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Al_2O_3 antireflection coatings for silicon solar cells

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Materials

ABSTRACT

Purpose: The aim of this paper was to investigate changes in surface morphology and optical properties of thin films of Al_2O_3. Thin films were prepared using atomic layer deposition (ALD) method.
Design/methodology/approach: The microanalysis was investigated by the Energy-dispersive X-ray spectroscopy EDS. The changes in surface topography was observed by the atomic force microscope AFM XE-100 and scanning electron microscope SEM. The results of roughness was obtained by the software XEI Park Systems. The measurement of thickness and dispersion of refractive index was performed using SE800 PV spectroscopic ellipsometer. The optical reflection was investigated by the spectrometer UV/VIS.
Findings: Results and their analysis allow to conclude that the atomic layer deposition method enables uniform coating of smooth and complicated shapes surfaces. The thin film thickness depends only on the number of cycles, so that can be easily control the thickness of the material.
Practical implications: Knowledge about the ALD Al_2O_3 optical parameters and the possibility to obtaining a uniform thin films show that the previously named material has a big potential in photovoltaic application.
Originality/value: The paper presents some researches of aluminium trioxide thin films deposited by atomic layer deposition method on monocrystalline silicon.
Keywords: Antireflection coatings; Silicon solar cells; Atomic layer deposition

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1. Introduction

The atomic layer deposition method ALD is a variation of the CVD method, which is distinguished by the use of cyclic alternating pulses of precursors between which the chamber is being rinsed with an inert gas. This allows the use of the precursors with a strong reactivity. Single atomic layer deposition in ALD process is based on two mechanisms: chemisorption on the surface and the chemical reactions at the surface of the coated component. In one cycle, there are the following steps:

- introducing the first precursor into the reaction chamber and injection by a pulse,
- flushing the reaction chamber with inert gas,
- introducing the second precursor into the reaction chamber and injection by a pulse,
- flushing the reaction chamber with inert gas [1-3].

The idea of the ALD method is shown in Fig. 1 and as an example the deposition of a thin film of Al_2O_3 in the reaction of $AlCl_3$ with H_2O is being demonstrated. By using highly reactive the precursors, which immediately reacts with the substrate to form a monolayer and do not allow for further reaction, each cycle causes an increase of the thin film thickness by a definite value in the range of 0.01-0.3 nm [4].

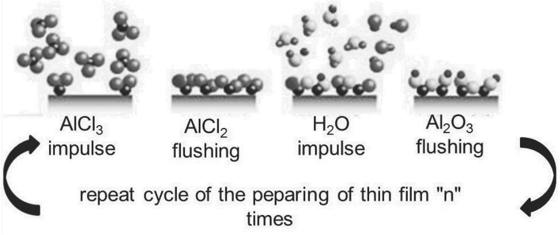


Fig. 1. Schematic representation of a cycle of the atomic layer deposition process

Atomic layer deposition method may be used for the deposition of:

- single elements, such as Group IV of the Periodic Table,
- binary compounds such as metal oxides,
- composite compounds such as hydroxyapatite.

Depositing the selected compound is closely related to the proper choice of precursors which should be characterized by:

- chemical stability at the selected growth temperature,
- ability to adsorb on the substrate,
- high reactivity with the other precursors.

Compared to the already used technology ALD method has the following advantages:

- the thin film thickness depends only on the number of cycles, so the thickness of the material can be easily controlled,
- contact of reactants takes place only on the substrate, so that the precursors with high reactivity can be used,
- the growth rate is not dependent on flow uniformity of precursors like in the case of physical vapor deposition (PVD) and chemical vapor deposition (CVD) methods.

A unique advantage of ALD method is the ability to uniformly deposit on geometrically complex surfaces (Fig. 2) [5-7].

