LIGO-G1600665

nm-Layered Composite Coating Materials: Status and TBD

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Università degli Studi del Sannio

Università di Roma Tor Vergata

INFN Istituto Nazionale di Fisica Nucleare

行政院國家科學委員會 National Science Council

LVC Meeting, Pasadena, CA (USA), March 14-18 2016

The INFN AdCOAT Project & WGs

Goals: - Characterizing the properties of nmLCM;
- Setting up a network of Italian Groups with an expertise/interest in coatings

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Alessio Rocchi (PI), Elisabetta Cesarini, Eugenio Coccia, Viviana Fafone, Yuri Minenkov

Funded by INFN CSN-V (2014,2015)

https://web2.infn.it/adcoat/

Outline

nm Layered Composite Coating Materials Study Status

- Confirmed Claims
- Un-confirmed Claims (as of March 2016)
- TBD

Floating ideas and Modeling Work

USannio coating facility

- Overview
- Installation status (as of March 2016)

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nmLCM – Confirmed Claims

Thinn(er) films crystallize at *high(er)* temperatures

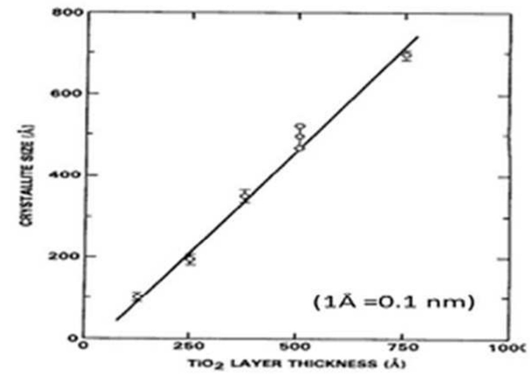
Seminal work on ***thin – layer Titania*** films by Sankur & Gunning [J. Appl. Phys. 66 (1989) 4747]

"Thinner layers (< 250 Å) required higher temperatures [to crystallize]. 65 Å layer films exhibit diffraction only after annealing at 600°C."

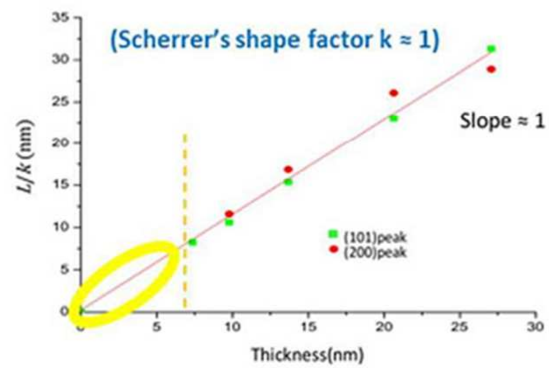
"Grain size, as deduced from diffraction line broadening, was comparable to the layer thickness"

"Thicker layers remain in the Anatase phase and never transform into Rutile, even for prolonged (72 h) annealing at the highest temperature s (1100°C). Thinner layers (65 Å) convert into Rutile starting at 900°C"

"Below a certain critical thickness crystallization in pure TiO_2 films is inhibited"



[Gluck et al., J. Appl. Phys. 69 (1991) 3037]



[S. Chao et al., LIGO-G1300921]

nmLCM – Confirmed Claims, contd

1st generation prototypes

	Total thickness (nm)	Averaged thickness of TiO_2 and SiO_2 layer(nm)	
		TiO_2	SiO_2
single TiO2	121.9	121.9	0
3 layer	119.8	40.9	40.7
5 layer	119.2	26.2	20.3
7 layer	120.0	20.6	12.5
11 layer	119.3	13.7	7.4
15 layer	112.4	9.8	4.8
19 layer	112.6	7.4	4.3

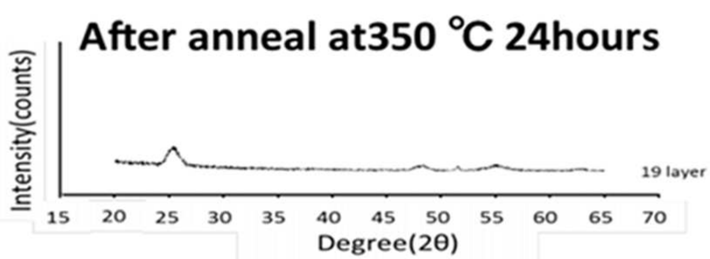
[S. Chao et al., LIGO-G1300921]

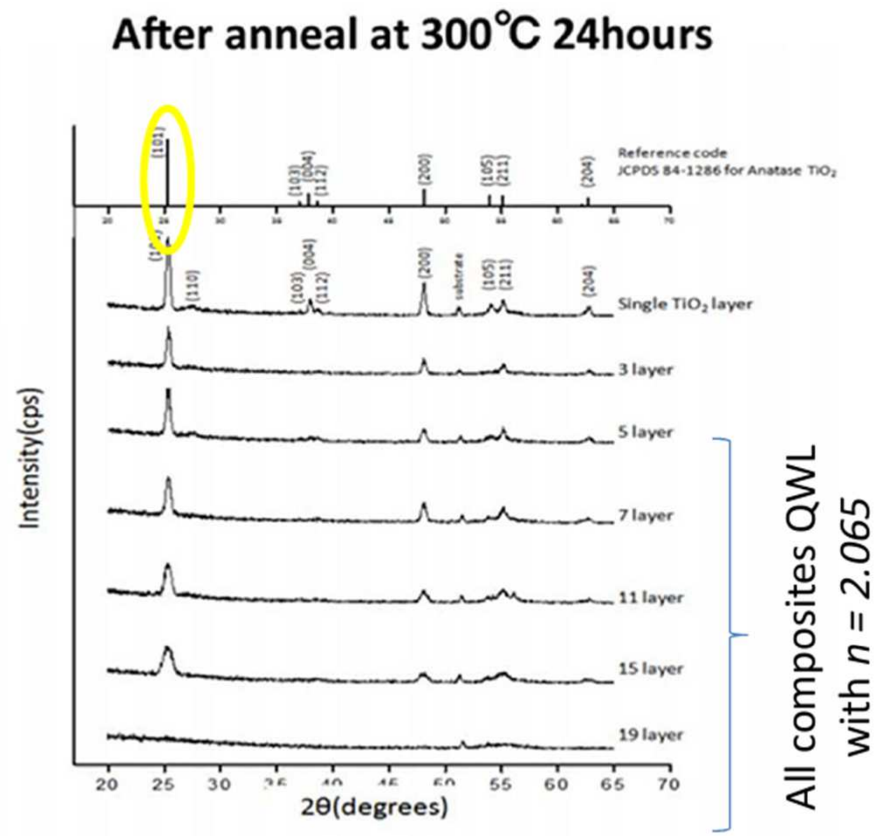
➡ All prototypes QWL thick @ 1064nm, all with *n = 2.065*

nmLCM – Confirmed Claims, contd

There is a threshold anneal temperature for the onset of crystallization (Anatase). The threshold temperature increases with the number of layers, or equivalently, with decreasing the (Titania) layer thickness.

