MECHANICAL AND OPTICAL CHARACTERIZATION OF SPUTTERED AMORPHOUS GaN THIN FILM FOR HIGH-REFLECTIVITY AND LOW-LOSS COATINGS

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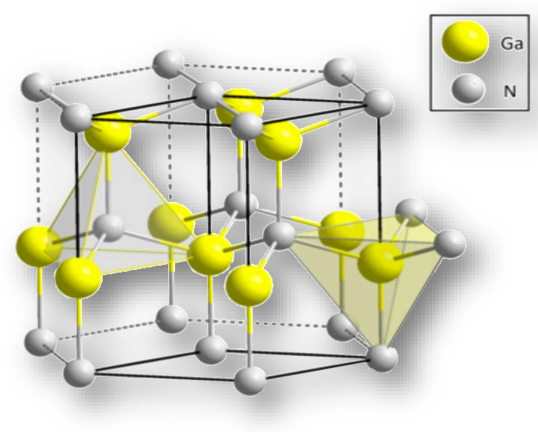
In nowadays gravitational wave detectors, the limiting noise at mid-frequency range is due to Brownian thermal noise in the multilayer reflective coating, in particular the intrinsic dissipation inside the high refractive index material. The anelastic behavior of amorphous materials is explained by the presence of metastable states that are separated by an energy barrier. To reduce the dissipation in the material a reduction of the total density of metastable state is needed. Amorphous films whose constitutive atoms have a coordination number larger than 3 should be characterized by a low amount of metastable states. Indeed, the structure is more rigid making structural reorganization more difficult. Sputtered amorphous GaN has been considered as a possible candidate for high refractive index material for future detector mirrors. After a first optimization of the deposition parameters, an explorative investigation on mechanical and optical properties has been conducted through GeNS and ellipsometry measurements.

Why Amorphous Gallium Nitride?

The losses in materials are explained by the presence of a number of metastable states, called Two Level System (TLS).

High coordination number materials, in which coordination number is higher than 3, shows a more rigid structure and TLS states are unlikely [1].

GaN coordination number is 4 and it has an high refractive index.

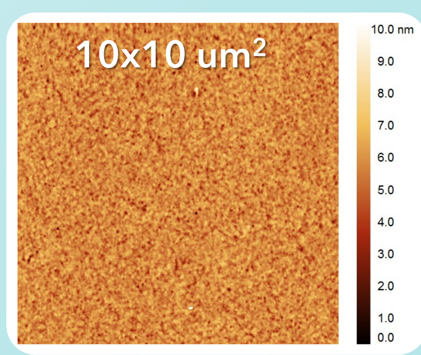


Preliminary characterizations

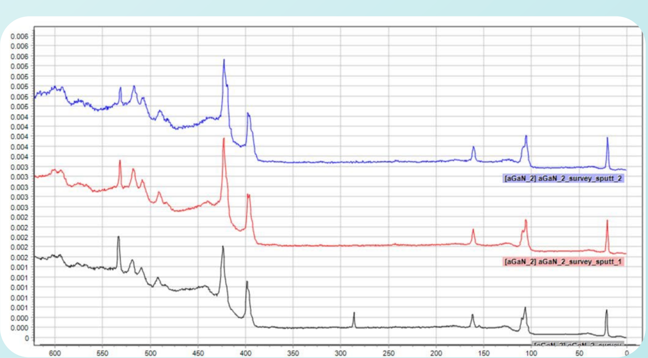
Preliminary characterizations already presented in [2].

AFM topographies acquired by tapping mode on a Veeco Multimode (Nanoscope IIIa)

- Amorphous films (also confirmed by *XRD characterization*)
- RMS roughness ≤ 1 nm
- The chosen sample was very uniform, with no particles on the surface and exhibiting a *RMS roughness of 0.65 nm*.

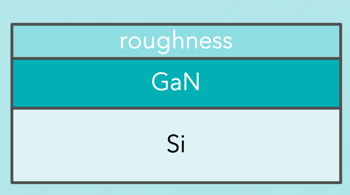


XPS characterization showed:



- The stoichiometry ratio between Ga and N is around 0.97 and it remarkably increases after the Ar sputtering.
- An oxygen contamination is detected. The nominal presence of oxygen decrease from the initial 25% to 11% after two sputtering.