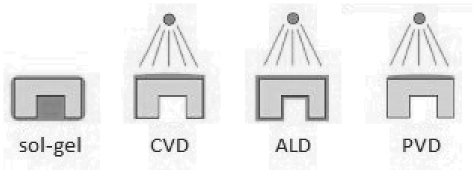
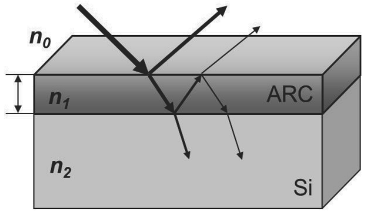


Fig. 2. Comparison of coverage ratio of complex shapes for different deposition methods

For this reason, atomic layer deposition method may be used for deposition of the optical thin film on the silicon solar cells as antireflection coating. There are many methods of optical thin films, for example, sol-gel, CVD, PVD but with the advantage of ALD earlier mentioned seems to be the most promising [8-11]. Antireflection coating reduces the reflection (Fig. 3) and by that increases the efficiency of the finished solar cell. About 8% of the energy losses is related with the reflection of light, but the application of the antireflection coating, this number can be reduced to 3-5%. The use of antireflection coating multiplies the reflection of light. The incident beam is reflected from the surface of the AR coating and silicon [12-18].

Antireflection coating should have a specific thickness, refractive index and transparency. Exemplary materials used as antireflection coatings and their refractive index are shown in Table 1.



$$n_1 d_1 = \frac{\lambda}{4}$$

Fig. 3. Effect of antireflection coating on the reflection of light from the surface, where n_o, n_1, n_2 are respectively refractive index of air, antireflection coating and silicon.

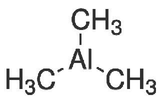
Table 1.
Summary of exemplary materials that are used as antireflection coating and their reflective index

Material	Refractive index
SiO_2	1.4, 1.5
SiO	1.8, 1.9
Si_3N_4	1.9
TiO_2	2.3
Ta_2O_5	2.1, 2.3
MgF_2	1.4, 1.5
a-SiN_x	1.7, 2.3

An interesting material which can be used as antireflection coating is Al_2O_3. Aluminum trioxide grown by atomic layer deposition (ALD) has been shown to provide a good surface passivation for lightly and highly doped p-type silicon and for lightly doped n-type silicon and good optical properties.

2. Materials and methodology

The Al_2O_3 thin films were prepared by the atomic layer deposition technique. Trimethylaluminum (TMA) was used as precursor material and water as reactant. This pyrophoric, colourless liquid is an industrially important organoaluminum compound. The chemical formula TMA is shown in Fig. 4.



$Al(CH_3)_3$

Fig. 4. The chemical formula of Trimethylaluminum (TMA)

The process temperature was 300°C and the number of cycles, respectively 420, 620, 820 and 1020. The thin films were deposited on the bare monocrystalline silicon substrate.

3. Results and discussion

The microanalysis of the as-prepared thin films has been carried out by the Energy-dispersive X-ray spectroscopy. In Figures 5-8 are shown the EDS spectra of thin films of ALD Al_2O_3. There are observed peaks at about 0.5 and 1.5 KeV in these EDS spectra's, which are assigned to oxide and aluminum. Such an analysis can be confirmed by the presence of aluminum trioxide. It can be seen that with increasing thickness of the Al_2O_3 thin film Al peaks are more pronounced.

The study of the surface topography was performed using scanning electron microscope SEM (Figs. 9-13). Images were taken at a magnification of 10 00 KX. Fig. 9 show strongly developed area of bare silicon. On the following pictures (Figs. 10-13) was found that Al_2O_3 thin film uniformly cover the surface of the silicon reproducing the irregularities

