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YEREVAN STATE UNIVERSITY

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SURFACE ANTIREFLECTION AND PROTECTION OF SOLAR PV

CONVERTERS FROM DESTRUCTIVE EFFECTS

ABSTRACT

of the Dissertation for Competition of Scientific Degree of

Doctor of philosophy (PhD) on Specialty 01.04.07 – Condensed matter physics

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ՀՀ ԿՐԹՈՒԹՅԱՆ ԵՎ ԳԻՏՈՒԹՅԱՆ ՆԱԽԱՐԱՐՈՒԹՅՈՒՆ

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ֆիզիկամաթեմատիկական գիտությունների թեկնածուի

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The defense of the Dissertation should be held on the <u>23 </u>of June 2012 at 12^{00} on the session of the Physics Specialized Council 049 of the Yerevan State University, address: 1 Alek Manukyan street Yerevan, Armenia

It is possible to familiarize with the Dissertation in library of YSU
The Abstract is dispatched on the <u>23-th of May 2012</u>.

Scientific Secretary of the Specialized Council   Ph. D. **V. Kalantaryan**

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Ատենախոսության թեման հաստատվել է ՀՀ ԳԱԱ Ֆիզիկայի կիրառական պրոբլեմների ինստիտուտում

Գիտական ղեկավար՝   Ֆիզ.-մաթ. գիտ. դոկտոր, պրոֆ. **Ժ.Ռ. Փանոսյան**

Պաշտոնական ընդդիմախոսներ՝
                          Ֆիզ.-մաթ. գիտ. դոկտոր, պրոֆ. *Վ.Գ. Թրունի*
                          Ֆիզ.-մաթ. գիտ. դոկտոր, պրոֆ. *Ֆ.Վ. Գասպարյան*

<u>Առաջատար կազմակերպություն՝   ՀՀ ԳԱԱ Ռադիոֆիզիկայի և Էլեկտրոնիկայի ինստիտուտի</u>
Պաշտպանությունը կայանալու է 2012թ. <u>հունիսի 23-ին</u>, ժամը 12^{00}-ին Երևանի պետական համալսարանում գործող ֆիզիկայի 049 մասնագիտական խորհրդի նիստում:
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Սեղմագիրը առաքված է 2012թ. <u>մայիսի 23-ին</u>:

Մասնագիտական խորհրդի գիտական
քարտուղար, Ֆիզ.-մաթ. գիտ. թեկնածու   **Վ.Պ. Քալանթարյան**

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THE GENERAL DESCRIPTION OF THE DISSERTATION

Large scale utilization of solar energy is modern not only from the points of views of energy consumables but also from the point of ecological view. Large scale utilization of solar photovoltaic solar converters is related to the increment of the efficiencies of separate components and their durability as well as to the decrement of the costs. Model of new type of photovoltaic solar converter with Fresnel lens is elaborated in the "Heliotechnic" laboratory of SEUA; patent AM number 1810 A2, 2005. Its main components are the refractive type concentrators Fresnel lens made from organic glass and the solar photovoltaic converter made from silicon.

Concentrators of refractive type have an advantage over the reflecting ones because the converters are installed in the backside of the accepting surface hereby they don't make any shaded surfaces. In case of refractive concentrators, the system is lightweighted and the cost is correspondingly low.

Until now it is not possible to obtain refractive concentrators from organic glasses which have antireflection properties and simultaneously high stability against mechanical, chemical and atmospheric erosion influences. Antireflectance (AR) of refracting lens and solar photovoltaic converter provide transmittance of higher amount of solar energy flow, conversion of solar energy and increment of efficiency.

The application of the diamond like carbon (DLC) multilayer deposited on the surface of silicon and organic glass provides the antireflection and stability against the external destructive influences.

Carbon forms a great variety of crystalline and disordered structures because it is able to exist in three hybridization, sp^3, sp^2 and sp^1. Each carbon atom contains four valence electrons. These electrons interact in different ways producing the mentioned different configurations. In the sp^3 configuration, as in diamond, these electrons form strong σ bonds with the neighbor atoms. In sp^2 configuration as in graphite, three σ bonds are forming in one plane and the fourth bond is a π bond formed perpendicular to the plan containing σ bonds. Finally in the sp^1 configuration, two σ and two π bonds are formed. The versatility of these properties is due to the strong dependence of their properties on the sp^2/sp^3 ratio in the material and the hydrogen content.

Another industry importance materials, plastics, such as acrylic (PMMA), need to be coated with protective or antireflective layers. Plastics in outdoor uses are exposed to diverse environmental effects which for some extent limits the uses of the plastic material via deterioration and degradation. Where degradation refers to the chemical destructive changes in the material and deterioration is the changes in the physical properties of the materials. During outdoor using of PMMA, it is subject to many types of failure effects such as humidity, soiling, temperature changes, sunlight and rain resulting in different changes in the surface and bulk of PMMA sheets like chemical changes, discoloration, surface cracking and crazing and changes in the electrical properties of the materials.

