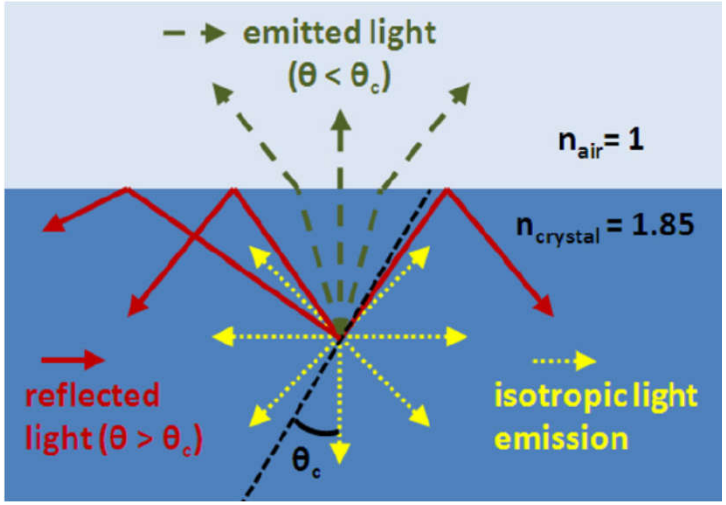
The modification of optical properties of the surfaces by the glancing angle deposition of TiO_2

Aleksey Lemzyakov[1,2], Konstantin Kuper[2], Vyacheslav Porosev[2], Ivan Azarov[1,3], Alexander Shklyaev[1,3]

1. Novosibirsk State University, Pirogova st. 2, Novosibirsk 630090, Russia
2. Budker Institute of Nuclear Physics of SB RAS, Lavrentiev av. 11, Novosibirsk 630090, Russia
3. Rzhanov Institute of Semiconductor Physics of SB RAS, Lavrentiev av. 13, Novosibirsk, 630090, Russia.

Introduction

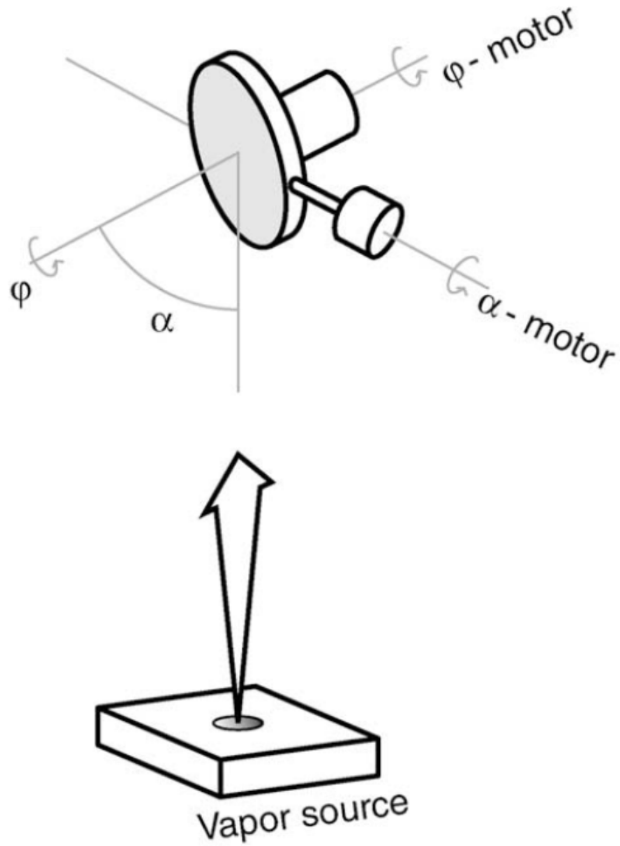
- The main limiting factor for the light yield in heavy inorganic scintillators is their high refractive index (n=1.8–2.3) relative to the ambient medium.
- Graded-refractive-index (GRIN) AR coatings are theoretically able to achieve broadband and omnidirectional AR characteristic.