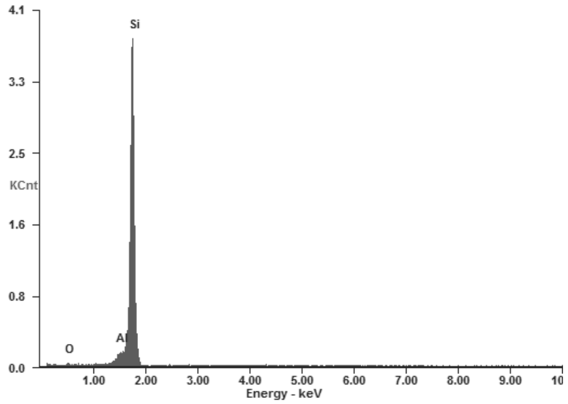


Fig. 5. EDS spectrum of a thin film of Al_2O_3 deposited with a 420 number of cycles

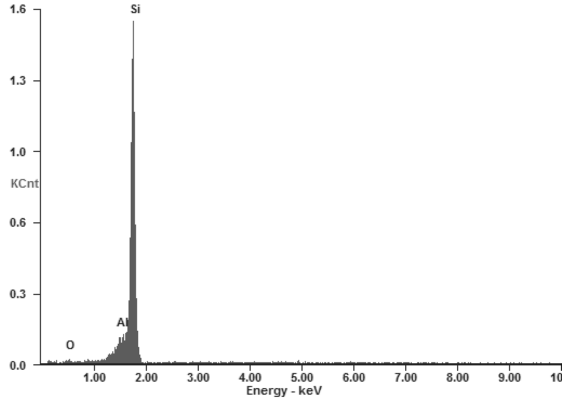


Fig. 6. EDS spectrum of a thin film of Al_2O_3 deposited with a 620 number of cycles

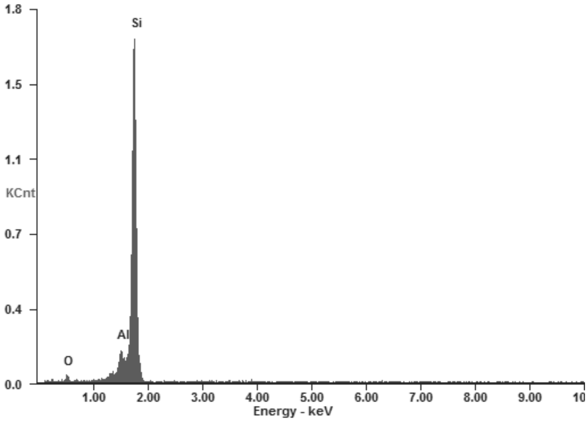


Fig. 7. EDS spectrum of a thin film of Al_2O_3 deposited with a 820 number of cycles

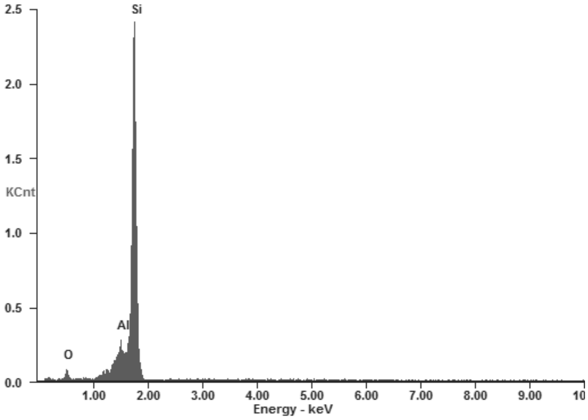


Fig. 8. EDS spectrum of a thin film of Al_2O_3 deposited with a 1020 number of cycles