As a result of that, optical and mechanical failure effects are expected to take place. Reduced transmittance was observed for acrylic sheet or lenses subjected to extended deployment in the outdoor environment. Accordingly and as a result of its excellent properties of hardness and transparency, DLC becomes a perfect candidate to be used as protective and antireflective coatings which becomes one of the most important application fields of coatings.

The principal aim of this thesis is to develop a protective and antireflective coating of diamond like carbon films on different components of such converter. The used coating is single or multi layer coating of diamond like carbon films.

For this aim, different tasks have been studied including;

1) Obtaining stable and adhesive DLC coating on Si and PMMA.
2) Creation of experimental setup and experimental investigation of the destructive effects on the properties of the obtained coating.
3) Developing a theoretical model to estimate the optical parameters required for the multilayer coating to obtain antireflection coating.
4) Based on the results of the theoretical model, a long term deposition process is used to modify the deposition condition in order to obtain the required layers.

Practical values of implemented investigations are

1. Elaboration of surface protection technology for PMMA against external erosion influences opens new opportunities for their applications in different industries.
2. Antireflection of organic and inorganic substrates by elaborated DLC films opens many opportunities in the applications of low cost glasses, photo lenses, and solar beam concentrators.

3. Elaborated technology is cheap where wide spread hydrocarbons and nitrogen is applied.

4. In the conditions of temperature, humidity and sand wind influences, DLC films provide significant prolongation of the lifetime for such optical element.

5. Coating of the surface of Si PV converter by triple layer DLC protects from external erosion influences and simultaneously decreases the reflectance, increases the photoactive absorption of solar incident radiation, increases the efficiency of photovoltaic converter and longevity.

The scientific novelty of the work goes as follows;

1) Deposition of adhesive DLC multilayer on different substrate and study the effect of the deposition parameters on the deposited layers.

2) Preparation of multi-layer DLC on different substrates in single technological processes is very important factor in industry.

3) High level of protection against humidity + temperature and small particle impact has been recorded for PMMA coated by multi layer DLC films.

4) Enhancing the thermal stability of the deposited DLC by using metal oxide as an intermediate layer between the DLC and the glass substrate.

5) Powerful model of antireflection parameter calculation has been produced

6) Tri-layer DLC as antireflection coating on PMMA and Silicon (Si) has been recorded as well.

7) The obtained antireflection behavior is stand against variation of the incident angle for PMMA.

The main scientific provisions of the work are

1) First time antireflection of refractive lenses made from organic glass has been implemented simultaneously increasing their stability against external erosion influences (sand winds and climatic influences).

2) Obtained experimental dependencies of antireflection have been confirmed on the basis of theoretical calculations.

3) It has been shown that single, double and triple layer diamond-like carbon films make different antireflection effects depending on whether they are deposited on the surfaces of Si photovoltaic cells or on the organic or inorganic glasses.

4) It has been experimentally approved that long term thermal treatments of diamond-like carbon films deposited on the surface of studied surfaces in case of low temperatures (80^0C, 60%, 1000 hours) don't change the optical characteristics of that films but high temperature (500^0C) influences change the nanostructure of films.

5) It has been shown that by selection of technological parameters and depending on the doping levels electrical conductivities of the films are increased, ban gap is decreased optical transparency is decreased, quantity of sp^3 hybridized carbon is decreased related to the sp^2 hybridized carbons.

Approbation and publication of the results. The principal statements and results of the disseratation are reported and discussed on annual scientific conferences of the State Engineering University of Armenia (2010-2012), International Renewable Energy Conference (2009) and seminars of SEUA Physics chair and "Heliotechnic" laboratory.

Structure and volume of the dissertation. The dissertation work includes: 5 chapters, an Introduction, Common Conclusions and References. It is expounded on *119* computer pages, including *55* Figures and *14* Tables.

THE PRINCIPAL SUBSTANCE OF THE DISSERTATION

In the introduction, the theme actuality is substantiated, the principal aim and studied problems and tasks are presented. The scientific newness and the practical signification of the work are formulated.

The 1st chapter gives an overview of the potentials of diamond like carbon, as well as background to its properties and applications. General properties of diamond like carbon, the effect of different deposition parameters like temperature and nitrogen and thermal annealing on the properties of obtained films are also presented. The results of other authors have been represented and the fundamental properties of DLC and the effect of deposition parameters have been demonstrated. At the end of this chapter carbon based materials are briefly mentioned.