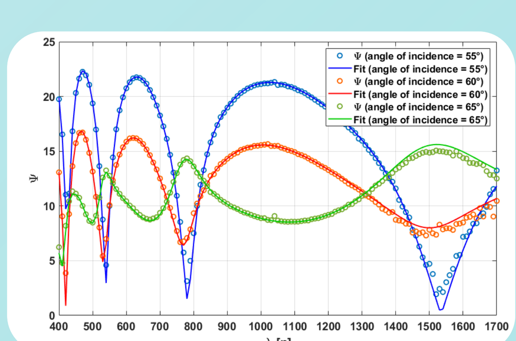
Optical characterization was performed on samples consist of Si substrate (0.1 mm) GaN layer and the roughness on the top.

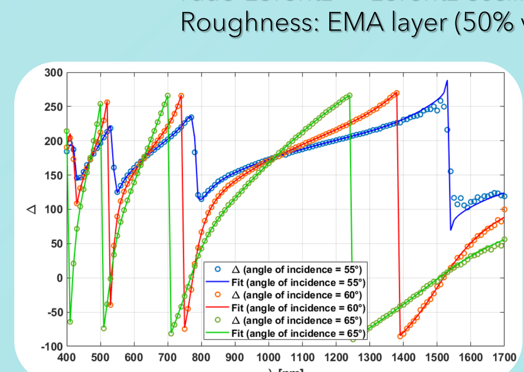


Refractive index n and *extinction coefficient k* are calculated from the fit model of GaN around λ = 1064 nm.

Dielectric function for GaN:
Tauc-Lorentz + Lorentz oscillator
Roughness: EMA layer (50% void)

Sample	AGAN2
n @1064 nm	2,1387
k @1064 nm	~5 × 10^{-4}



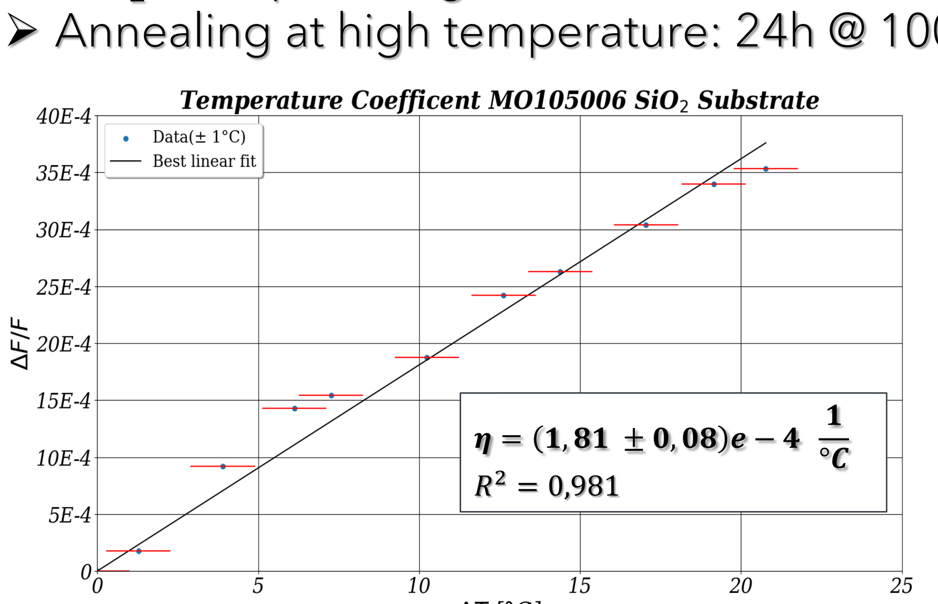


Substrate's mechanical stability

*Stability of the **substrate's losses** and **resonant frequencies** is mandatory.*

To avoid spurious losses contributions, the SiO_2 substrates undergoes to:

- CO_2 laser polishing of the lateral surface [4]
- Annealing at high temperature: 24h @ 1000°C [5]



To take in consideration frequency variations related Young's modulus [6] and temperature ones, a characterization of measured frequencies of (3,0) and (4,0) modes have been performed.

$$\frac{1}{E}\frac{dE}{dT} = k \qquad \frac{f - f(T_0)}{f(T_0)} = \eta\, \Delta T$$

$$k = 2\eta$$

Conclusion and next steps

- The amorphous *GaN coating loss angle* ranges from 1.13E-3 rad to 1.31E-3: still *too high* with respect to desired value (≲ *1E-4* rad).