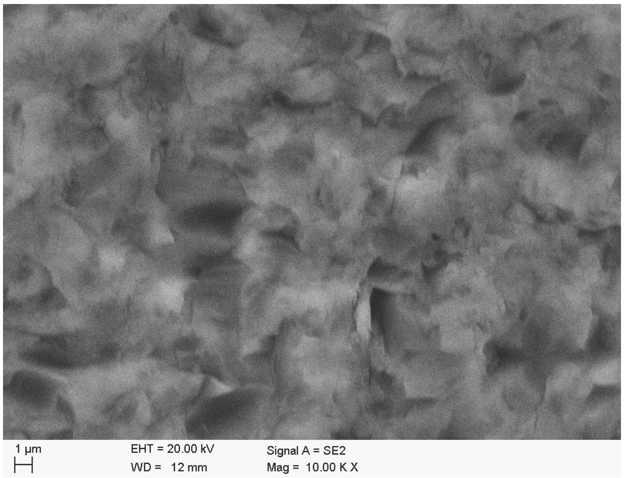


Fig. 9. SEM image of the surface topography of bare monocrystalline silicon

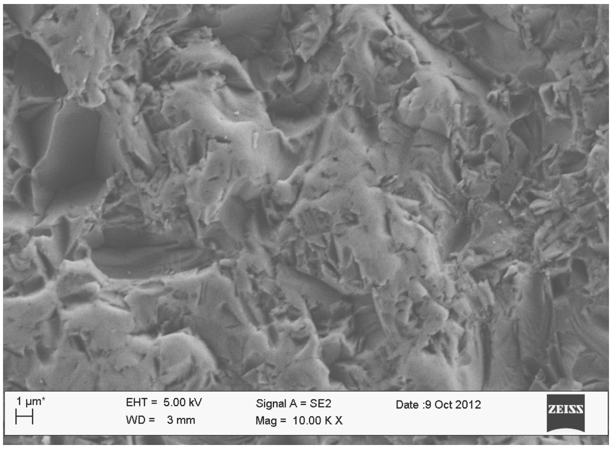


Fig. 10. SEM image of the surface topography of Al_2O_3 thin film deposited with an 420 number of cycles

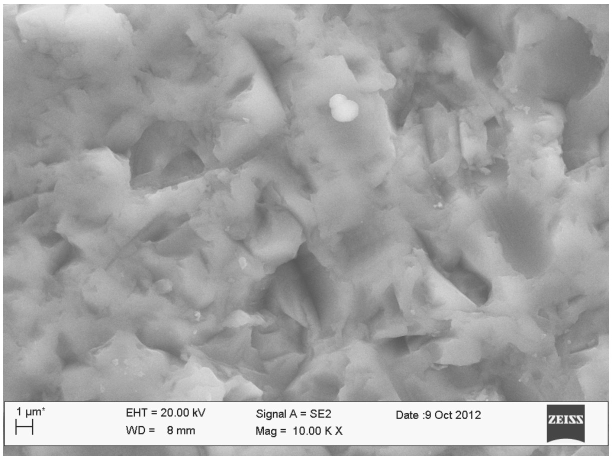


Fig. 11. SEM image of the surface topography of Al_2O_3 thin film deposited with an 620 number of cycles

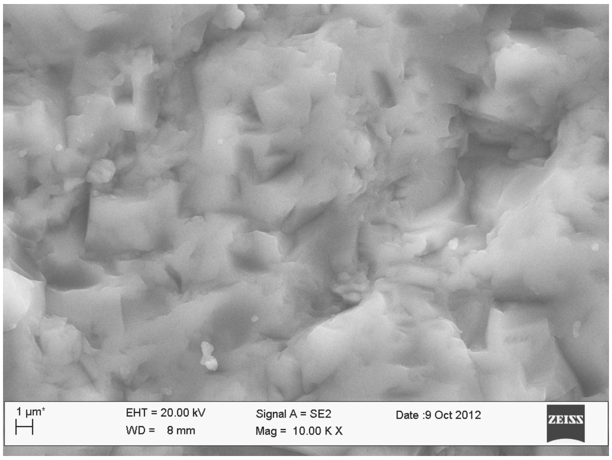


Fig. 12. SEM image of the surface topography of Al_2O_3 thin film deposited with an 820 number of cycles