At 300C the Anatase peak gets smaller and broader as the nanolayer thickness decreases (and the nanolayer number Increases), signaling crystallization frustation, until it disappears for N=19.

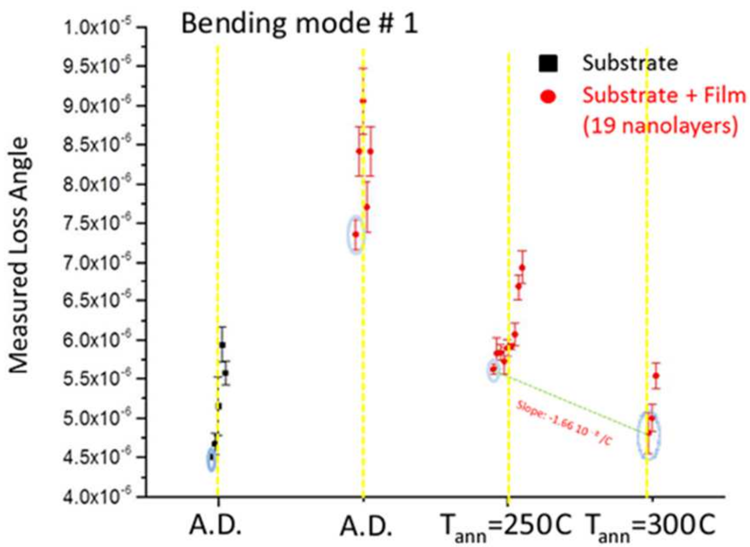




[S. Chao et al., LIGO-P1400122;
Optics Express , 22 **(2014)** 29847

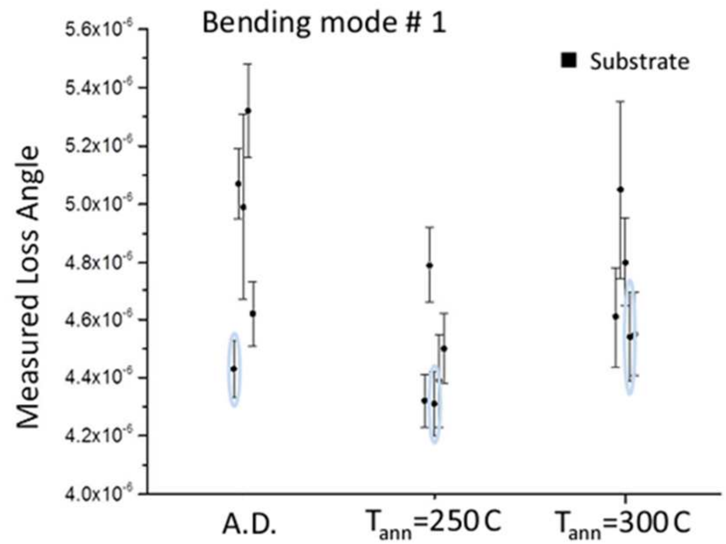
nmLCM – Confirmed Claims, contd

Loss angle of annealed ***nmLCM*** reduces upon annealing .
Losses better than Ti doped Tantala



	Loss Angle	
T_{ann}	μ	σ/μ
A.D.	7.36 10^{-6}	0.082
250	5.64 10^{-6}	0.074
300	4.81 10^{-6}	0.074
substrate + film (19 layers)		

[S. Chao et al., LIGO-G1401055]

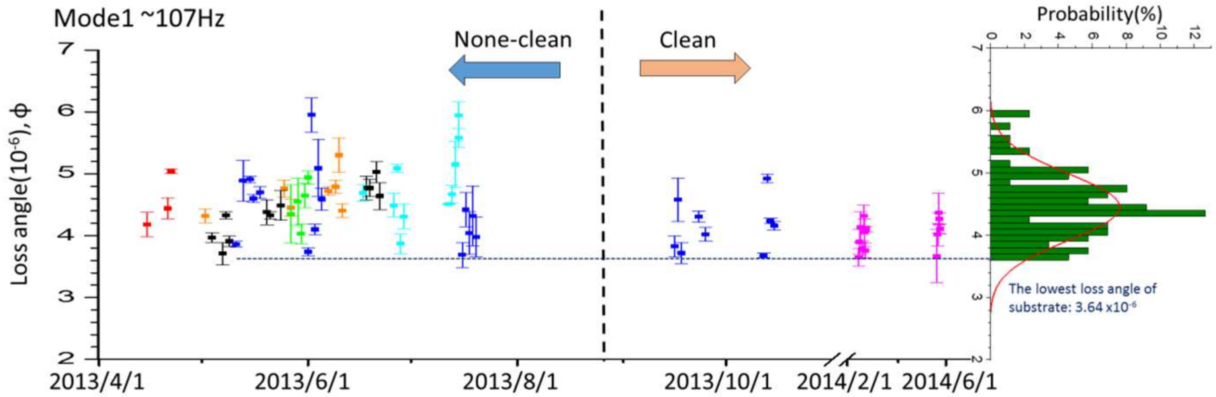


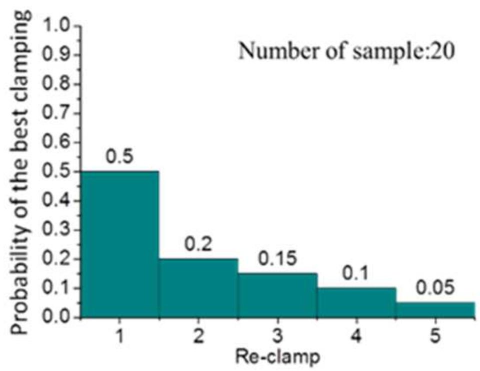
	Loss Angle	
T_{ann}	μ	σ/μ
A.D.	4.48 10^{-6}	0.073
250	4.32 10^{-6}	0.044
300	4.55 10^{-6}	0.046
substrate only (Silicon)		