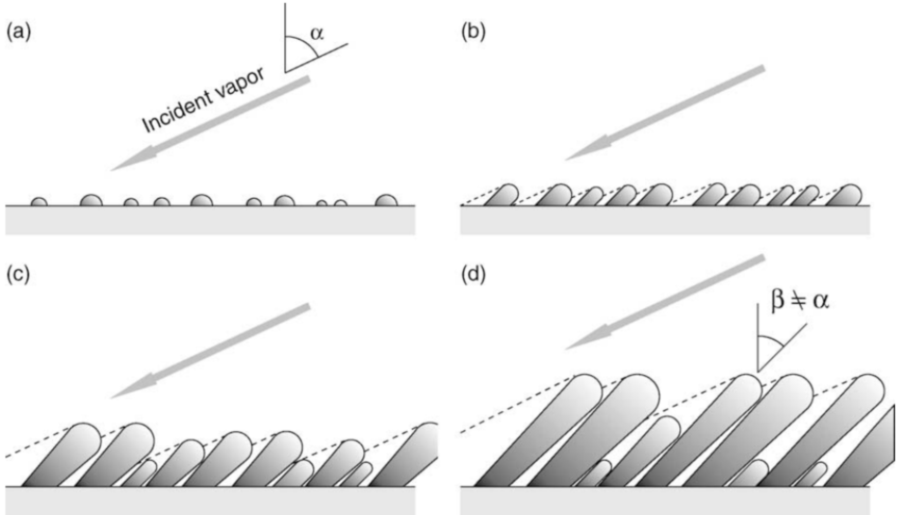


Reflected and emitted light at a crystal–air interface when having isotropic light emission within the crystal. [Knapitsch, A.; Auffray, E.; Fabjan, C. W.; Leclercq, J.-L.; Lecoq, P.; Letartre, X. & Seassal, C. (2011), 'Photonic crystals: A novel approach to enhance the light output of scintillation based detectors', *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment* ***628(1), 385--388.]***

Glancing Angle Deposition

Glancing angle deposition (GLAD) is an extension to oblique angle deposition where the substrate position is manipulated during film deposition. GLAD developed as researchers realized they could manipulate the columnar structure by actively managing substrate position during deposition.



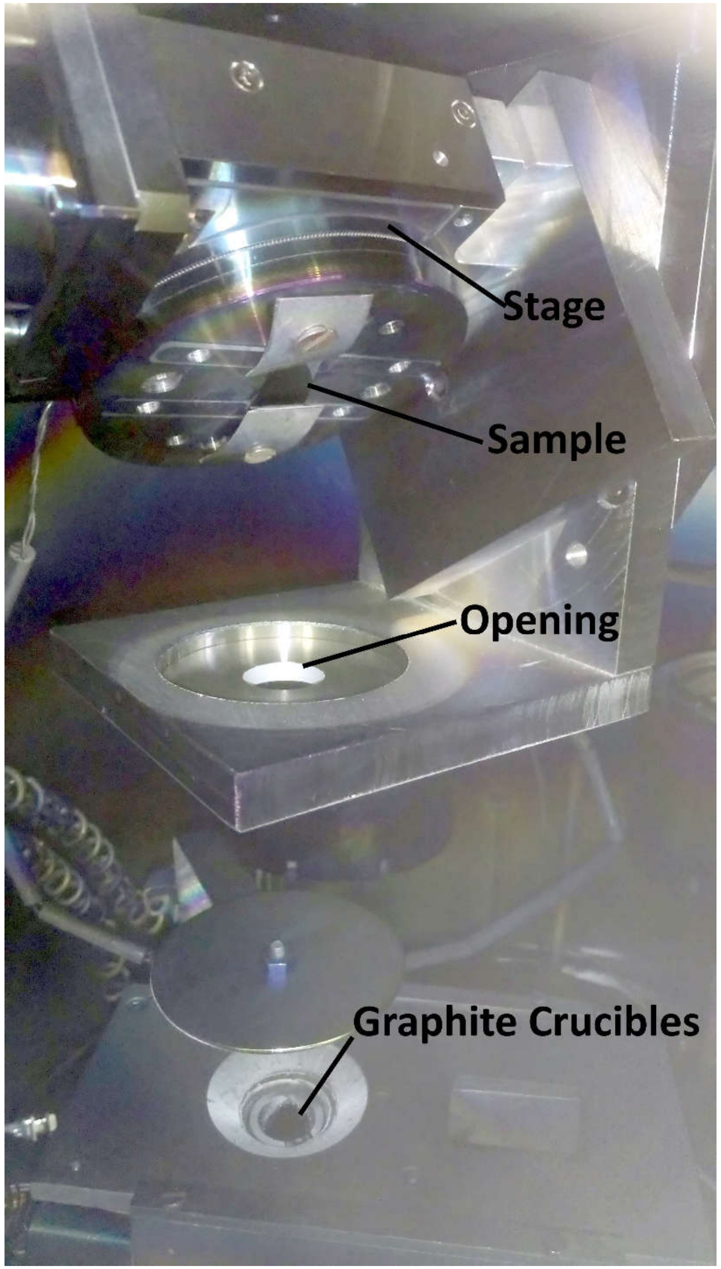


Schematic view of GLAD growth: (a) initial island growth; (b) nuclei grow, casting shadows across substrate; (c) columns develop, partially shadowing smaller neighbors and suppressing their growth; (d) columns grow at an inclined angle.

[Taschuk, M. T.; Hawkeye, M. M. & Brett, M. J. (2010), Glancing Angle Deposition 'Handbook of Deposition Technologies for Films and Coatings', Elsevier, , pp. 621--678.]

