Hybrid organic-inorganic SiO_2 and SiO_2-ZrO_2 sol gel coatings with incorporation of silica nanoparticles for PV protecting glass applications

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INTRODUCTION

Placing solar panels in deserts is an interesting topic for photovoltaic (PV) energy. However, the challenging climatic conditions of the desert can limit their expansion. The combination of strong winds blowing with grains of desert sand can cause serious damage to the solar panels. The sand, with different particle sizes and shapes, generates defects similar to Vickers indentation. The interactions between adjacent defects lead to the formation of damaged zones, decreasing the optical transmission, producing light scattering and reducing the photovoltaic efficiency, and also decreasing their mechanicals properties [1,2]. One of the proposed solutions is to repair the defects by the deposition of transparent coatings, with acceptable mechanical properties. Hybrid organic-inorganic composite coatings have interesting potential for glass protection and defect correction; the incorporation of organic groups increases the coating thickness and flexibility of coating, and decreases the internal stresses in the coating, thus preventing the appearance of cracks in thick films.

Different methods, based on the deposition of hard and transparent thin layers were proposed in the literature. Sol-gel route is the most used and simplest techniques for the preparation of thin films. It has been reported that the sol-gel coatings can increase the strength of the glass by filling the micro-defects, leading to the increase of KIC factor [3]. Different kinds of compositions have been also used such as SiO_2, ZrO_2, SiO_2-ZrO_2, Al_2O_3 [4, 5, 6]. In this work, SiO_2 and SiO_2-ZrO_2 sol-gel coatings have been prepared by varying the ZrO_2 amount and reinforced with silica nanoparticles.