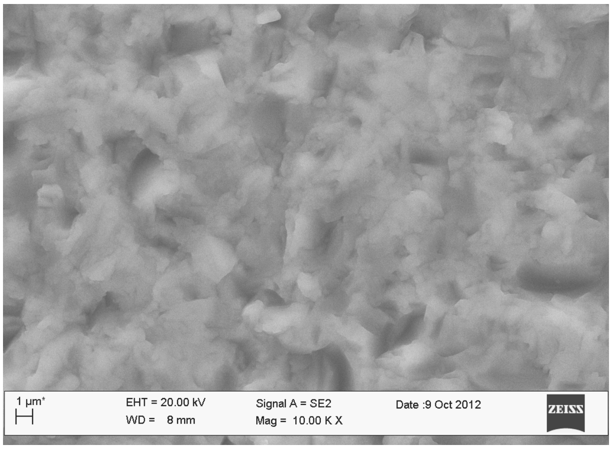


Fig. 13. SEM image of the surface topography of Al_2O_3 thin film deposited with a 1020 number of cycles

The study of the surface topography was performed by atomic force microscope AFM XE-100 working in a non-contact mode. Was observed an area of 25x25 µm. Figs. 14-17 shows 2D and 3D surface topography of bare monocrystalline silicon and Al_2O_3 thin film deposited with a 820 number of cycles. The roughness results were made in the XEI software. Figs. 16 and 17 shows differences in surface topography, respectively: bare silicon and a thin film of 60 nm Al_2O_3. The Fig. 18 and Table 2 presents an analysis of the roughness of a thin films deposited with a 820 number of cycles and bare silicon in the program XEI Park Systems. Surface roughness was characterized by calculating the roughness parameters root mean squared (Rq), arithmetic average of absolute values (Ra), maximum evaluation and presenting histograms.

Table 2.
The roughness parameters of a bare silicon and 80 nm of Al_2O_3 thin film

Sample	Max height, µm	R_q, µm	R_a, µm
Bare silicon	1.427	0.411	0.328
Silicon with 80 nm of Al_2O_3 thin film	3.917	0.328	0.253

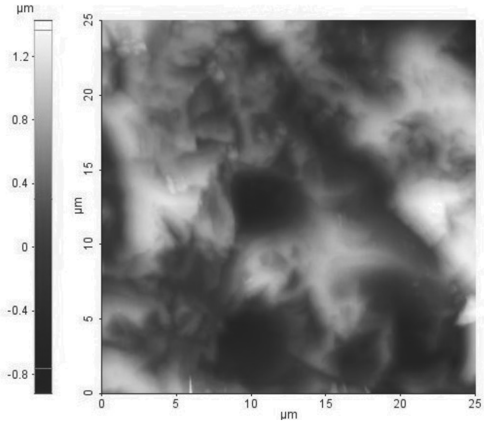


Fig. 14. AFM 2D image of the surface topography of bare monocrystalline silicon

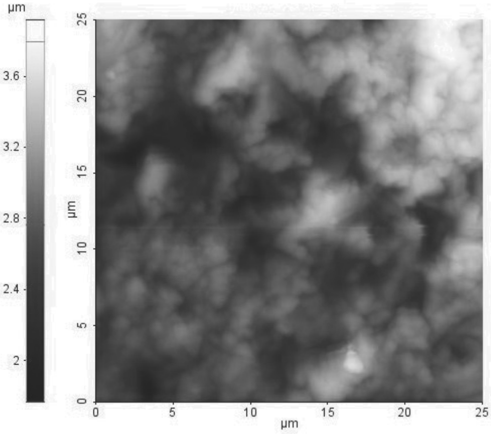


Fig. 15. AFM 2D image of the surface topography of Al_2O_3 thin film deposited with an 820 number of cycles