Experimental setup

Titanium oxide was deposit by
e-beam evaporation from crucible
with O_2 partial pressure
of ≈$2x10^{-4}$ mbar
Preliminary vacuum ≈$5x10^{-6}$ mbar
Deposition rate at α=0
was ≈0.2..0.4 nm/s
Rotation speed along ϕ axis 1.7 rpm
Tilt was in range α=0..85°
Stage temperature during deposition
up to 130 °C



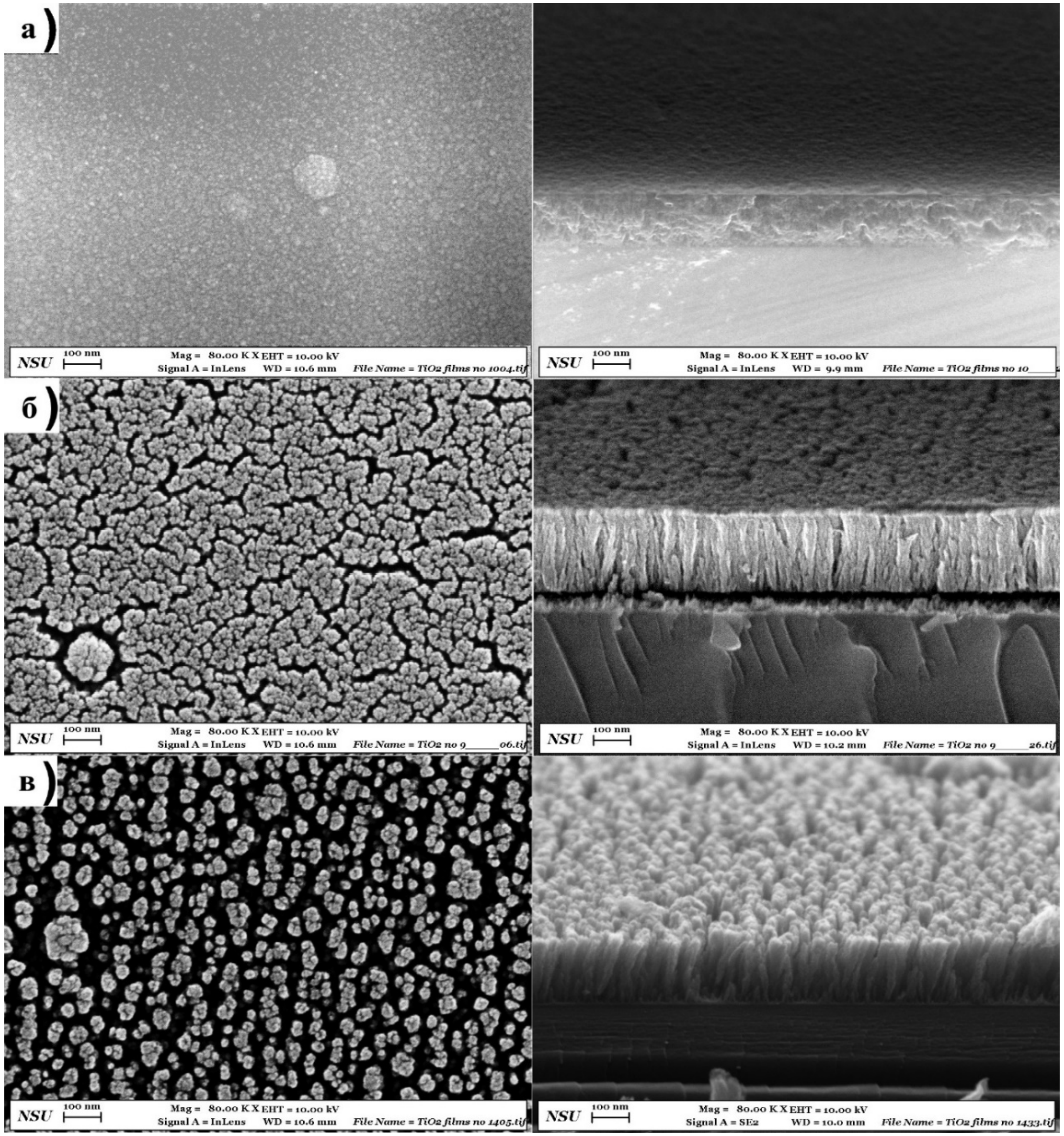
Results

TiO_2 on Si substrate

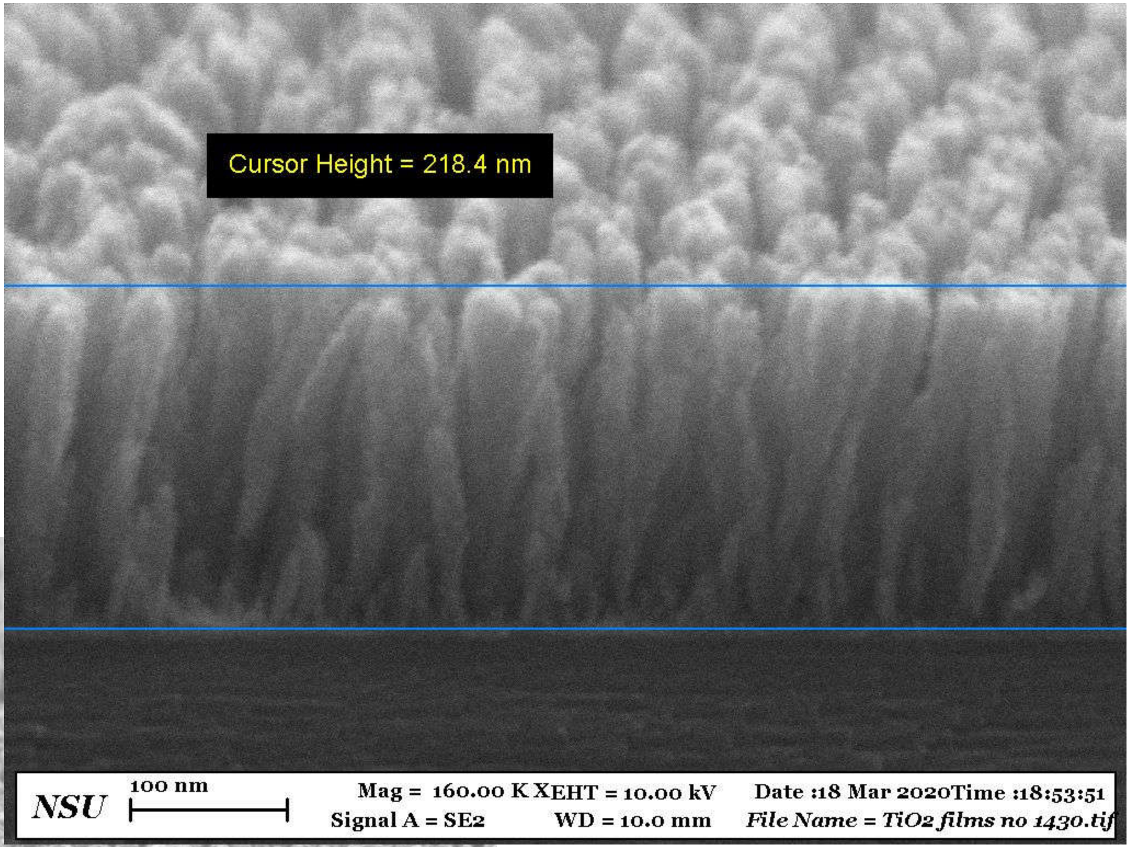
α=0

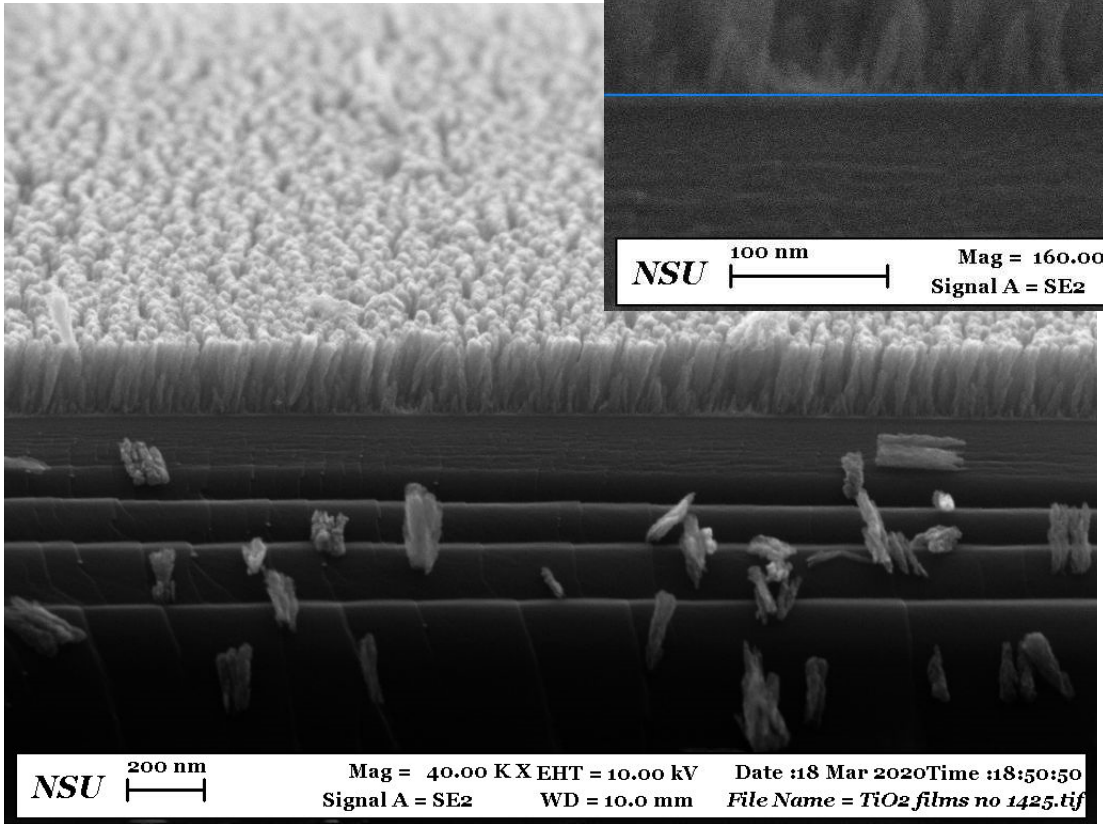
α=75°

α=85°