Further steps:

- *Improve data analysis*: possible spurious losses raising from coating deposited on lateral surface [7];
- Repeat loss angle characterization after *thermal treatment*;
- *Other deposition processes* and/or use of higher purity GaN target.

Deposition Information

Gallium Nitride films were deposited by *RF magnetron sputtering* by using a target of 99.99% pure GaN with diameter of 4".

An extensive deposition run has been performed to optimize deposition parameters:

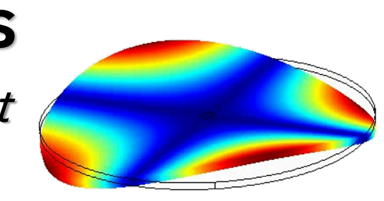
- low deposition rate
- high pressure

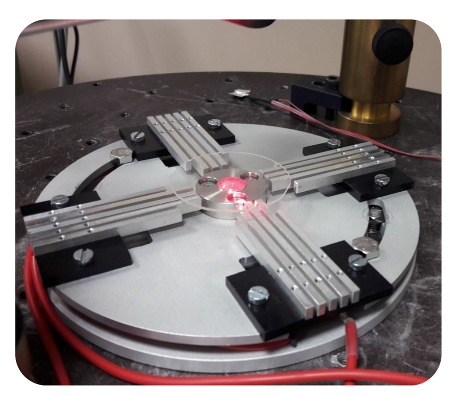
Sputtering system	
Target diameter	up to 6.5"
Power	up to 1000 W
Gas channels	3
Gas	N_2, O_2, Ar
Gas Flow	up to 100 sccm/channel
Substrate temperature	from cooled to 600 °C
Background pressure	10^{-7} Torr

Sample	AGAN2
Total flux (sccm)	100
Ar partial flux (sccm)	80
O partial flux (sccm)	20
Pressure (mTorr)	15
Power (W)	100
Substrate temperature (°C)	18
Nominal thickness (nm)	300x2

Mechanical Characterizations

Mechanical characterizations are performed through *resonant ring-down method* and *Gentle Nodal Suspension (GeNS)* [3].





The sample is placed in balance on sapphire half-sphere, fixed on a stainless-steel platform, and excited by HV actuation combs at its resonant frequencies; the damping period of free oscillations at the resonance frequency is measured. The dissipation can be quantified extracting the loss angle from the decay time: $\varphi = \frac{1}{\pi f \tau}$

Coating loss angle detection $\varphi_{coat} = \frac{\varphi + (D-1)\,\varphi_0}{D}$ where: $D = 1 - \frac{m_0}{m}\left(\frac{f_0}{f}\right)^2$

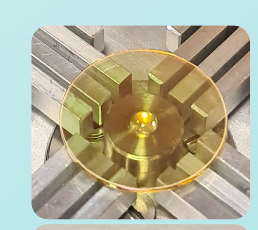
- ✓ Substrate mechanical characterization before coating deposition, φ_0;
  - ✓ *Substrate losses supposed independent of the coating deposition process;*
- ✓ Coated sample mechanical characterization after coating deposition, φ;
- ✓ Dilution factor directly evaluated by shifts of mode frequency (f and f_0) and mass (m and m_0) before and after coating deposition.

