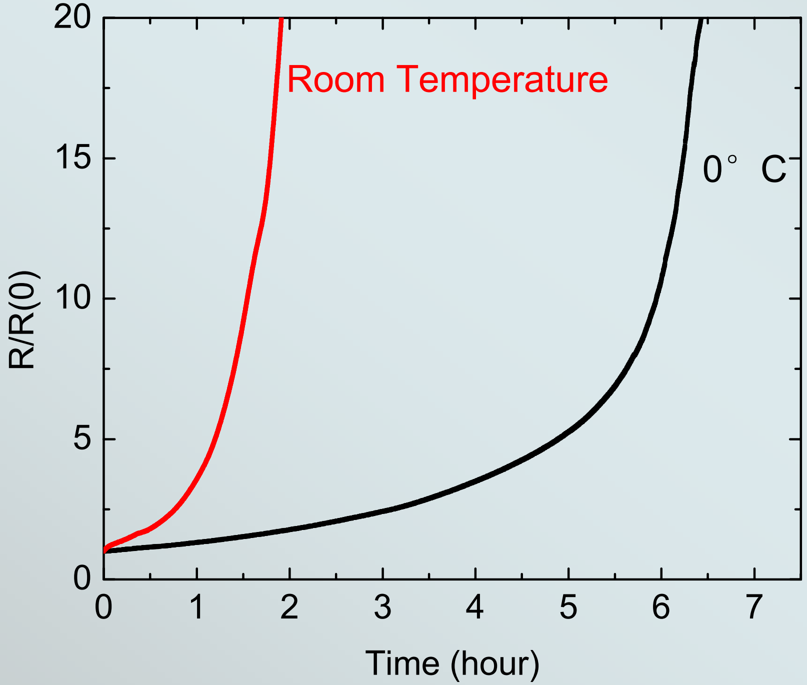
Very Clean HPCVD MgB_2 Films: *RRR* > 80

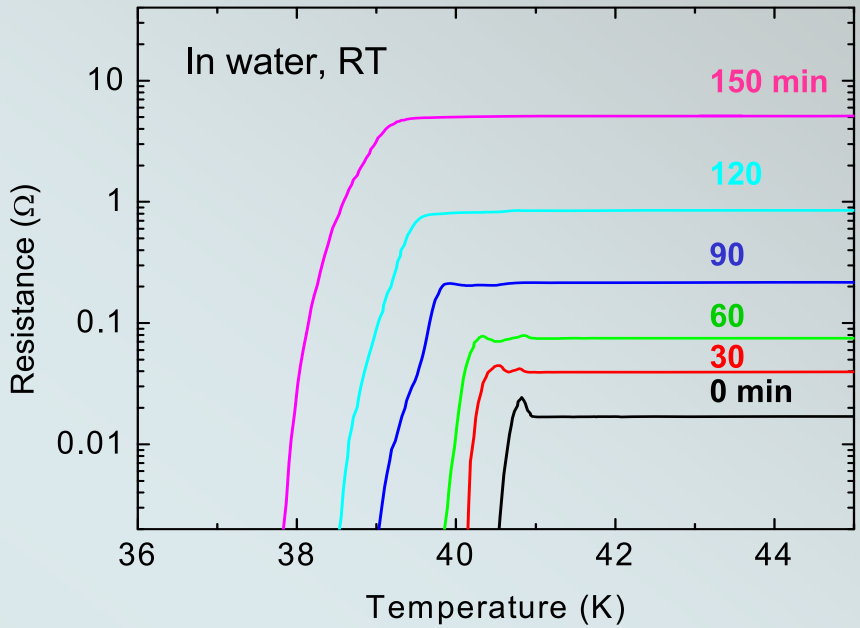


Mean free length is limited by the film thickness.



Degradation of HPCVD MgB_2 Films in Water





— Film properties degrade with exposure to air/moisture: resistance goes up, T_c goes down

— Experiments show that MgB_2 degrades quickly in water, and is sensitive to temperature.