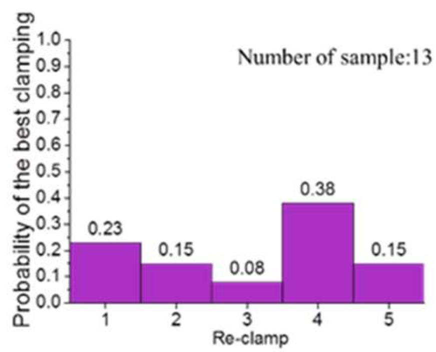
nmLCM – Confirmed Claims, contd

Re-clamping issues characterized

S. Chao et al. LIGO G-1501024







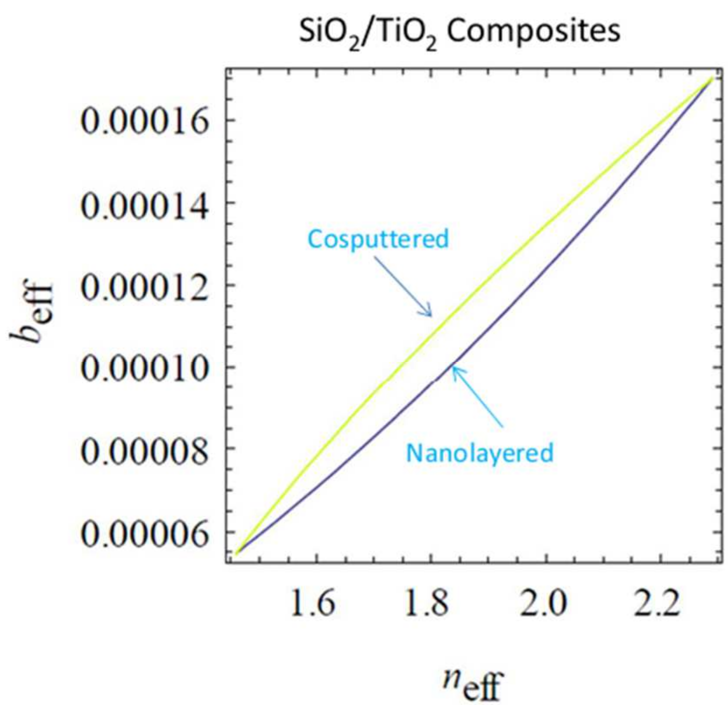
Probability of hitting the lowest loss angle vs. order of re-clamping (none-clean: only the clamp surface was cleaned in between re-clamping)

Probability of hitting the lowest loss angle vs. order of re-clamping (both clamp surface and sample surface were cleaned in between re-clampings)

nmLCM – Unconfirmed Claims

Nanolayered less noisy than co-sputtered (for the same value of refraction index)

(as of March 2016)



$$\phi_{c=} d_L b_L + d_H b_H$$

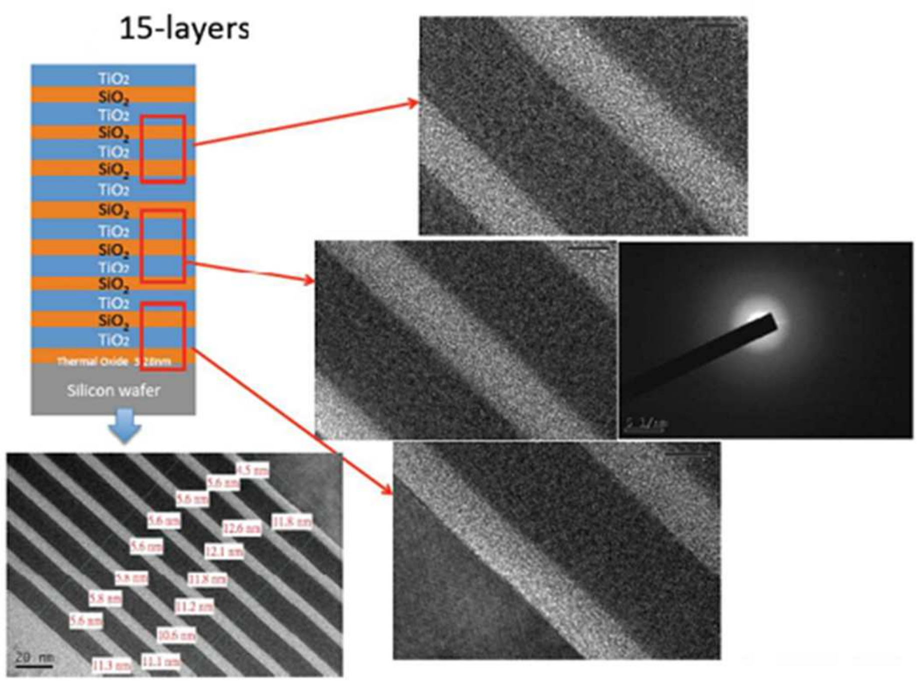
$d_{L,H}$ decreases with dielectric contrast

Nanolayered SiO2/TiO2 composites are *less noisy*, compared to co-sputtered SiO2/TiO2 composites having *the same refraction index*

nmLCM – Unconfirmed Claims

Interfacial losses/scattering ?

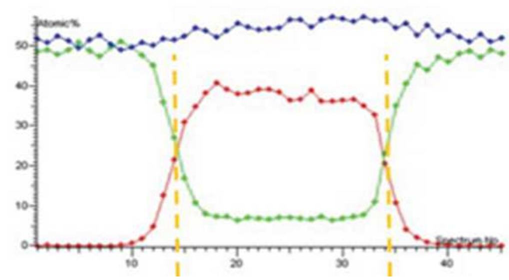
(as of March 2016)



[S. Chao et al., LIGO-G1200489]

Morphology of witness samples investigated using TEM and electron diffraction.

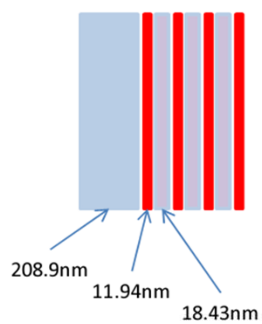
Interface profiles characterized via energy-dispersive X-ray diffraction (EDXRD)



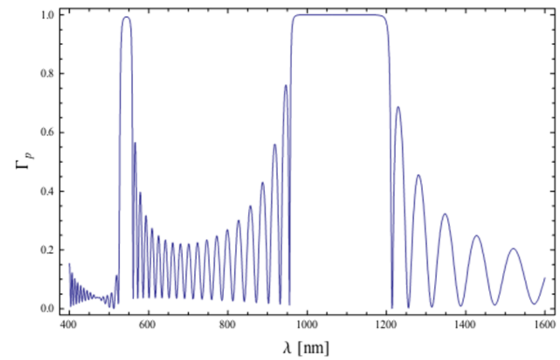
nmLCM – Unconfirmed Claims

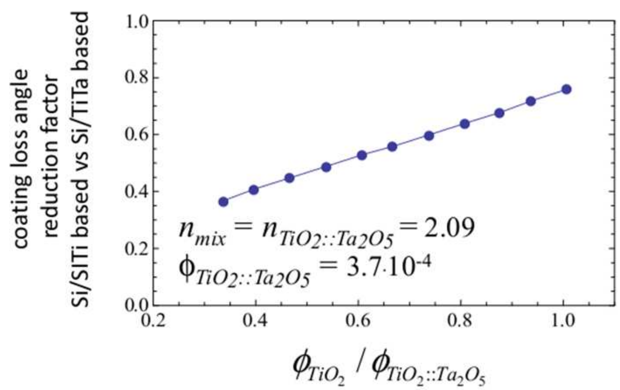
One could build a whole nm-layered (dichroic) A-LIGO like mirror using nmLCM for the high (and maybe also the low) index material

(as of March 2016)



λ [nm]		
1064	6.	τ_P [ppm]
532	0.95	Γ_P
670	0.0362	
946	0.7610	
980	0.9993	
1319	0.0275	
1550	0.0981	