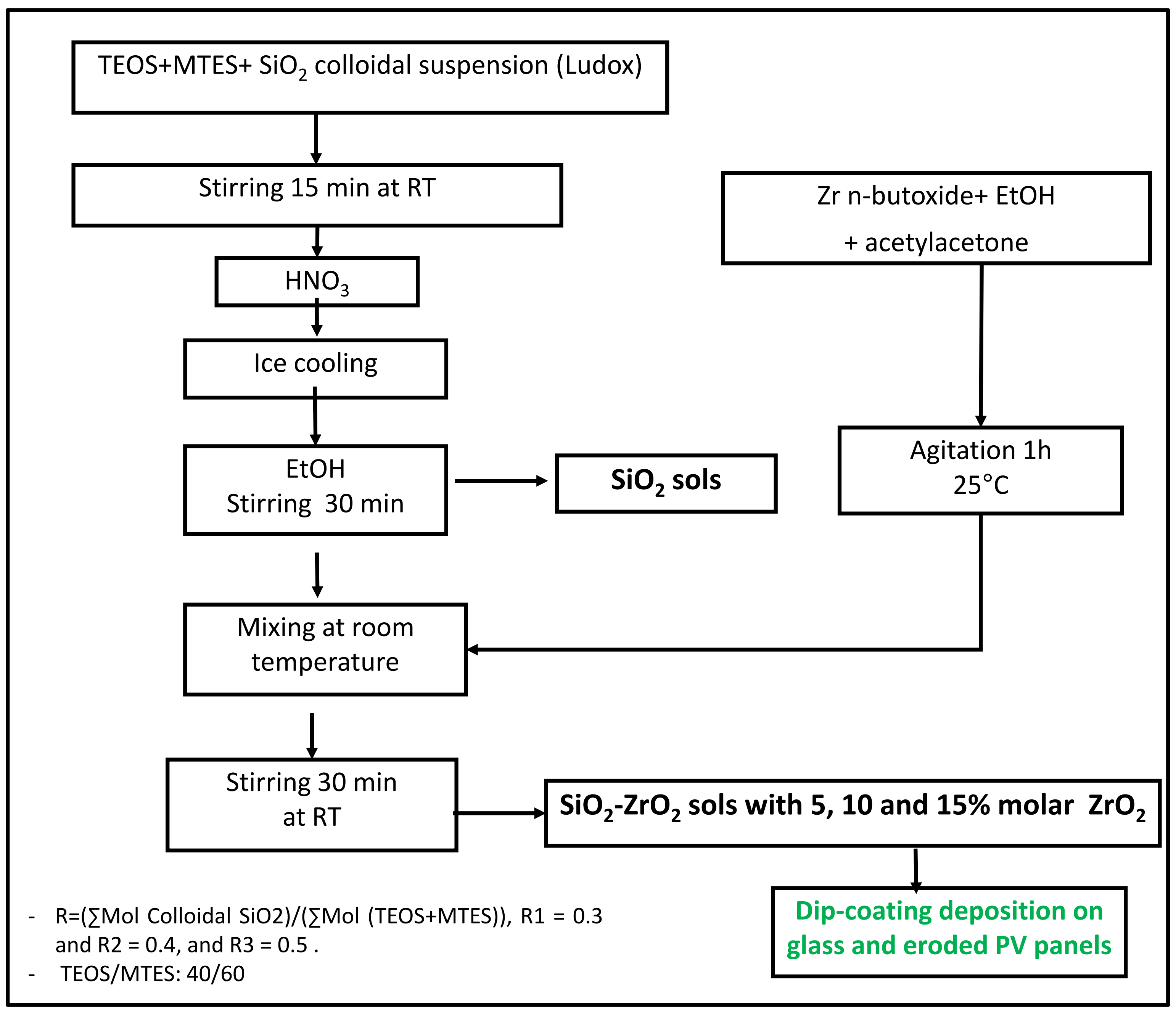
OBJECTIVES

Objectives:

1. Preparation of stable silica sols incorporating silica nanoparticles suspensions.
2. To optimize the amount of silica nanoparticles to obtain thicker and transparent SiO_2 coating with adequate mechanical properties.
3. Preparation of stable silica-zirconia sols by varying the ZrO_2 percentage (5, 10 and 15% molar) .
4. Application of the best coating on eroded PV protectoral glass.
5. Characterize the coated surfaces.

EXPERIMENTAL

Synthesis of SiO_2-ZrO_2 sols



TEOS+MTES+ SiO_2 colloidal suspension (Ludox)

Stirring 15 min at RT

HNO_3

Ice cooling

EtOH
Stirring 30 min

SiO_2 sols

Zr n-butoxide+ EtOH
+ acetylacetone

Agitation 1h
25°C

Mixing at room temperature

Stirring 30 min
at RT

SiO_2-ZrO_2 sols with 5, 10 and 15% molar ZrO_2

Dip-coating deposition on glass and eroded PV panels

- R=(∑Mol Colloidal SiO2)/(∑Mol (TEOS+MTES)), R1 = 0.3 and R2 = 0.4, and R3 = 0.5 .
- TEOS/MTES: 40/60