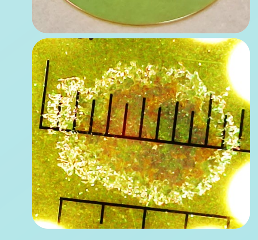
a-GaN coating mechanical losses

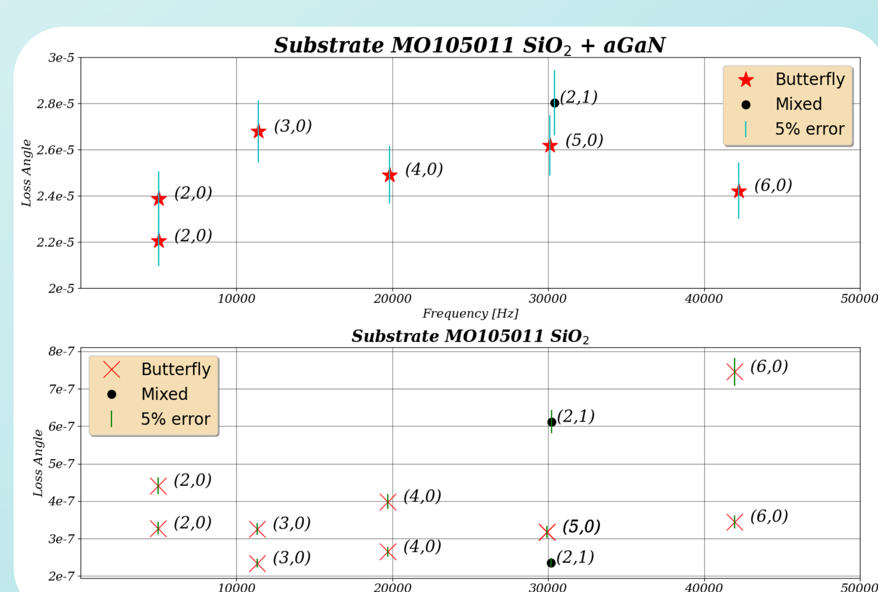
Three SiO_2 substrates (nominally equal, of 1" thick. and 0,5 mm diam.) has been characterized:

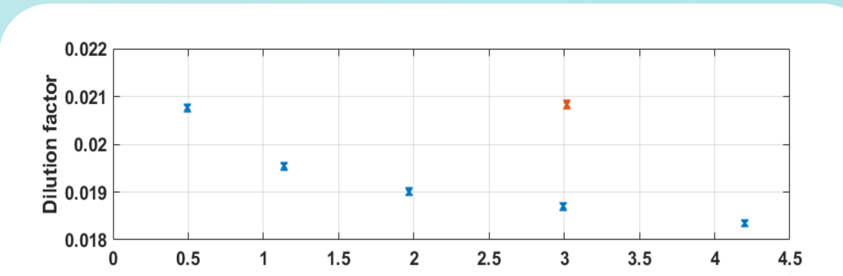
- One of them showed some blistering (~6 mm) after coating deposition and could not be used for coating loss angle estimation;
- The other two showed similar results; MO105011 sample one's are shown.

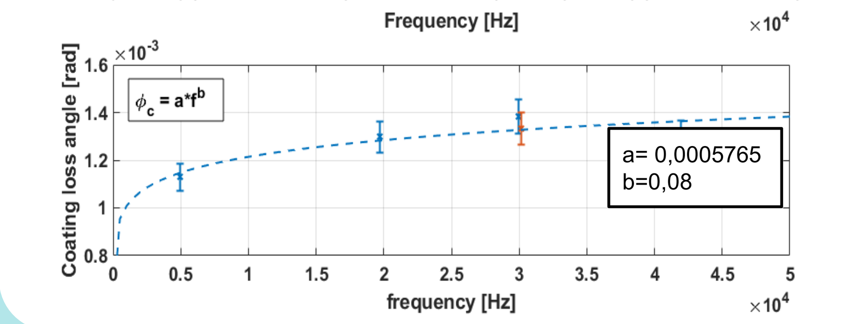
Substrate - SiO_2	
Thickness, t	(0,51 ± 0,03) mm
Diameter, d	(25,4 ± 0,05) mm
Mass, m_0	(0,5758 ± 0,0013) g
Sample - SiO_2 + GaN	
Mass, m	(0,5794 ± 0,0013) g
Coating film - GaN	
Nominal thickness, t_c	300 nm / each side











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