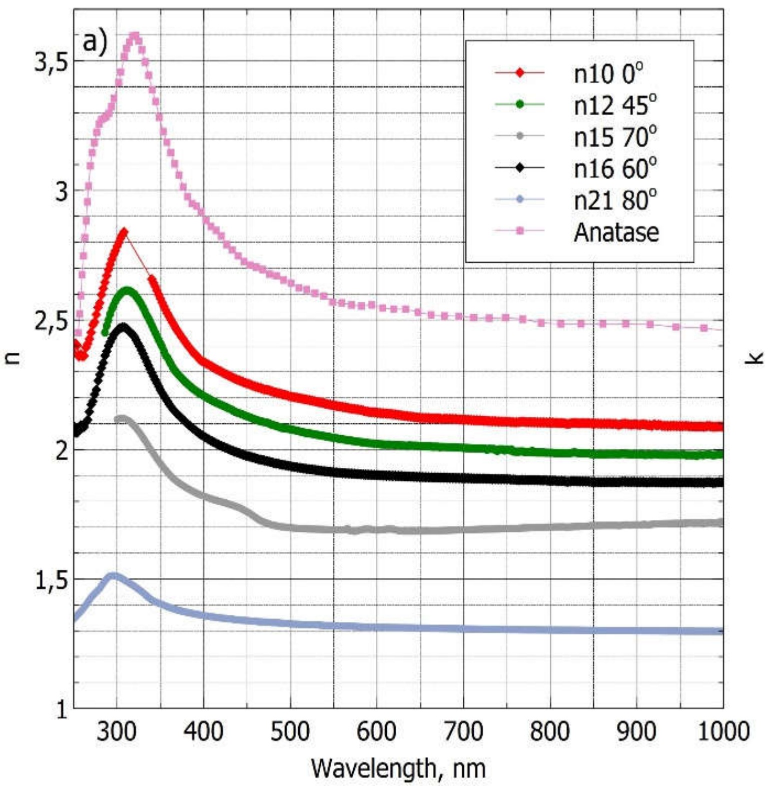


α=85°

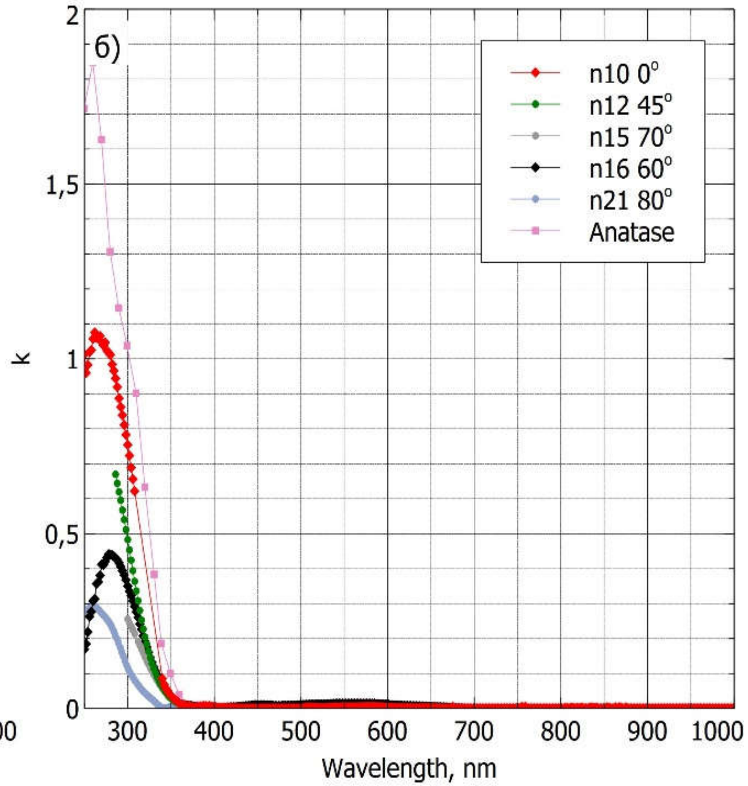

Cursor Height = 218.4 nm
NSU
100 nm
Mag = 160.00 K X EHT = 10.00 kV
Signal A = SE2
WD = 10.0 mm
Date :18 Mar 2020 Time :18:53:51
File Name = TiO2 films no 1430.tif