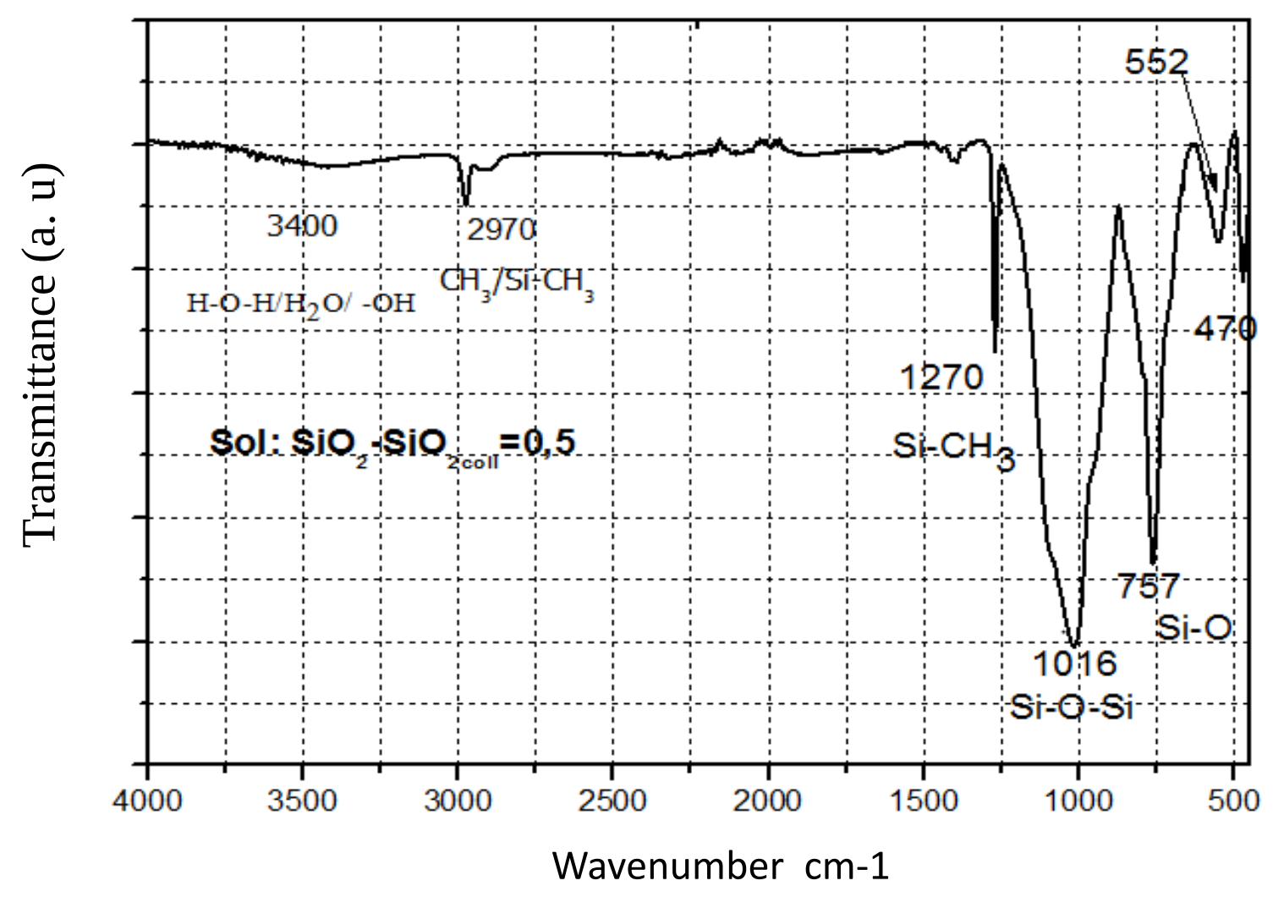
Table of sols compositions

Names	R (SiO_2/T+M)	ZrO_2	Particle g/l	SiO_2 colloidal particle g/l
S1	**0.3**	**0**	211	49
		5	163	30
		10	177	27
		15	189	25
S2	**0.4**	**0**	220	63
		5	170	39
		10	183	36
		15	194	33
S3	**0.5**	**0**	229	76