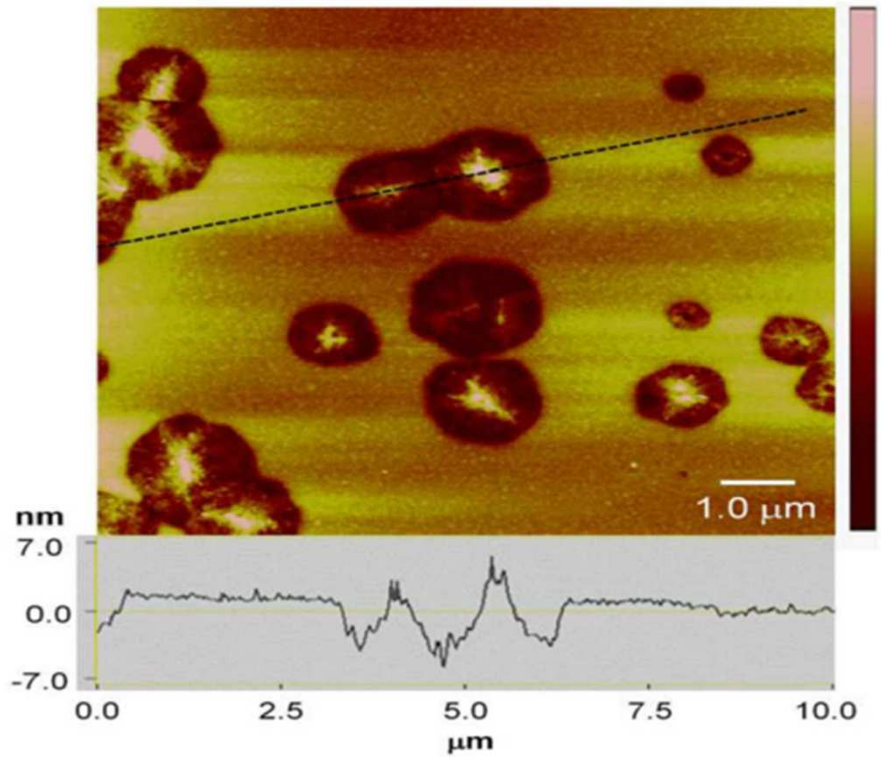


[I. Pinto et al. LIGO G-1100586]

nmLCM Ongoing Work

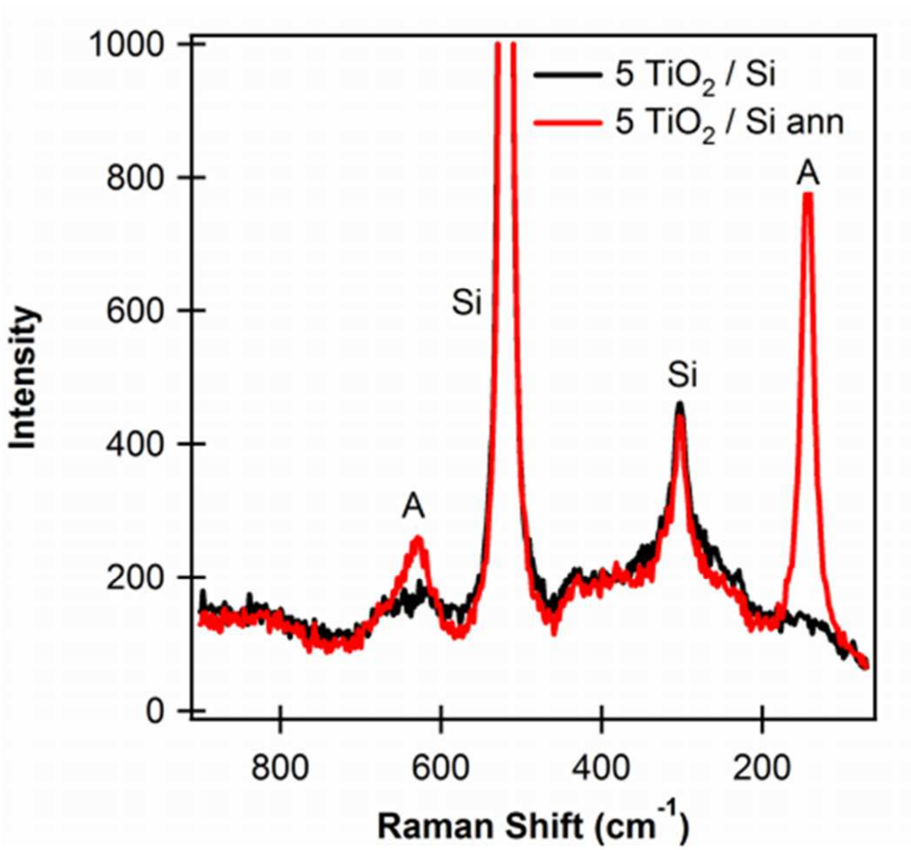
In thick layers, Titania crystallites grow isotropically. Their surface to volume ratio increases roughly $\propto$ their radius. Once started, nucleation is hence accelerated until a depleted region (a sort of moat) forms, inhibiting its further growth.
(The crystal/moat size depends on *T*, affecting material viscosity).
In thin Titania layers, buffered both sides by glassy (Silica) layers, crystallites may grow isotropically only until their size becomes comparable to the layer thickness h.
Further "lateral" growth does not increase the volume/surface ratio, that remains $\sim h$.
Hence lateral crystal growth is not promoted.

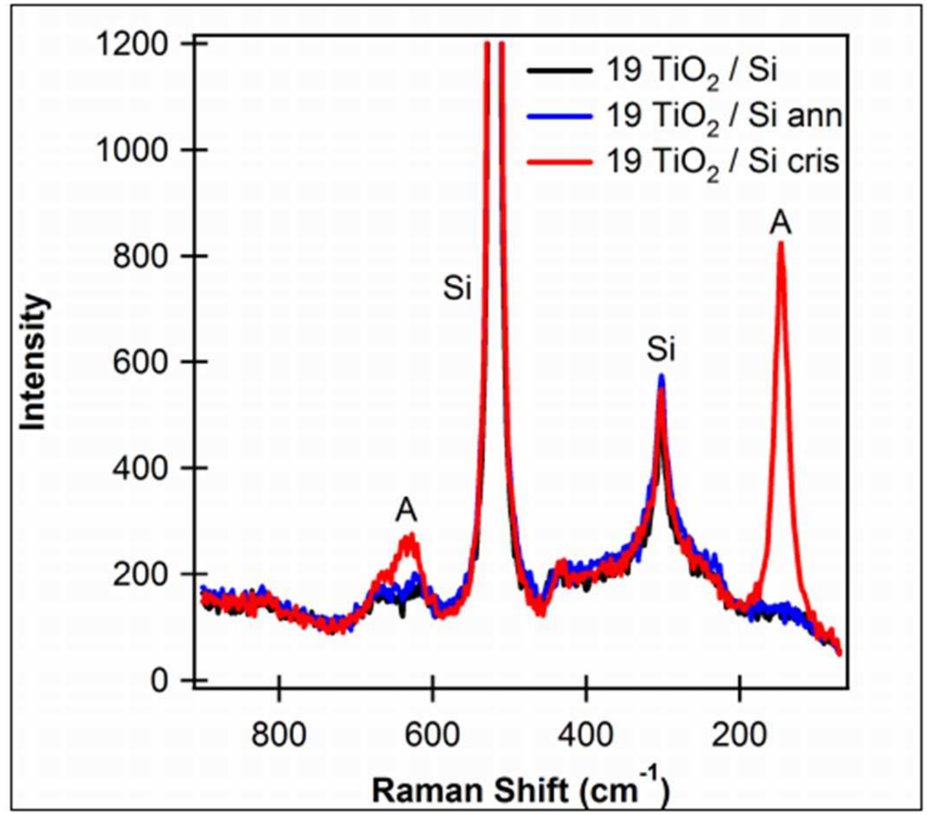
(AdCOAT Genoa Working Group)



thick (121nm) Titania layer annealed to crystallization (24h@300C).

nmLCM Ongoing Work





Raman shift spectra (adCOAT project)

nmLCM Ongoing Work

GeNS based mechanical ringdown measurement system.