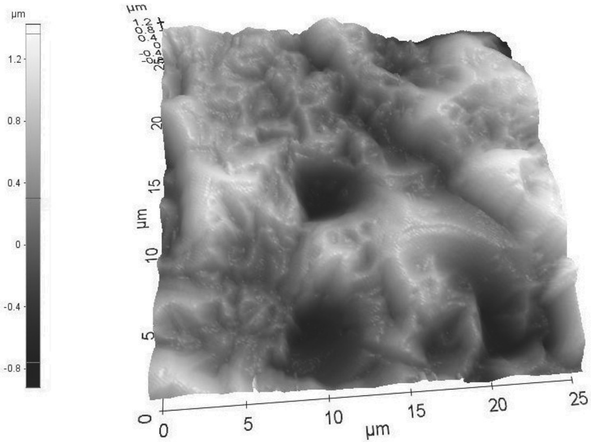


Fig. 16. AFM 3D image of the surface topography of bare monocrystalline silicon

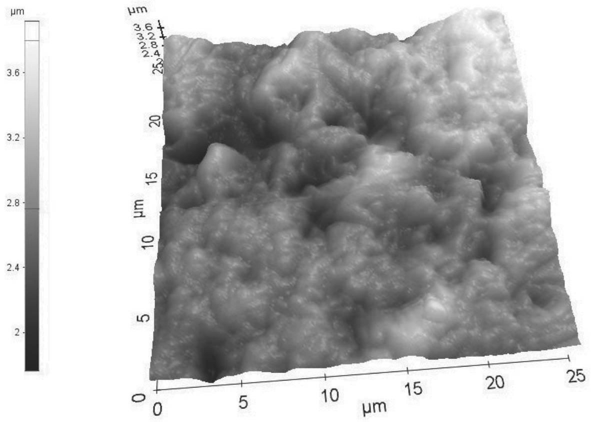


Fig. 17. AFM 3D image of the surface topography of Al_2O_3 thin film deposited with an 820 number of cycles

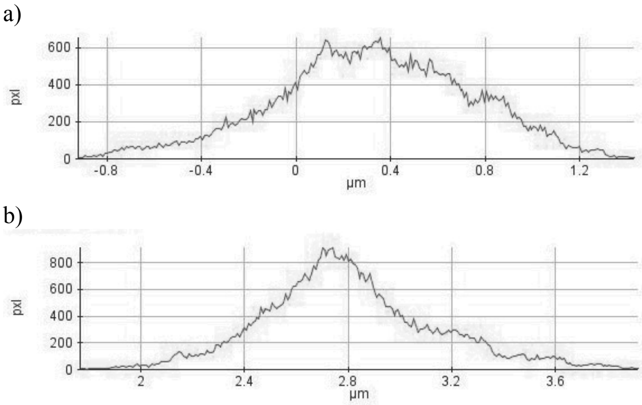


Fig. 18. The histogram of frequency of the occur height for a: a) bare silicon, b) 80 nm of Al_2O_3 thin film

The measurement of thickness and refractive index was performed using SENTECH's SE800 PV spectroscopic ellipsometer. The used spectral range was 280-930 nm. The samples were measured at a fixed angle of incidence of Phi=65°. Figs. 19 and 21 show measured and modelled ellipsometric spectra of Al_2O_3 deposited respectively with 620 and 820 number of cycles. The model fits the measurement excellently. Figs. 20 and 22 show dispersion of n. Refractive index measured at a wavelength of 632.8 nm which was equal 1.652 and 1.656 respectively (Table 3).