		5	176	48
		10	189	44

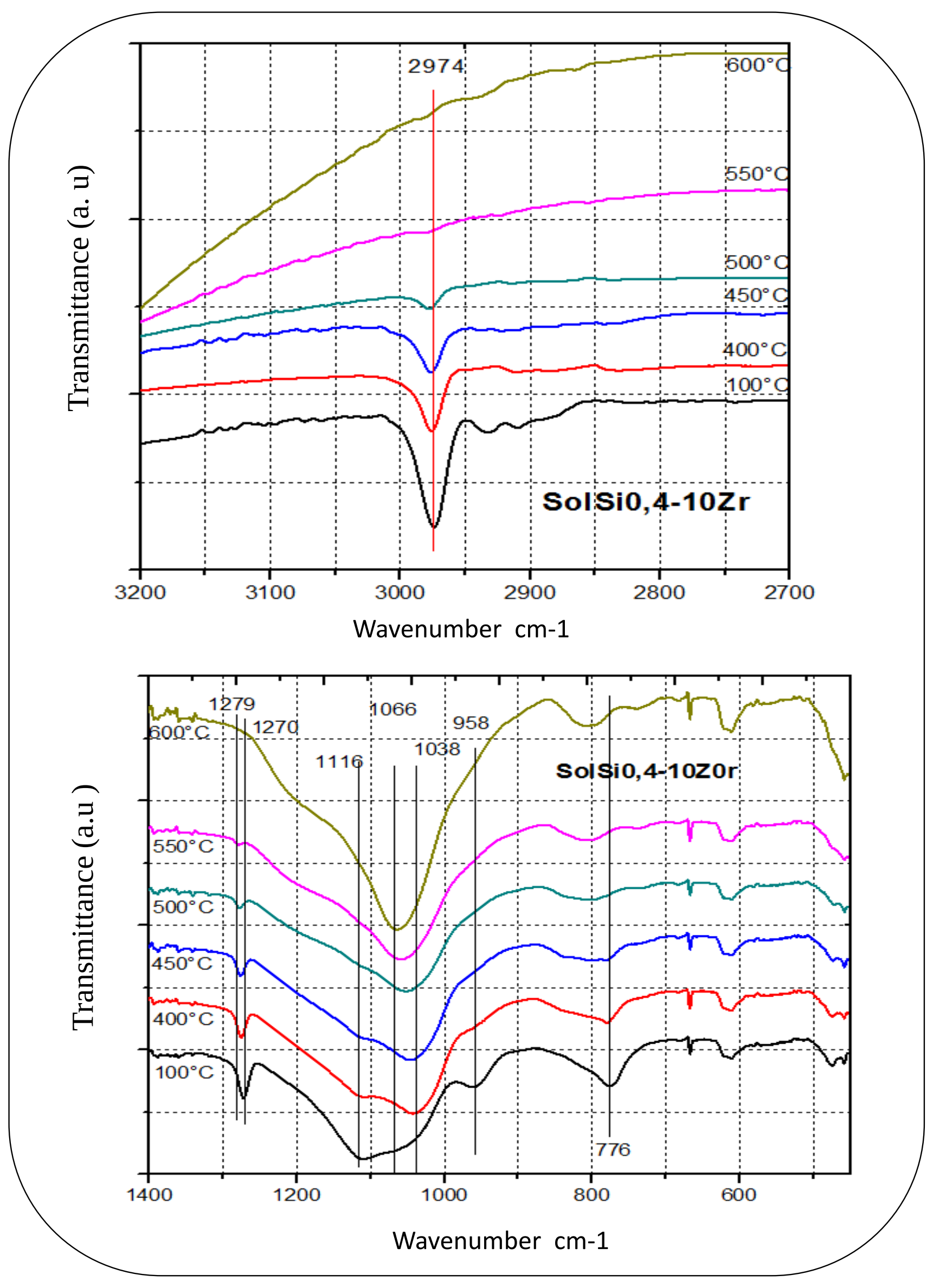
Characterizations of the sols and coatings:
- Structural characterization by FTIR.
- Coating thickness by ellipsometry spectroscopy.
- Optical transmission by UV-Vis.
- Hardness and Young`s modulus by nano-indentation.