Designed to be free from well known re-clamping issues

(AdCOAT Rome TV Working Group)

First batch of disc-deposited nmLCM proto types presently being tested

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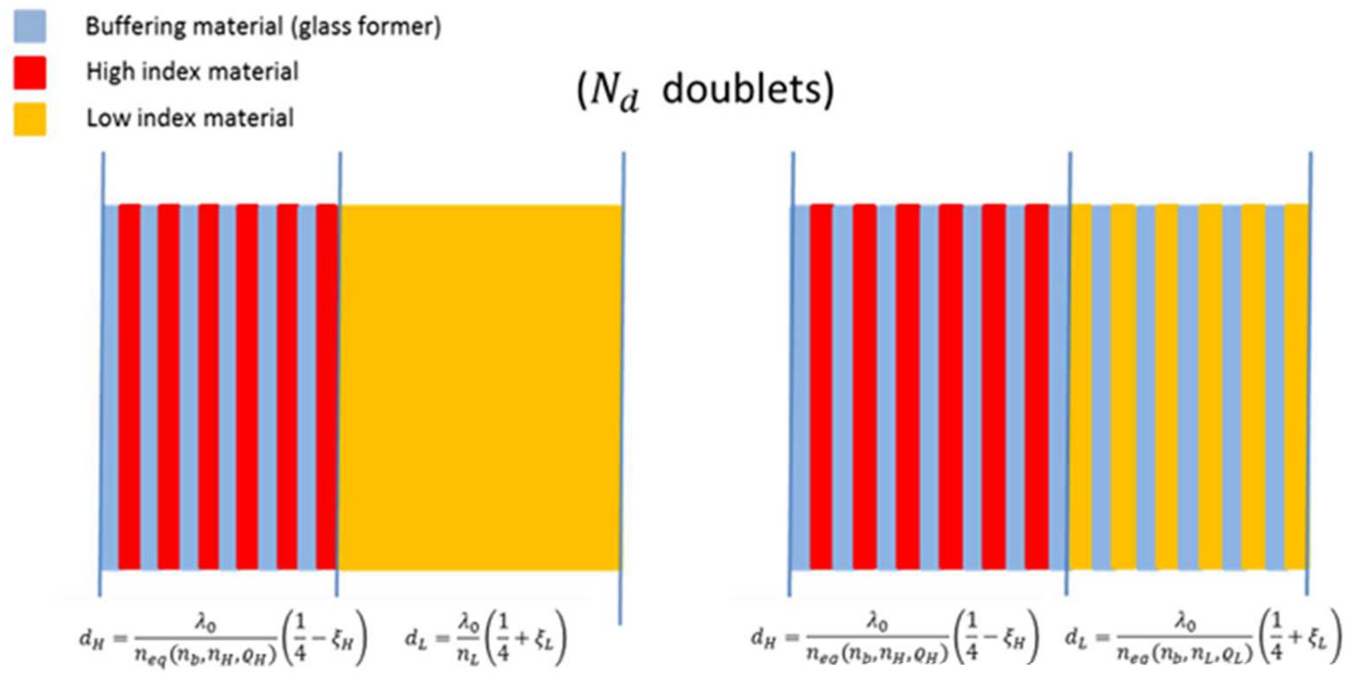
Thickness Optimized Coatings Using nmLCM



Done, on paper, but we need to make *a real prototype*

Optimization parameters	*One doublet layer nanocomposite*	*Both doublet layers nanocomposite*
Single wavelength transmittance constraint	$\xi_H (= \xi_L), N_d, \varrho_H$	$\xi_H (= \xi_L), N_d, \varrho_H, \varrho_L$
Double wavelength transmittance constraint	$\xi_H, \xi_L\ N_d, \varrho_H$	$\xi_H, \xi_L\ N_d, \varrho_H, \varrho_L$

RF Induced Cryo Loss Reduction

Low energy excitations in glasses at low T couple to both Elastic and EM fields. Acoustic attenuation is reduced upon Simultaneous RF exposure.

[Laermans et al. J. Phys. C: Solid State Phys. 10 (1977) L161]

Potentially interesting, put to the attention (?) of the OWG community by Matt Abernathy (OWG Wiki)

Practical constraints/feasibility to be understood.

m-ary Coatings

In particular, ternary (Steinlechner & Martin). Clever idea.

Lot of Literature (Larruquert, Singh & Braat, Boher et al.)

Optical (transmittance/loss tradeoff) optimization criteria (and structure) are well settled;

Noise minimization under prescribed optical const-raints (optmal design) *yet to be done;*

Different dispersion properties of the materials should be taken in due account to check spectral response (in band flatness)

Crystalline Coatings

Loss angle(s) and (scalar) dielectric contrast (e.g., with Silicon) are *not* the whole story.
Still un-answered questions (to the speaker's knowledge):

Full EM calculation of (long) cavity, taking material anisotropy into account (alignment)

Nonlinear (e.g.,Pockels) effects

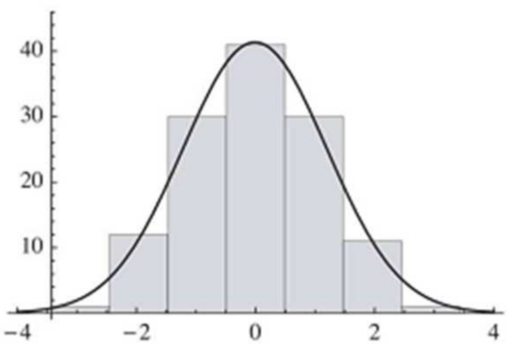
} Extra thermal noise terms ?