NSU
200 nm
Mag = 40.00 K X EHT = 10.00 kV
Signal A = SE2
WD = 10.0 mm
Date :18 Mar 2020 Time :18:50:50
File Name = TiO2 films no 1425.tif

Ellipsometry measures



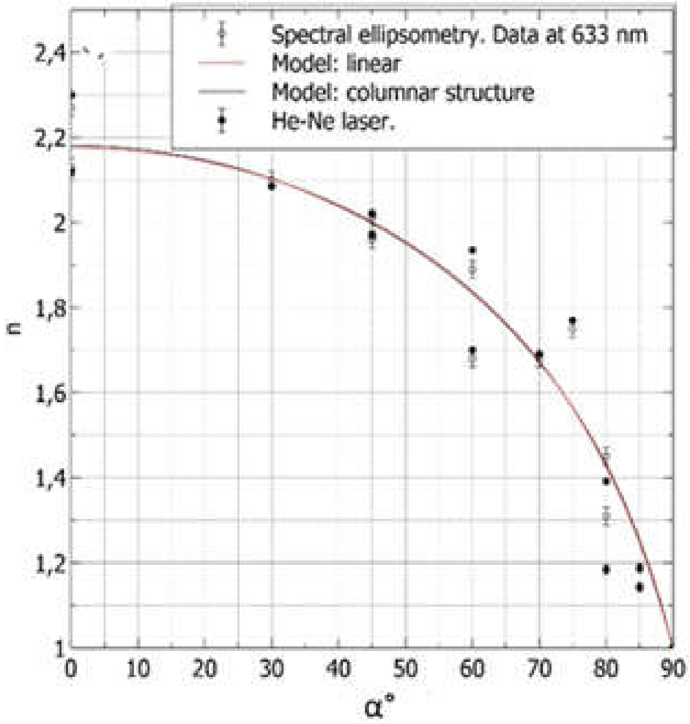
Refractive index



Attenuation coefficient

For sample 85° refractive index n=1.15..1.2

Dependence of the refractive index on the inclination angle



Linear model: $n_f = (1-p)n_0 + pn_1$

[Kinosita, K. & Nishibori, M. (1969), 'Porosity of MgF2 FilmsEvaluation Based on Changes in Refractive Index Due to Adsorption of Vapors', *Journal of Vacuum Science and Technology* ***6(4), 730--733.***]

Columnar structure model: $n_f^2 = \frac{(1-p)n_0^4+(1+p)n_0^2 n_1^2}{(1+p)n_0^2+(1-p)n_1^2}$

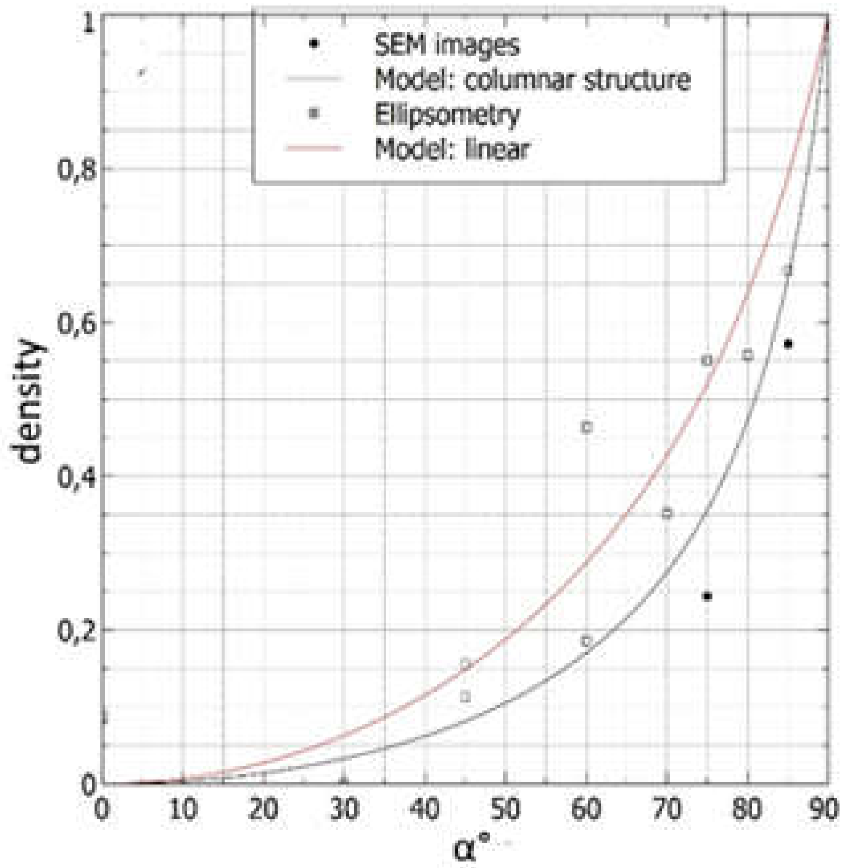
[Harris, M.; Macleod, H. A.; Ogura, S.; Pelletier, E. & Vidal, B. (1979), 'The relationship between optical inhomogeneity and film structure', *Thin Solid Films* ***57(1), 173--178.]***