RESULTS

FTIR spectrum of SiO_2 sol

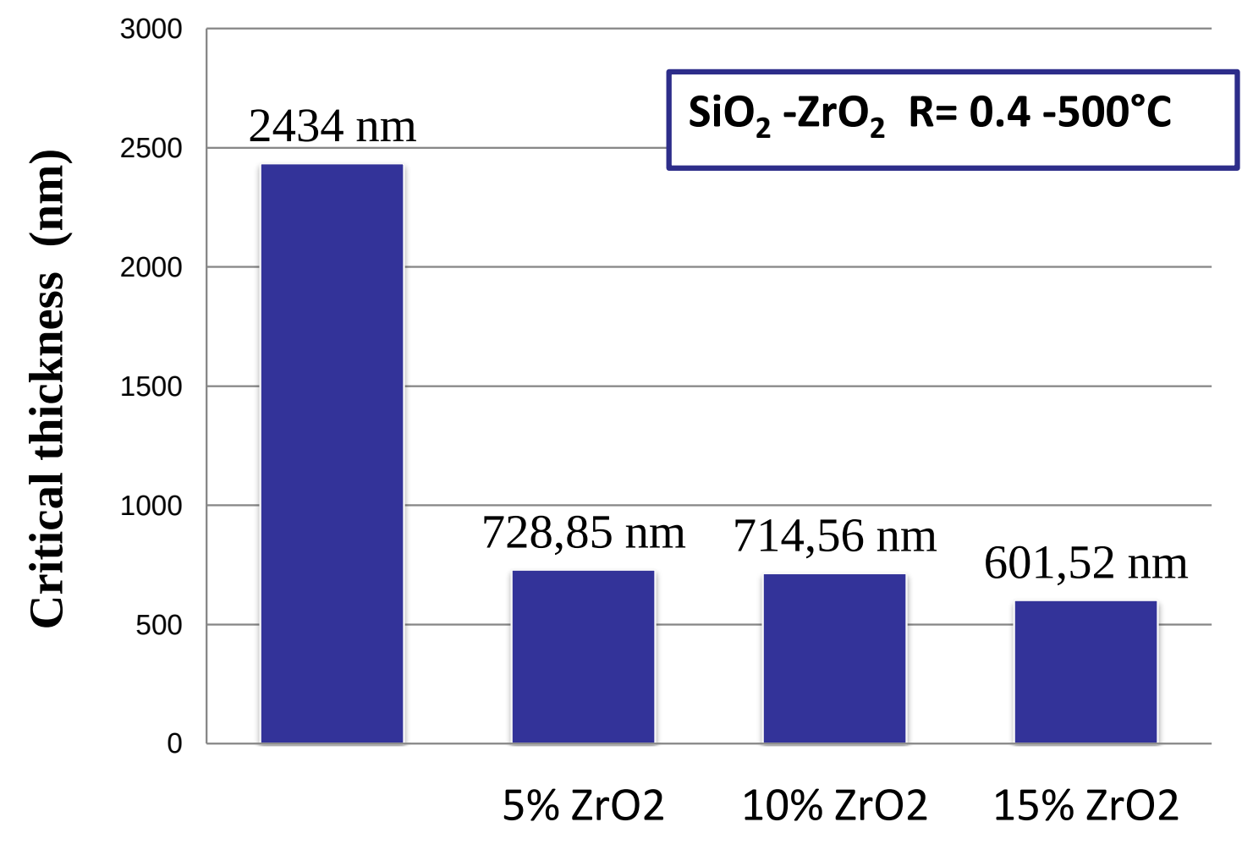


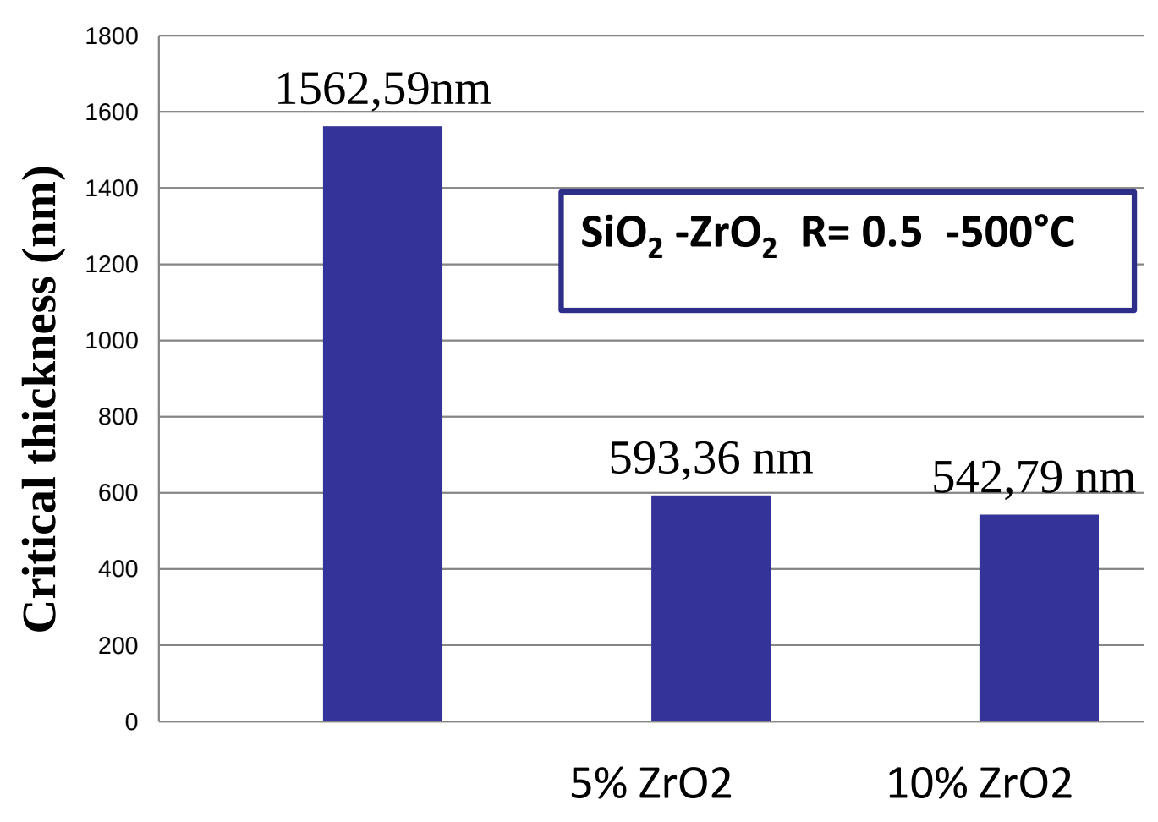
Evolution of FTIR spectra of SiO_2–ZrO_2 coatings



- The formation of Si-O-Zr network is confirmed by FITR.
- Si-CH_3 band shifts to high frequencies with temperature and its disappearance is confirmed at temperatures above 500°C