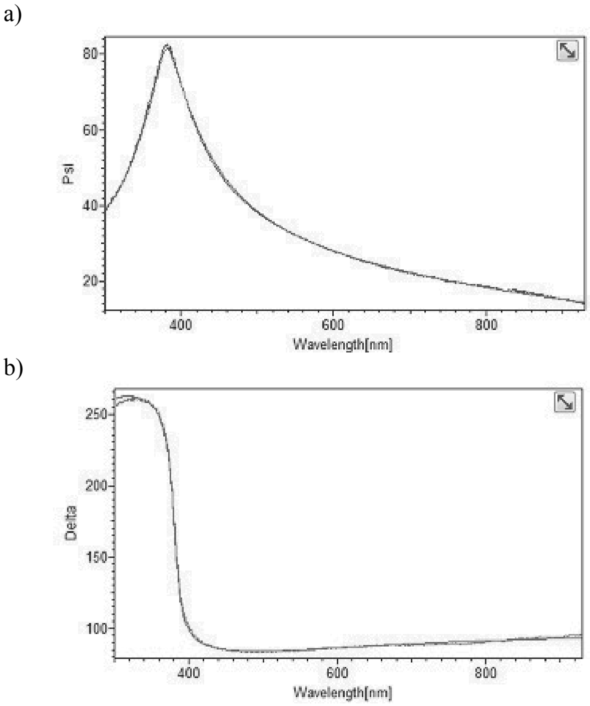


Fig. 19. Measured and modelled ellipsometric spectra (Phi = 65°).of Al_2O_3 thin film deposited with a 620 number of cycles: a) Psi, b) delta

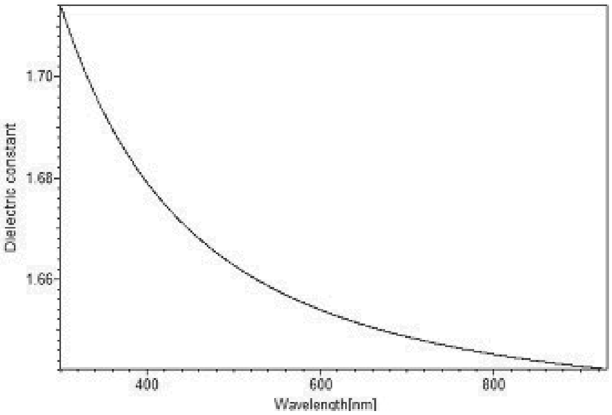


Fig. 20. Dispersion of n of Al_2O_3 thin film deposited with an 620 number of cycles

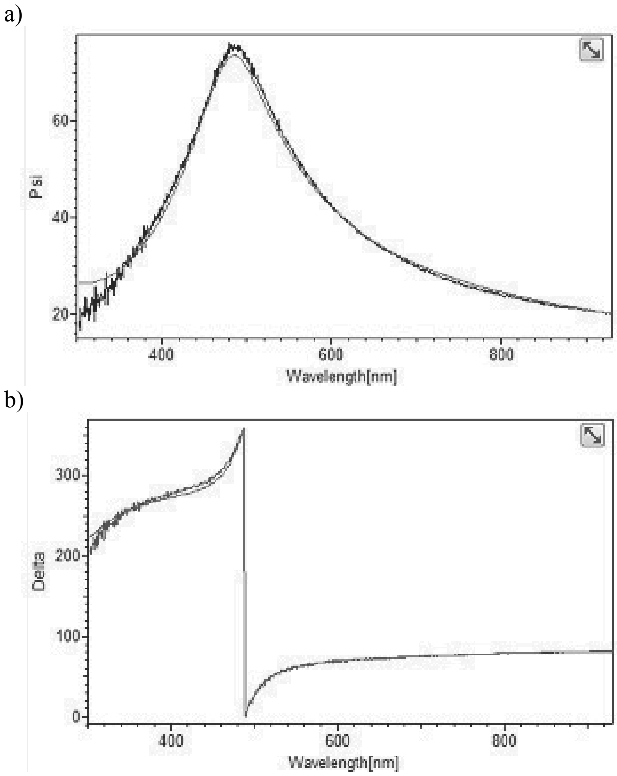


Fig. 21. Measured and modelled ellipsometric spectra (Phi = 65°).of Al_2O_3 thin film deposited with an 820 number of cycles: a) Psi, b) delta

Table 3.
Refractive index and thickness of Al$_2$O3 thin films

Sample	Thickness [nm]	Refractive index n (in 632.8 nm)
Al_2O_3 deposited with an 620 number of cycles	58.5	1.652
Al_2O_3 deposited with an 820 number of cycles	78.5	1.656