Porosity estimation

$$P = 1 - p = \frac{\alpha \cdot \tan\alpha}{c + \alpha \cdot \tan\alpha}$$

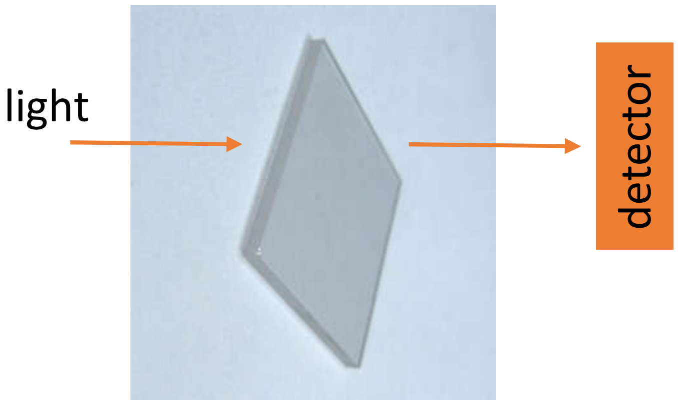
P – porosity, p – filling factor, c - fitting parameter

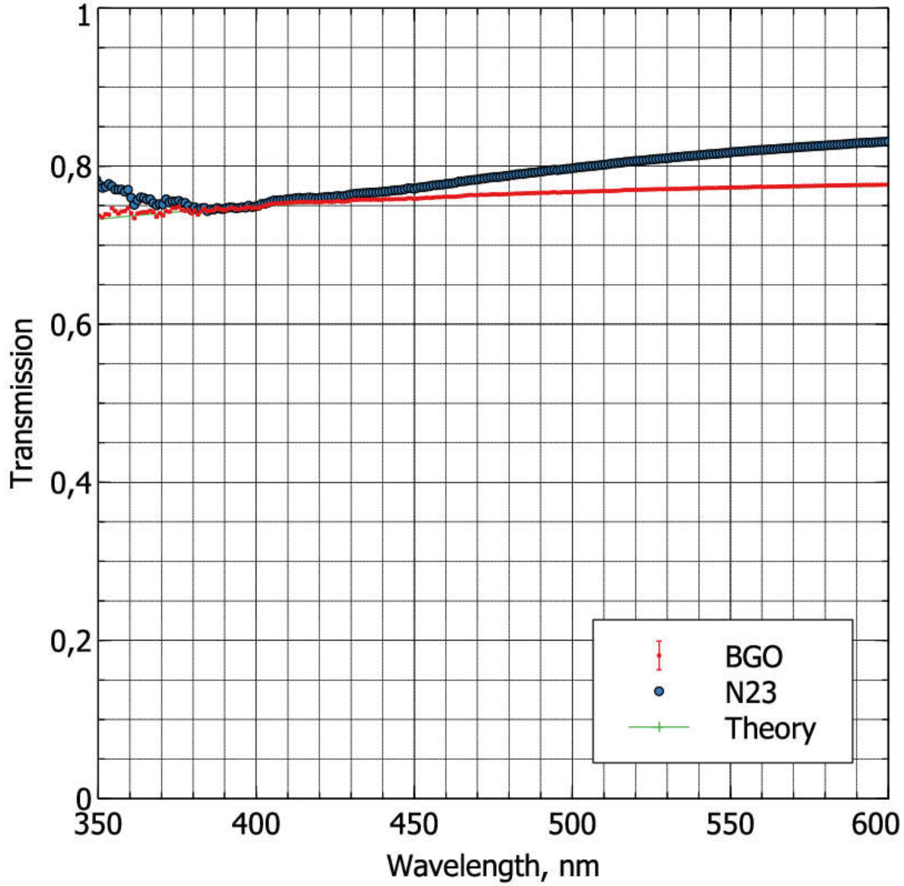
[Poxson, D. J.; Mont, F. W.; Schubert, M. F.; Kim, J. K. & Schubert, E. F. (2008), 'Quantification of porosity and deposition rate of nanoporous films grown by oblique-angle deposition', *Applied Physics Letters* ***93(10), 101914.***]