Bonding contribution to thermal noise

[etc. / see, e.g. Matt Abernathy wish list in the OWG Wiki]

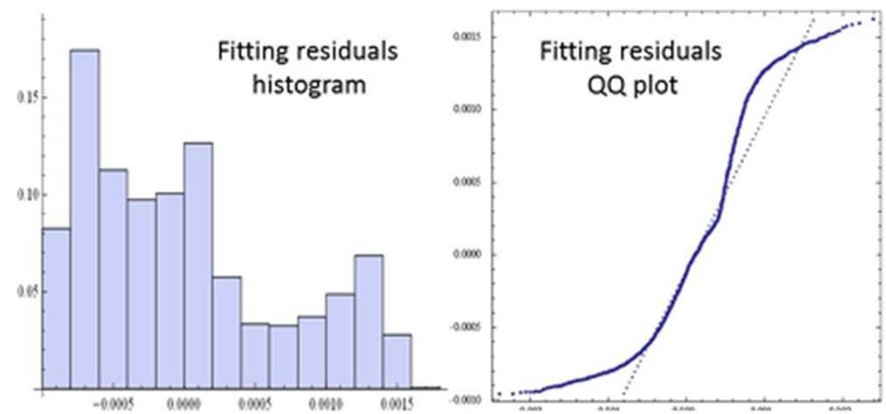
Residuals

Typical loss angle fitting residuals, TNI measurements



[Villar et al., PRD 81 (2010)]

Typical loss angle fitting residual, clamped cantilever based ring-down measurement



[data courtesy N. Morgado (2008)]

Confidence intervals must be robustly estimated in the non Gaussiann case.

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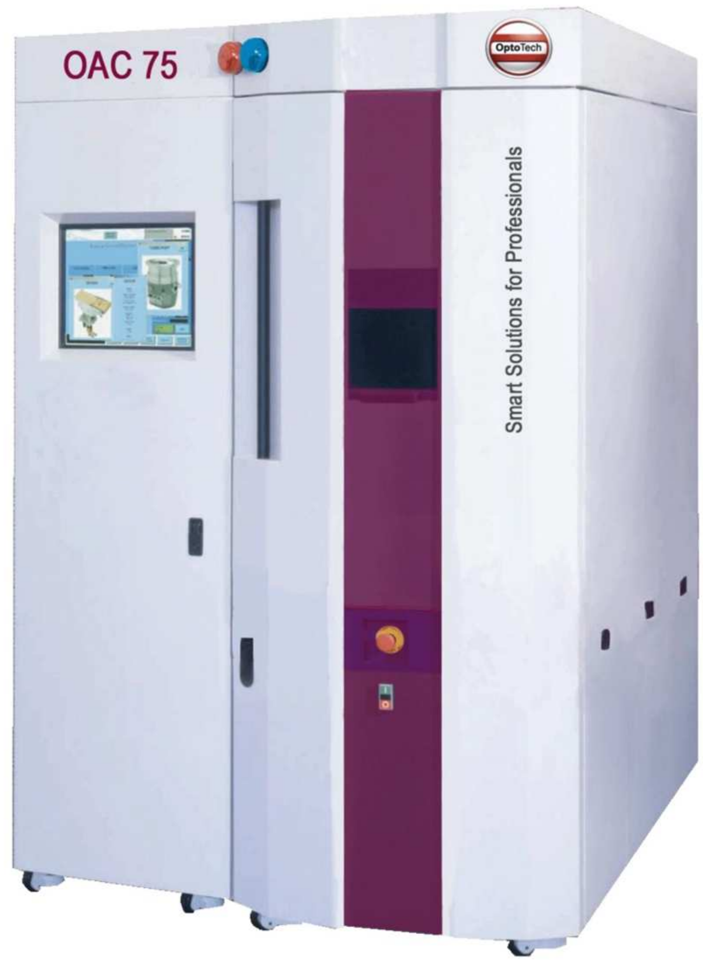
The USannio Coater

Custom version of Optotech OAC-75

- Plasma assisted deposition
- High quality /density of layers
- Dual eb-gun
- Multimaterial
- Fully programmable
- Cold coating possible
- R&D configuration
- IBS as possible future option



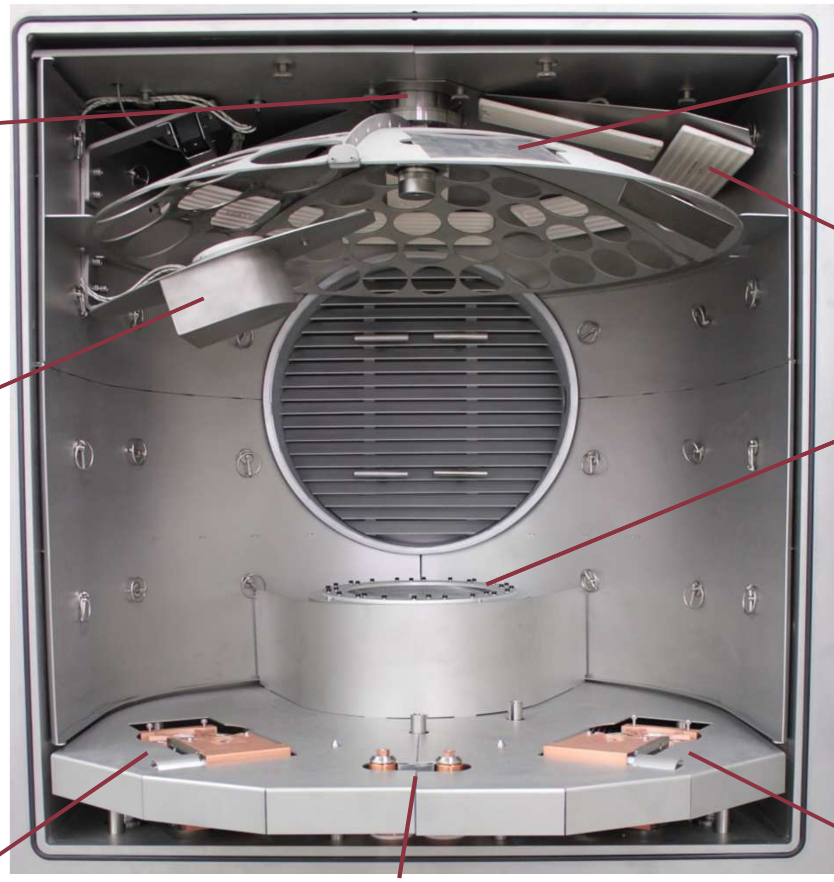
Cost $\sim \approx 0.5\ MEUR$
Funding by Regione Campania
(University research empowering progam)

The USannio Coater, contd.

- Multi-stage vacuum Edwards E2M80 rotary+EH500 booster; Pfeiffer HP2300 turbo, optionally replaced by a diffusion (HSR DIF400) or cryo (HSR VELCO 400A) unit w. Meissner trap (Polycold PFC-672). High-vac gate-valve between turbo pump and vac. chamber; 3 active vac gauges.
- Deposition rate / thicknesses are monitored by Xtal (Inficon SQM-242) and/or optical (IOF) systems, acting on shutter and mask(s).
- 3-sectored spherical dome substrate holder (up to 54 blanks, max 75mm Ø each).
- 2xEB-guns; 6 x 20cc pockets, O2 gas flow w. MKS controller; plasma source; substrates IR front-heater;

Optional add-ons : Thermal evaporation system, different Ar-ion sources (filament, Kaufman) .