In the 2nd chapter contains details of the deposition technique, treatment systems and analysis equipments and procedures are described. Plasma enhanced chemical vapor deposition (PECVD) used technique is mentioned at the beginning of this chapter, together with description of the different subsystems and its operation is briefly discussed. The

analysis techniques principles and procedure have been illustrated. Also home made humidity and sandblasting equipments construction details are presented.

In the 3ed chapter In the first section of this chapter, the effects of deposition parameters on the properties of DLC films deposited on PMMA have been investigated. For this purpose, two sets of samples have been prepared; each one consists of 5-samples.

The first set was deposited at different nitrogen contents in the gas mixture at constant negative substrate bias voltage at 150V at constant plasma power watt and the second set deposited at different plasma power in the range 50-150w at constant Toluene to nitrogen ratio of 60% and substrate bias voltage of negative 150v. Films growth rate and optical properties changes have been used to probe the changes brought in the films upon deposition parameters changes.

By increasing the nitrogen content in the plasma gas the growth rate of the deposited films was found to increase up to 16% of nitrogen. Subsequently, stability in the growth rate is observed. The recorded stability in the growth rate of the deposited films against increases of the nitrogen concentration in the plasma gas could be a result of chimerical sputtering process. Chemical sputtering process comes from the formation of nitrogen rich chemical species which has very low sticking coefficient to the substrate. By recording the transmission spectra of the deposited films at different nitrogen contents shows an insignificant reduction up to 16% of nitrogen. It is observed that higher nitrogen content produces more and significant reduction in transmission up to 4% transmission reduction at
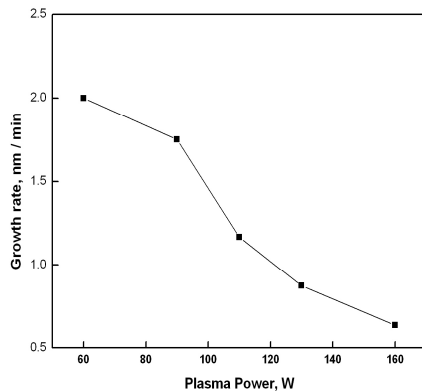
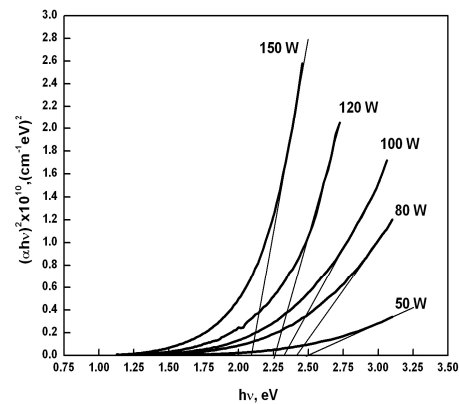Figure 1: Growth rate and plasma power

Figure 2:$(\alpha h\nu)^2$ against photon energy

30% nitrogen content. The optical band gap has been decreased from 2.25 eV to 2.02 eV. Such reduction in the optical band gap suggests an infinitesimal increase in the sp2 structure in the materials. It's worth noting here that the band gap has been increased at nitrogen content of 10% which could be attributed to a reduction in the stress level in the deposited films.

Figure 1 shows the growth rate changes for samples deposited at different plasma power. As shown in the figure the growth rate decrease as the power increases. Such reduction in the growth rate could be attributed to the back scattering of the incident ions on the substrate and also chemical sputtering process. Figure 2 shows the variation of $(\alpha h\nu)^2$ against $(h\nu)$ to estimate the optical energy gap values at different plasma power according to the following equation;

$$\alpha = Q\frac{(h\nu - E_g)^m}{h\nu} \quad (1)$$

where α is the linear absorption coefficient. E_g is the optical band gap and $h\nu$ is the photon energy. The exponent m is parameters depend on the transition nature. Here it has the value of 2 for direct allowed transition. As shown in the figure by increasing
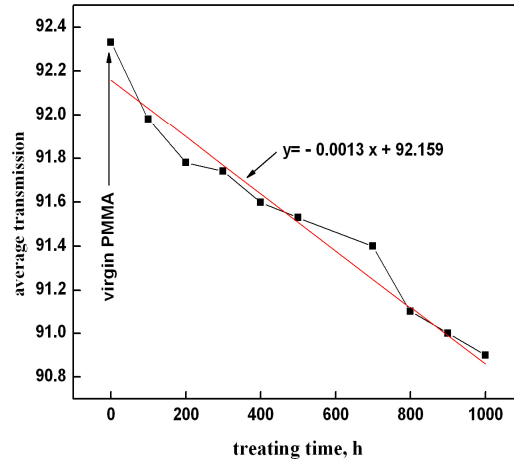