Advanced Cleaning

Case 3

A woman etching computer chips developed a pin-hole in her glove during the four hours that she was working in a dip tank with 5% hydrogen fluoride. She went to a doctor's office where **a non-specific burn ointment was applied** (no calcium gluconate was applied). She continued to have pain during the next four days. At that time she had severe pain under the finger nail and the subungual tissues were black. There was mild erythema around the proximal cuticle. Upon removal of the finger nail at a burn treatment center where she was referred, exposed and necrotic bone was identified. The distal phalanx was demineralized and the patient required distal amputation of the finger (Edelman, 1986).

Hydrofluoric acid (HF) differs from other acids because the fluoride ion readily penetrates the skin, causing destruction of deep tissue layers, including bone.

Pain associated with exposure to solutions of HF (1-50%) may be delayed for 1-24 hours. If HF is not rapidly neutralized and the fluoride ion bound, tissue destruction may continue for days and result in limb loss or death.

… Do you really want I continue with case 4?

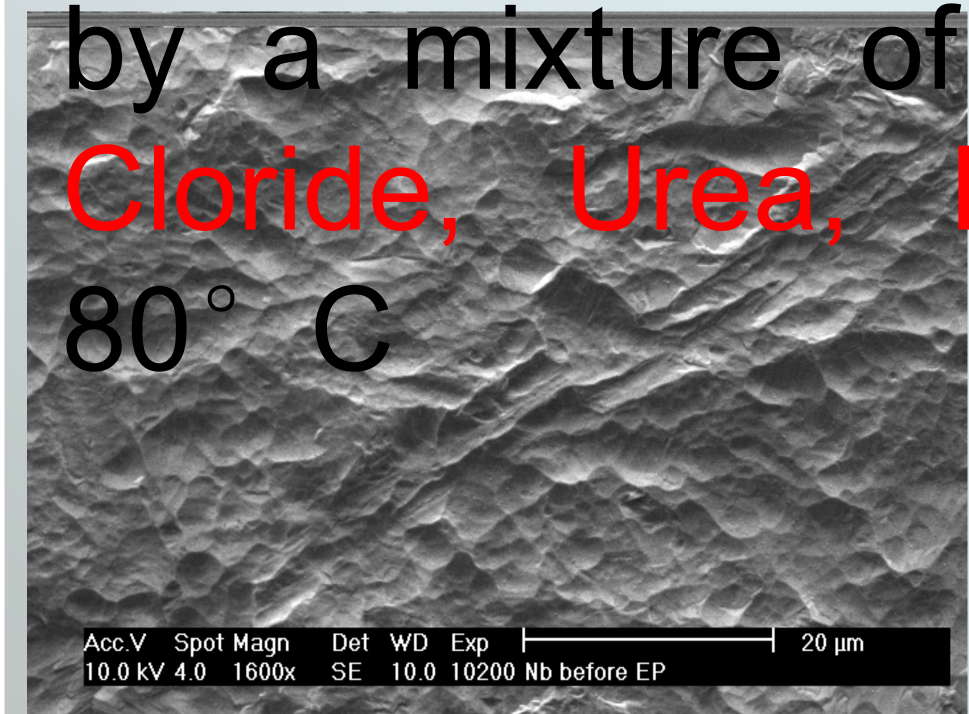
On the basis of Abbott Patent,

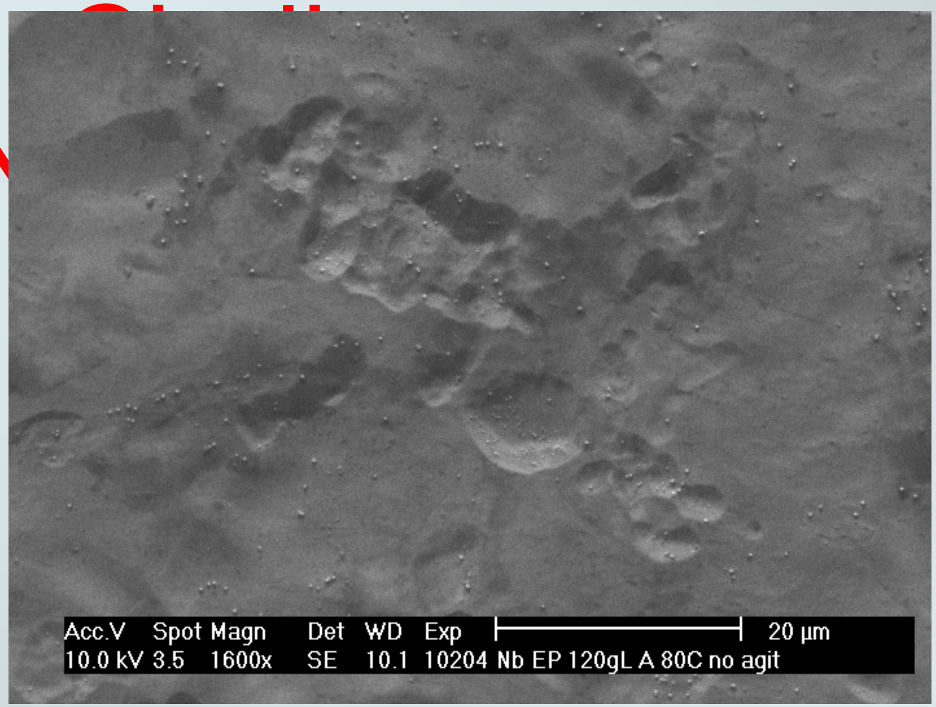
We succeeded in electropolishing Nb!

by a mixture of

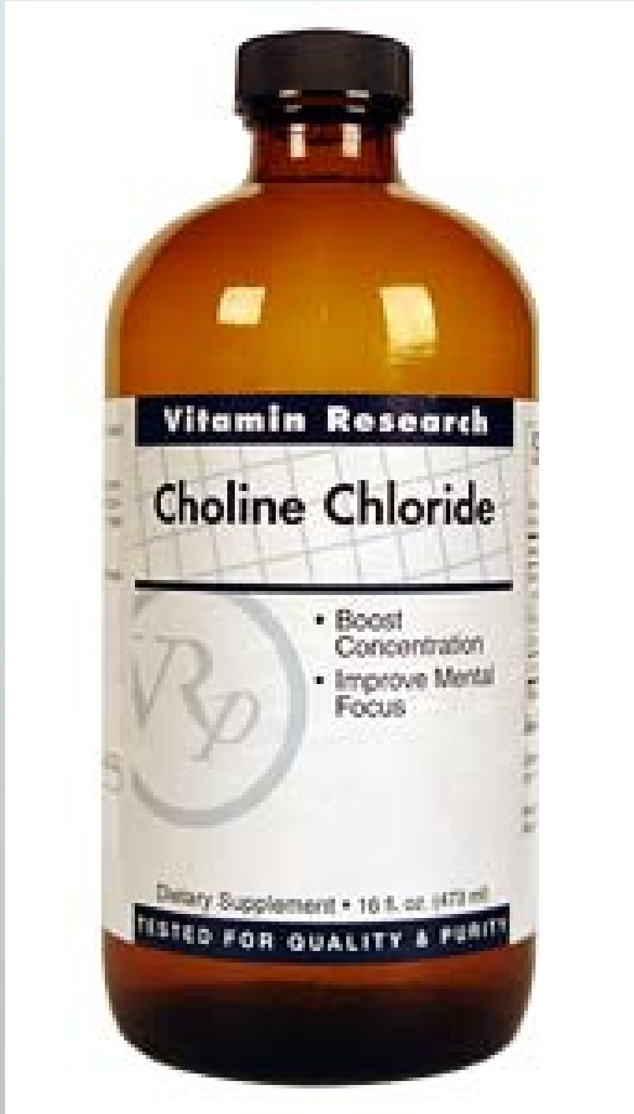
Cloride, Urea,

80° C





Choline Chloride Drink



The brain has a voracious appetite for choline. There are two main reasons for the brain's huge need for this nutrient: Choline is required for synthesis of the key neurotransmitter acetylcholine, and it is used for the building and maintenance of brain cell membranes. Acetylcholine is vital for thought, memory and sleep, and is also involved in the control of movements