Graded-refractive-index antireflection coatings on BGO

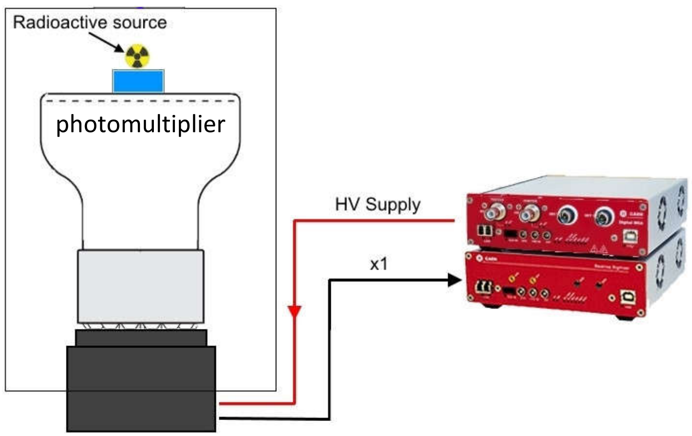
BGO crystal 20x20x1.5 mm size
3 layer of 100 nm thickness of TiO_2
with angles α=0°, 75°, 85°

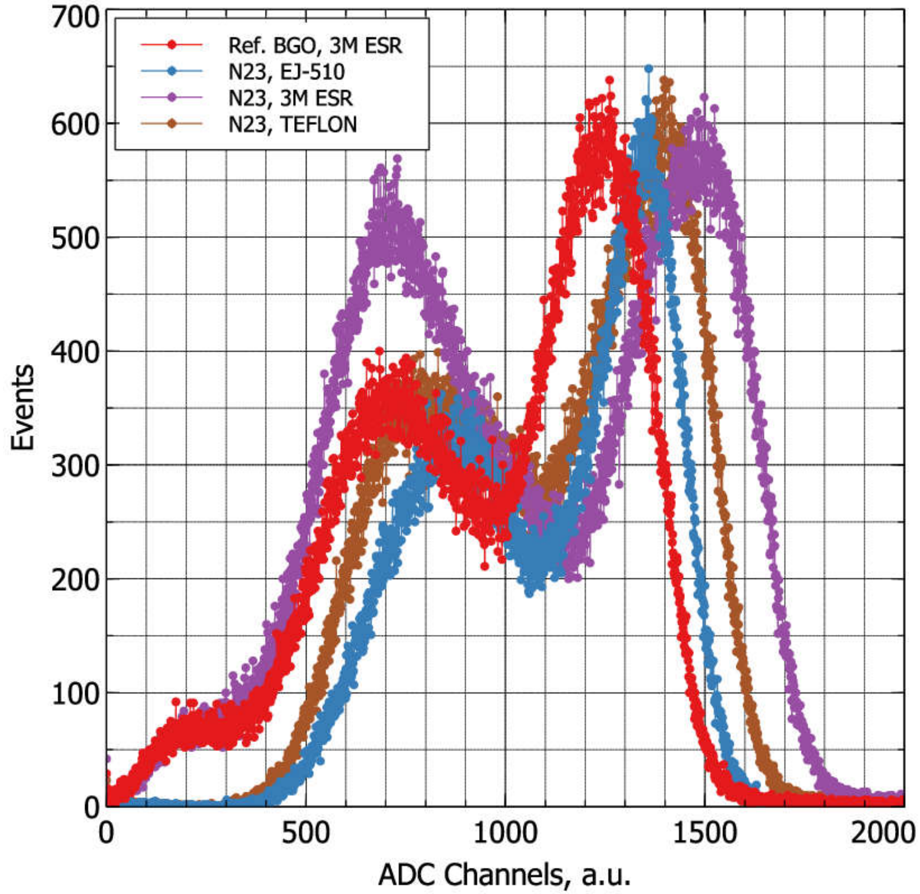




First results on BGO

Isotope Cs-137





Light output was improved on **16%**

Results

- The dependences of the refractive index on the oblique angle for thin films of TiO_2 are obtained.
- The first results of using graded-refractive-index anti-reflection coatings of TiO_2 on BGO scintillator crystals were obtained. Increasing in light output is about 16%

Further plans

- One more rotate stage for changing of oblique angle during deposition and for more precision angle control.
- To improve control over the deposition process to increase the reproducibility of the parameters of the resulting coatings.

Thank for you attention!