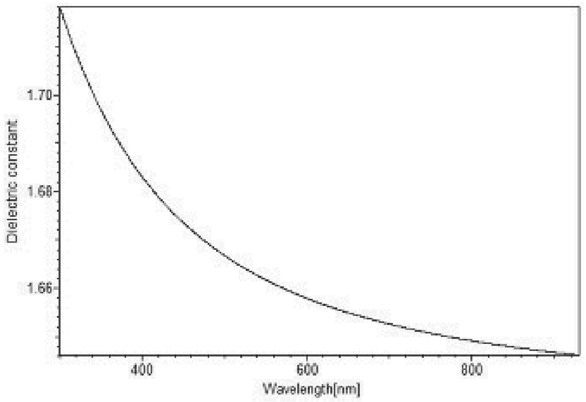


Fig. 22. Dispersion of n of Al_2O_3 thin film deposited with an 820 number of cycles

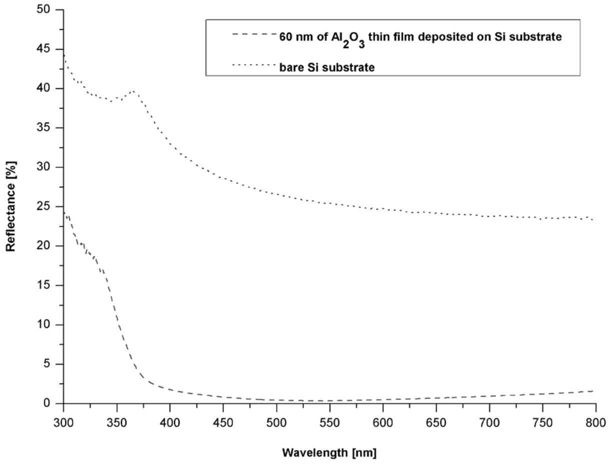


Fig. 23. The spectrum of reflection for the Al_2O_3 thin film deposited with an 620 number of cycles

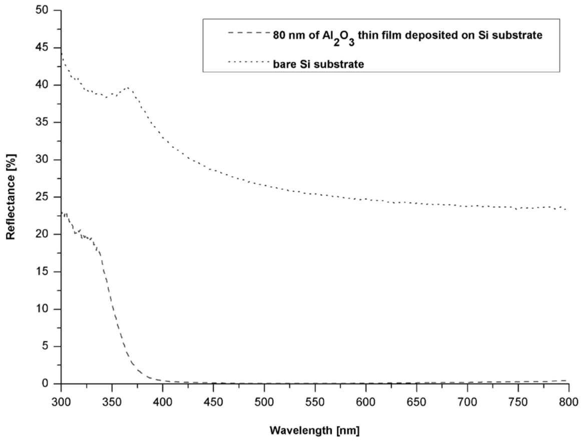


Fig. 24. The spectrum of reflection for the Al_2O_3 thin film deposited with an 820 number of cycles

The optical reflection has been investigated by the spectrometer UV/VIS. The reflection of 60 and 80 nm of Al_2O_3 thin films as compared with the reflection of a bare silicon are shown in Figs. 23 and 24.

For a 60 nm of Al_2O_3 the best results were obtained in the wavelength range of 450 and 650 nm reducing the reflection by less than 1%. For a 80 nm of Al_2O_3 the best results were obtained in the wavelength range 400 to 800 nm reducing the reflection by less than 1%.

4. Conclusions

Results and their analysis allow to conclude that the Atomic layer deposition method enables uniform coating of smooth and complicatedly shapes surfaces. The thin film thickness depends only on the number of cycles, so that the thickness of the material can be easily control. Best results were obtained with a thin film of Al_2O_3 obtained at 830 cycles at a temperature of 300°C. The knowledge about the ALD Al_2O_3 optical parameters and the possibility to obtain a uniform thin film has been shown and named in the previously material - it proves that it has a big potential in photovoltaic applications.

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