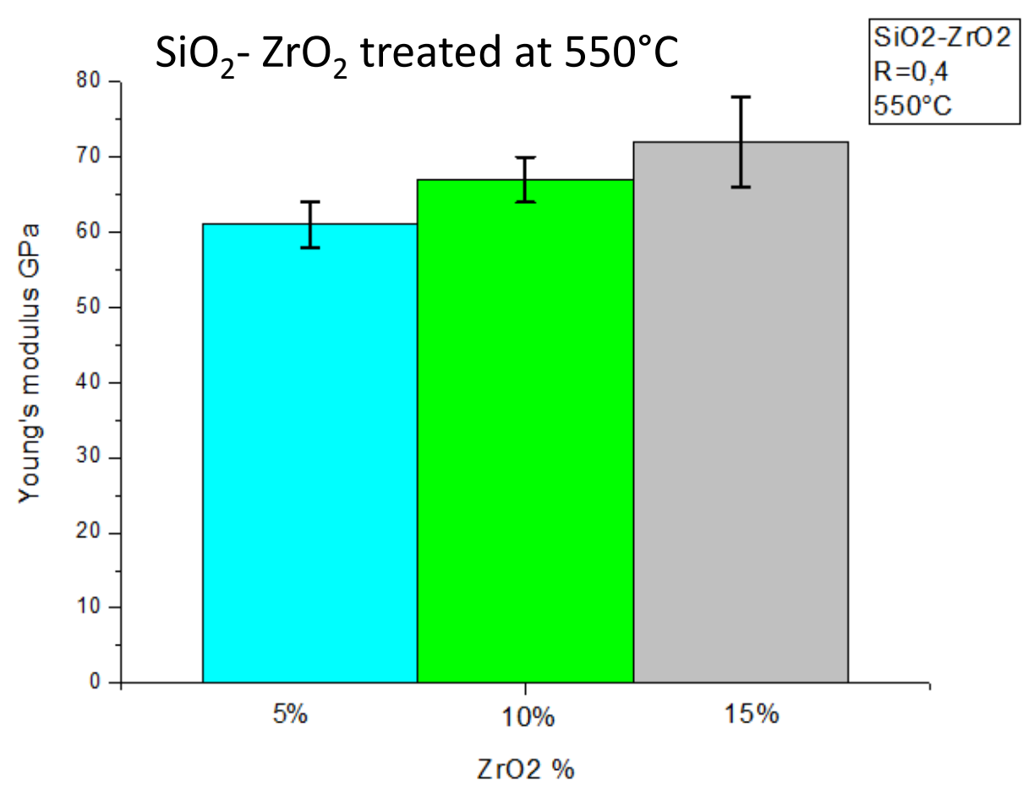
Coatings Thickness



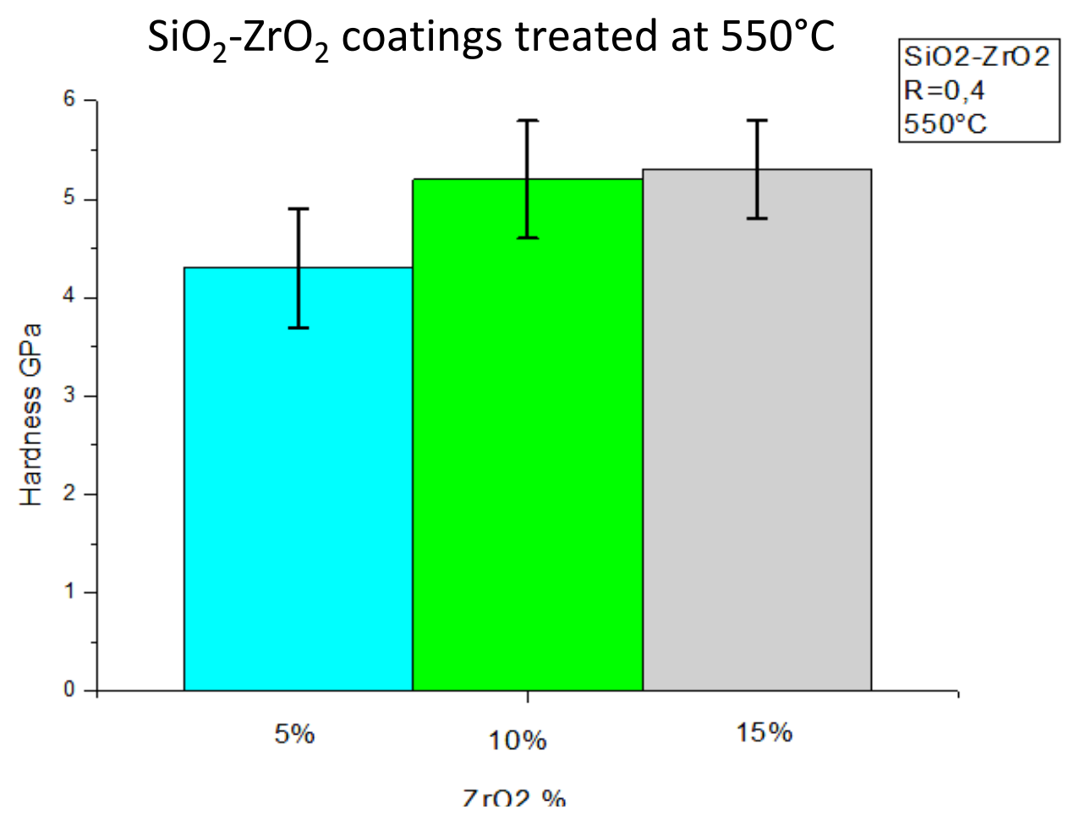


Maximum critical thickness of 2.4 µm was obtained for SiO_2 -ZrO_2 R= 0.4.