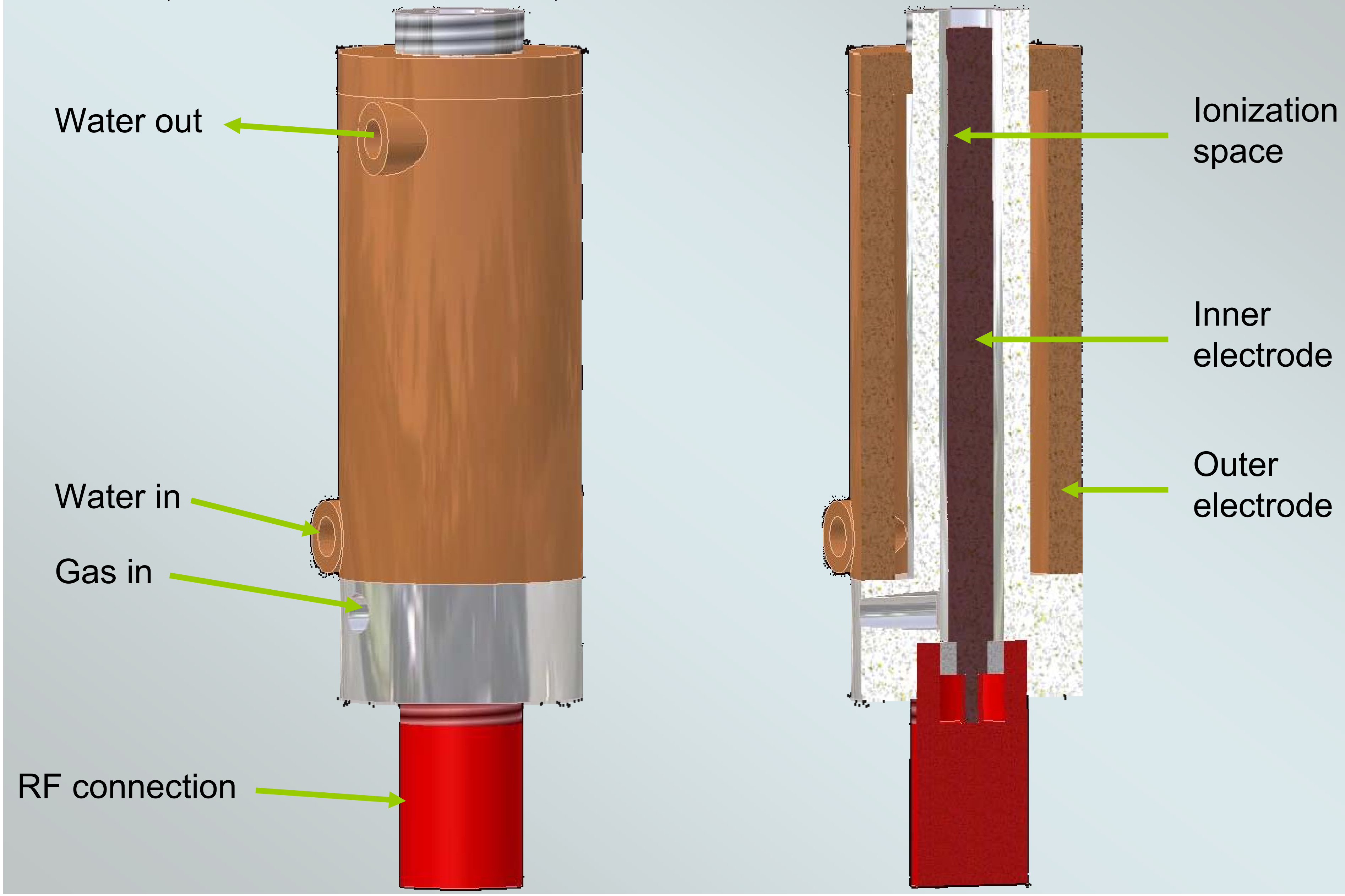
Dosage and Use

Take 1 to 3 teaspoons daily.

It is best mixed with approximately 2 oz. of juice per teaspoon.