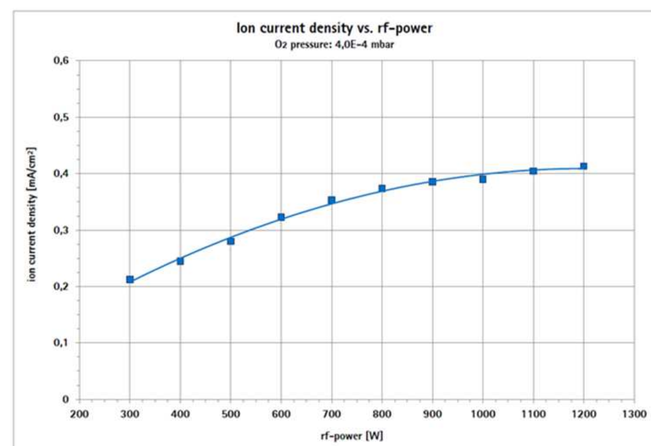
Coater Chamber



USannio Coater, contd.

(COPRA® IS200 plasma source)

- Built-in source w. flexible position & changeable inclination
- Powered @ 13.56 MHz, max. power 1500 W
- Large beam extraction Ø 110 mm for uniform distribution
- Ion energy 50 to 180 eV
- Ion current density up to 0.5 mA/cm^2
- Pressure range 1E-4 to 1E-3 mbar
- Operation with pure oxygen possible
- Highest n-values for stress free films



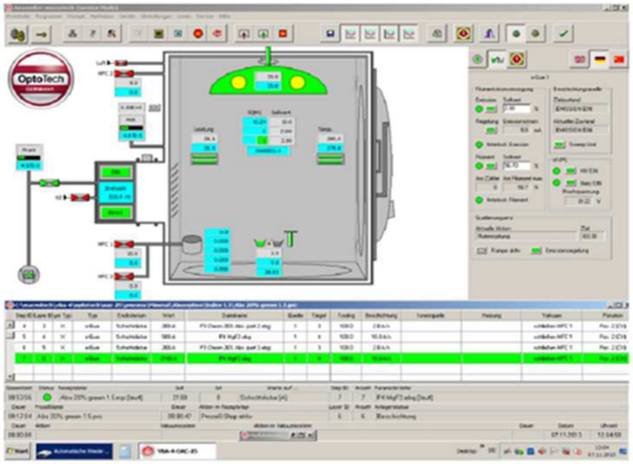
USannio Coater, contd.

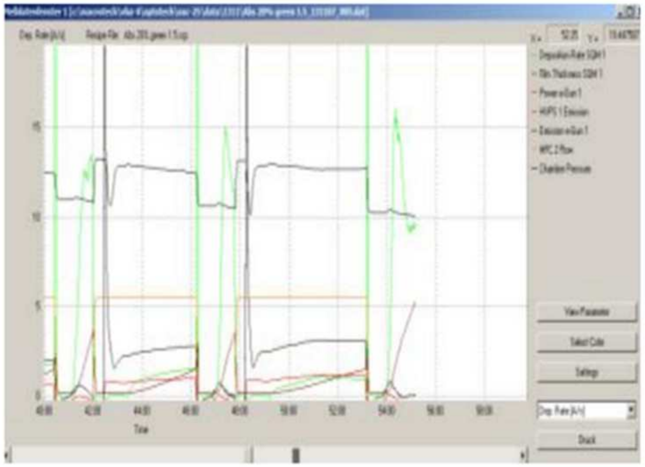
[Ferrotec EVM-8 eb-gun systems]

- 2 eb-guns
- Multiple (6) pocket configuration
- Evaporation of all kind of oxides (and metals)
- Co-evaporation of different optical materials possible
- Freely adjustable HV from 6 to 8 kV (layer-to-layer)
- Sweep parameters and sweep pattern easy preset
- Variable pocket rotation speed (single pocket)

USannio Coater, contd.

Built in GUI-based MacroTech control unit enables fully automated coating process scheduling and control