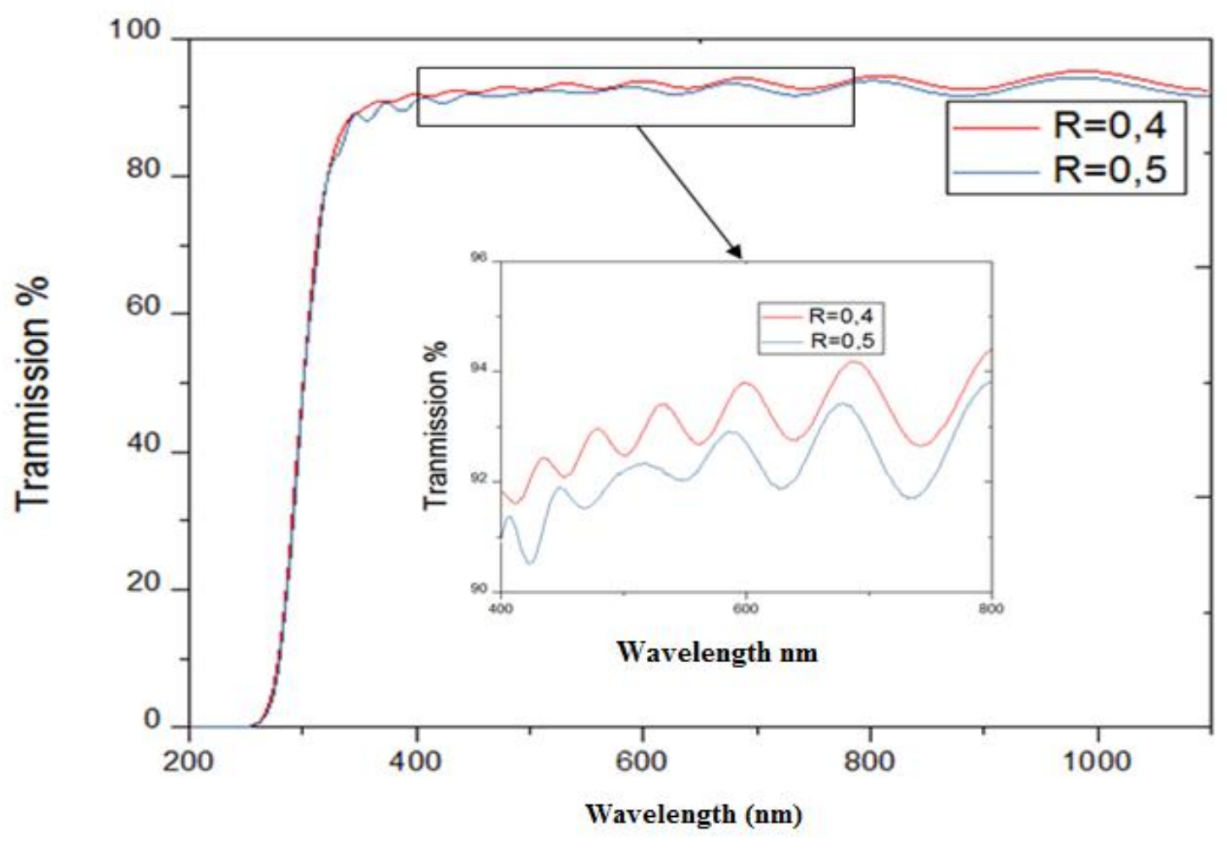
Mechanical characterization



Hardness and Young’s modulus increase with the sintering temperature and ZrO_2 amount, reaching values of 5 GPa and 70 GPa for 15% molar of ZrO_2.