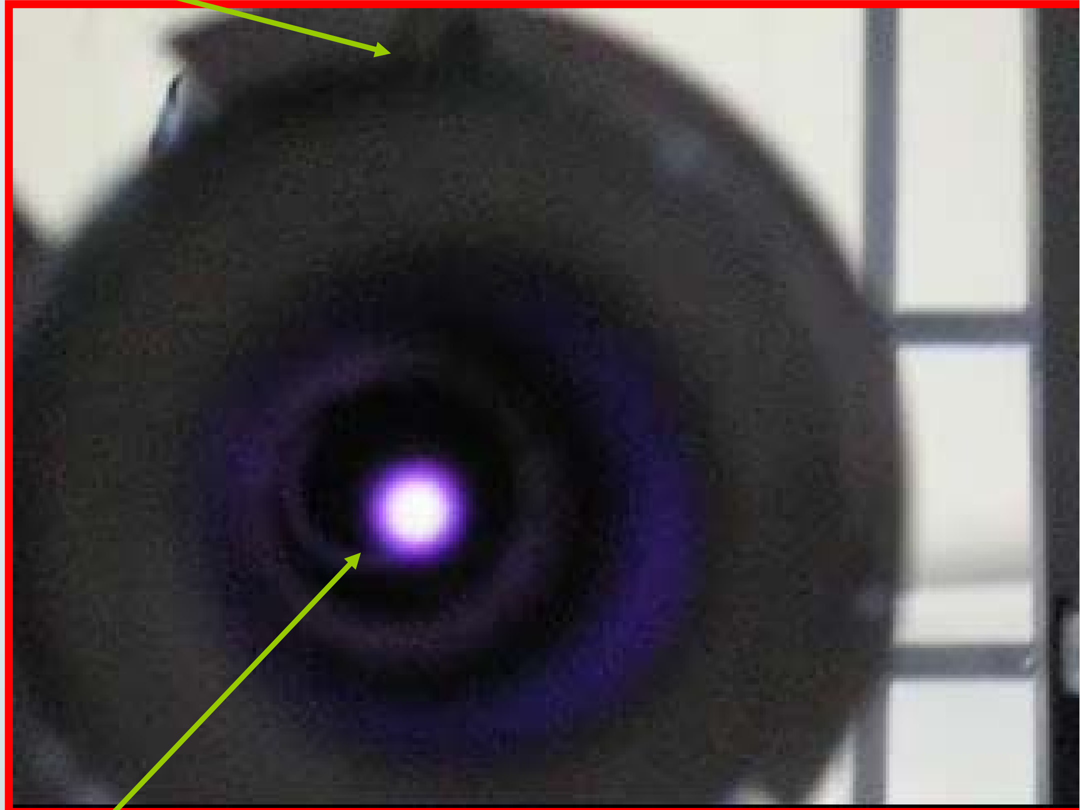
- AP plasma
  - DC
    - CORONA
  - RF
    - RF resonance
    - AP Plasma Jet
  - MICROWAVE
    - MW plasma torch

13,56 MHz / 2,45 GHz APPJ Device



6 GHz cavity

Cavity



TM010 plasma at a power of 50 W

JUST AN EXAMPLE of how we also should work:

Xiaoxing Xi group (Physics and Materials Sci & Eng); Ke Chen, Derek Wilke, Yi Cui, Chenggang Zhuang (Beijing), Arsen Soukiassian, Valeria Ferrando (Genoa); Pasquale Orgiani (Naples); Alexej Pogrebnyakov, Dmitri Tenne, Xianghui Zeng, Baoting Liu: CVD growth, electrical characterization, junctions

Joan Redwing Group (Materials Sci & Eng): HPCVD growth, modeling

Qi Li Group (Physics): Junctions, transport and magnetic measurements

Darrell Schlom Group (Materials Sci & Eng): structural analysis

Zi-Kui Liu Group (Materials Sci & Eng): Thermodynamics

Xiaoqing Pan Group (U. Michigan): Cross-Section TEM

John Spence Group (ASU): TEM

N. Klein Group (Jülich): Microwave measurement

A. Findikoglu (LANL): Microwave measurement

Qiang Li Group (Brookhaven National Lab): Magneto-optic measurement

Tom Johansen Group (U Oslo): Magneto-optic measurement

Qing-Rong Feng Group (Peking University): SiC fiber

Chang-Beom Eom Group (U Wisconsin): Structural analysis

J. B. Betts and C. H. Mielke (LANL): High field measurement