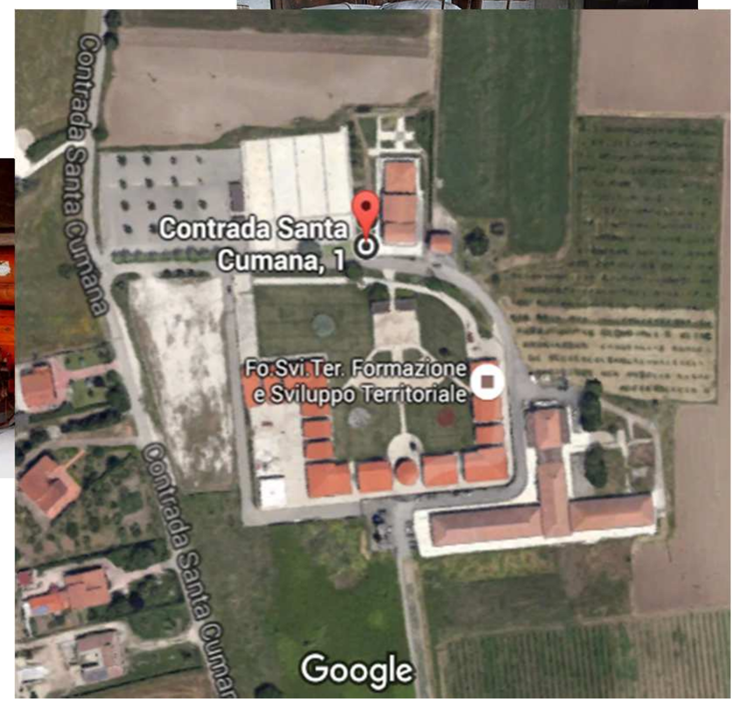




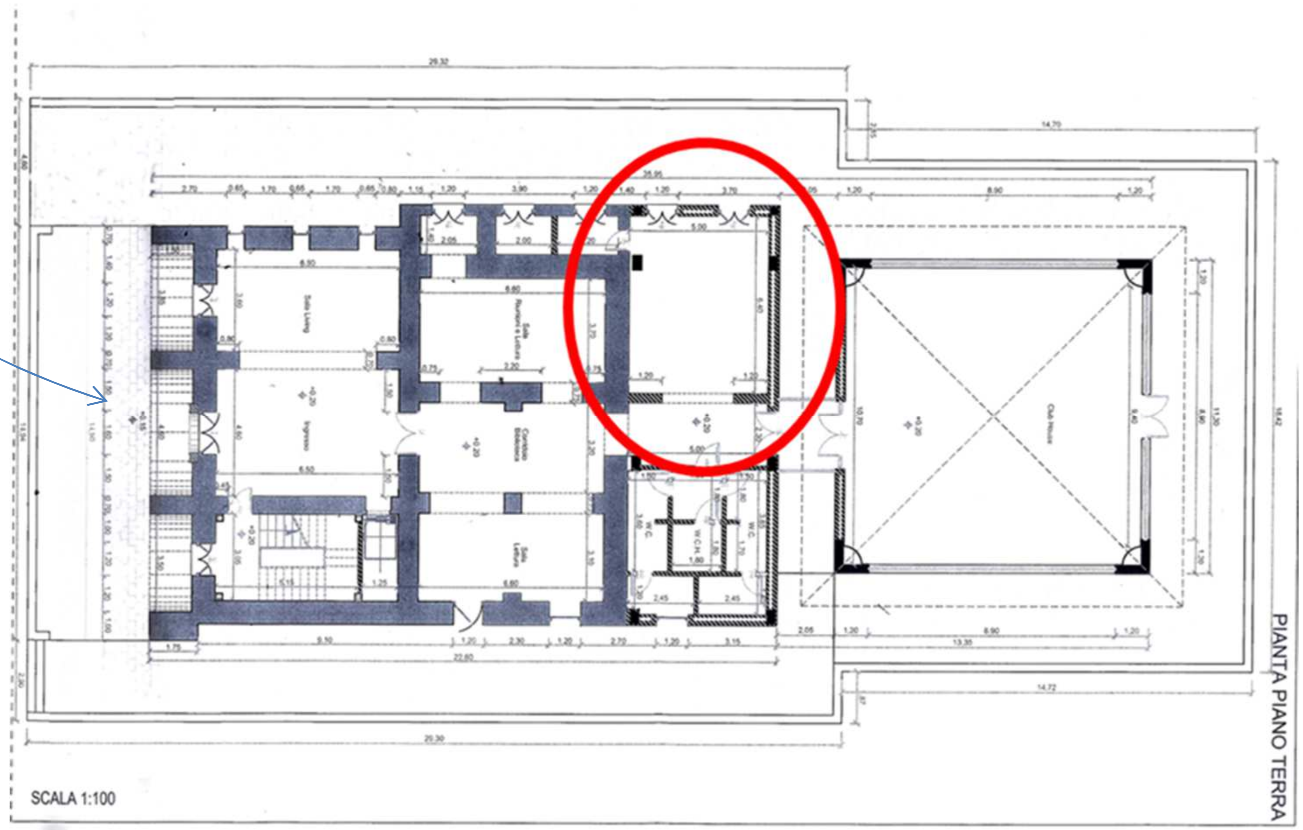
Coater Location

MUSA - MUSEUM OF TECHNOLOGY AND LABOUR IN AGRICULTURE BENEVENTO

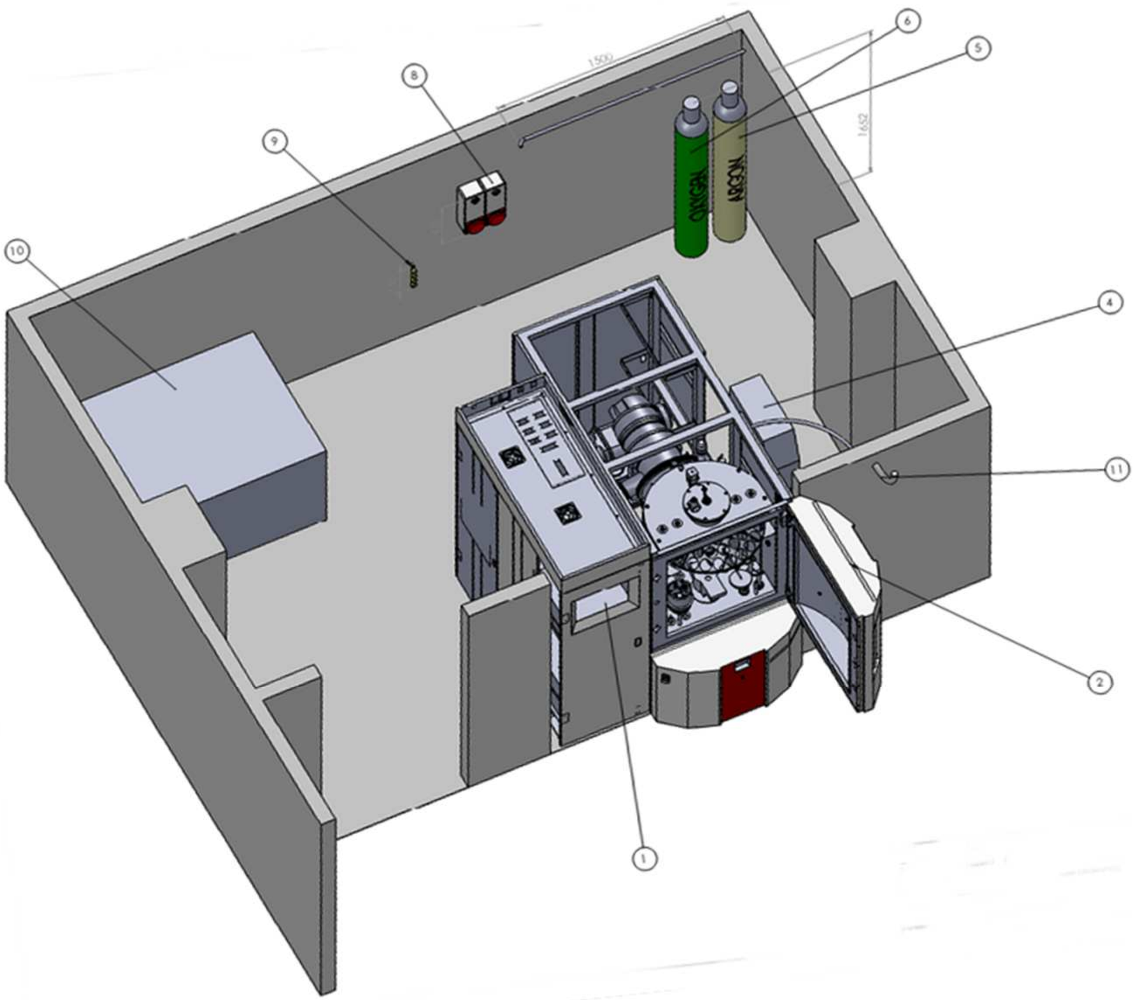
… A MUSEUM, A FAIR ….



Coater Location, contd.



Coater Location, contd.



Num. articolo	Descrizione	Quantità
1	Rack OAC75	1
2	OAC 75 D	1
3	Scarico Rotativa	1
4	Riscaldatore	1
5	Bombola (argon)	1
6	Bombola (ossigeno)	1
7	Scarico aria	1
8	Prese elettriche (1x16V, 1x32V)	2
9	Messa a Terra	1
10	Mobiletto	1

Requirements

- 1st Dedicated Power Line :
  400V, 40kW 3-phases+neutral+ground
  Nominal absorption : 27KW (includes heater)
  Average absorption : 15KW (includes heater)

- 2nd Dedicated Power Line (water chiller):
  400V, 12kW 3-phases+neutral+ground
  Nominal absorption : 8KW
  Average absorption : 6KW

- Dedicated Ground (≤ 1.5 Ohm impedance)

  Gas Supplies (Oxygen, Argon)
  required pressure 1.2 / 1.5 bar
  required purity : 99,998 %

- Compressed Air
  Rotary Pump Exhaust Line

(as of march 11 2016)

Conclusions