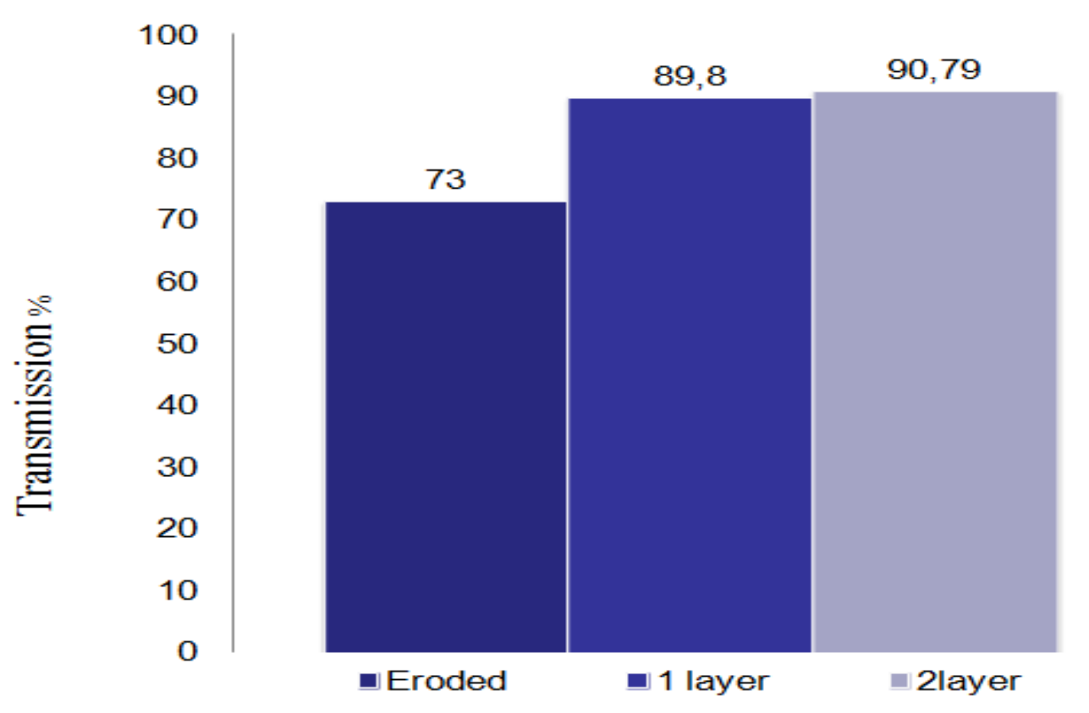


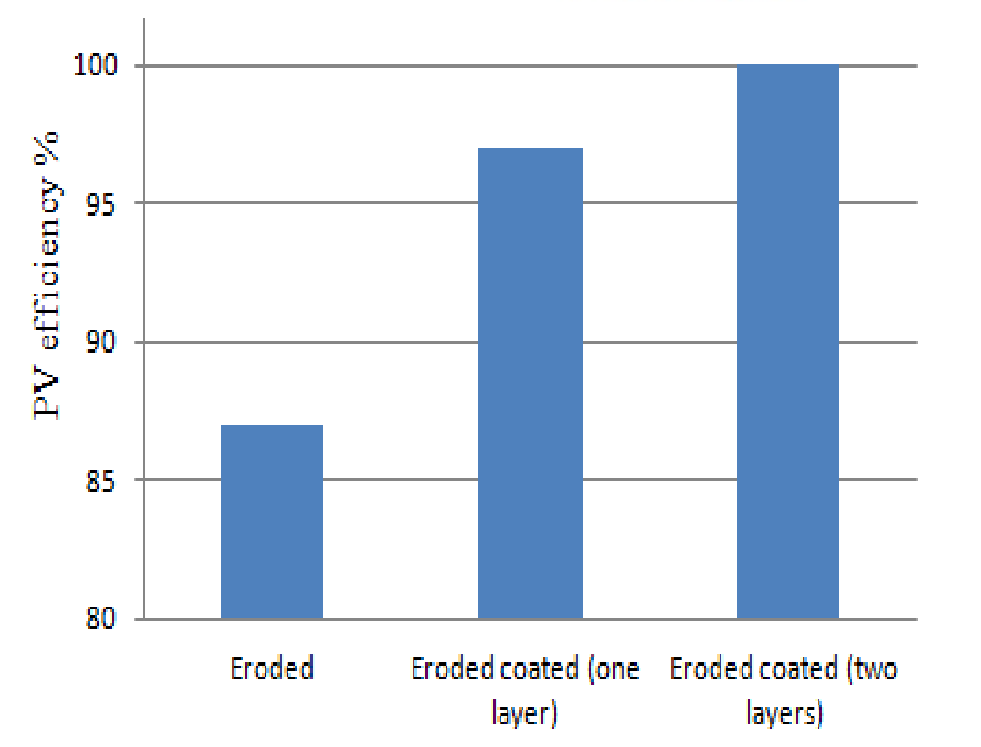
Optical characterization



- ☐ Maximum optical transmission between 92 and 95% for SiO_2 coatings.
- ☐ The incorporation of ZrO_2 decreases the optical transmission down to 91.4 – 93.5% depending on ZrO_2 % molar.

SiO_2 coatings on eroded PV panels





The deposition of SiO_2 coatings increase the optical transmission of eroded samples from 73 up to 90.8%, near to the as- received glass, reaching an 18% of improvement.

The measurement of PV efficiency of eroded panels with one or two SiO_2 coatings (R=0.4) confirms that it is possible to restore the PV efficiency from 87% to 97-100%.

Conclusions:

- The incorporation of colloidal SiO_2 nanoparticles up to 0.4, increases the critical thickness of SiO_2 coatings. However, for higher amount of colloidal SiO_2 nanoparticles the critical thickness decreases associated with agglomerations and defects.
- Maximum thickness of 2.4 and 4.3 µm (single and double layer) was obtained for SiO_2 coatings with silica nanoparticle rate of 0.4 and treated at 500 °C.
- The incorporation of ZrO2 in the matrix leads to remarkable improvement of mechanical properties(hardness and elasticity) and tailoring of optical properties, increasing the refractive index and slightly decreasing the optical transmission.
- The deposition of SiO_2 coating on eroded panel increases the optical properties reaching a 18% improvement, from translucent glass to transparent as pristine glass.
- The PV efficiency of eroded panel is practically recovered by the deposition of SiO_2 coatings. It is possible to restore the PV efficiency from 87% to 97-100% for monolayer or bilayer SiO_2 coatings.

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