Figure 3: Average transmission of uncoated PMMA sample against treatment time
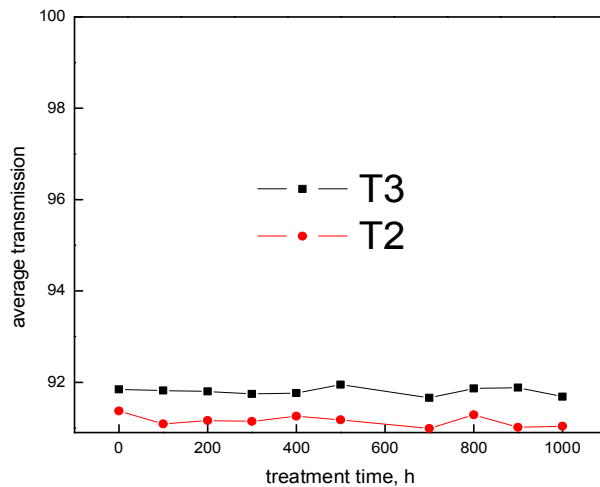
Figure 4: variation of average transmission of double layer coated DLC films on PMMA

the plasma power the optical band gap decrease from 2.5 for sample deposited at 50 watt to

2.08 for sample deposited at 150 watt. Such reduction could be attributed to sp^2 ratio increase.

In the second section of this chapter the protection that DLC can offer the surface of PMMA is investigated. Two destructive effects have been tested: 1) humidity at high temperature and 2) particle erosions. The effect of these two effects on uncoated PMMA is demonstrated. At humidity level of 60% and high temperature with respect to that PMMA can hold bare and coated PMMA has been tested for 1000 hours in home made humidity incubator. The samples have been taken out each 100 hour to record the transmission spectra and follow the changes that happen upon treating. As can be observed in figure 3 about 1.3% linear total reduction in the average transmission values measured in the spectral range 400-1100nm after 1000 hour of treating. Such degradation rate will lead to ~80% transmission level after about one year of working in such environment. Single layer and double layers DLC coated PMMA were tested in the same conditions. Single layer samples deposited using different deposition conditions of plasma power and samples deposited at low plasma power shows good stability in the transmission as a result of DLC. Samples coated with DLC deposited at high plasma power shows lower protection level and after 500 hours a significant reduction in transmission is recorded. The degradation rate was found to be higher than uncoated PMMA. Such behavior could be attributed to the diffusion of water vapor inside the graphite structure in the material. Figure 4 shows the average
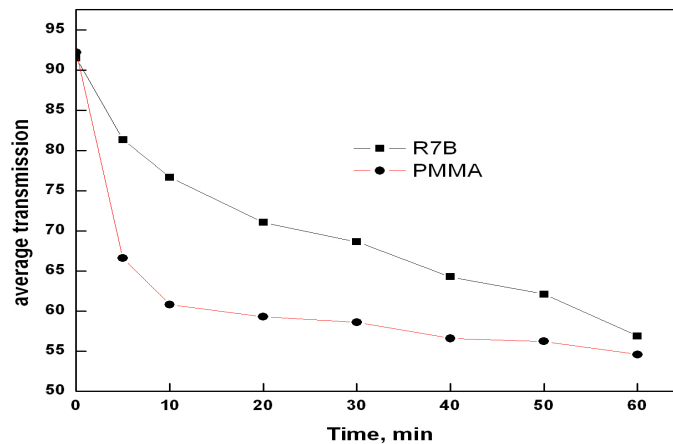

Figure 5: Average transmission variation of multi-layer DLC/PMMA for different blasting time

transmission spectra recorded in the spectral range 400-1100 nm for double layer DLC on PMMA surface. As can be observed the average transmission shows an excellent stability which reflect excellent protection level.

Subjecting the uncoated PMMA sample to a stream of quartz particle with size 50-150 μm for 60 minutes, about 40% reduction in transmission is recorded, see figure 5. Such result shows the fragility of the PMMA surface against particle impact which is very common in the outdoor environment in desert like countries as Egypt. The air velocity which carries the quartz particles to hit the PMMA surface was calculated according to;

$$v = \frac{q}{A} \qquad\qquad (2)$$

where q is the flow rate and A is the internal diameter of the used tubes. The velocity of the air was found to be about 150 kilometer per hour. Such velocity is very big with respect to the 35 kilometer per hour recorded average velocity in some places in Egypt. PMMA covered with 2-DLC layers got tested against particles impacts show better stability than uncoated surface. Figure 5 shows the average transmission of coated, sample R7B, and uncoated PMMA samples. After 5 minutes of treatment the average transmission of the coated samples is about 82 % while the uncoated glass shows 66% average transmission. This gives 16% higher average transmission for the coated PMMA and slower transmission reduction.

In the 4th chapter: Contains a detailed study of the effect of thermal annealing on the structural, optical and electrical properties of DLC films deposited on inorganic glass substrate. The deposition parameters are listed in table 1, where sample given symbols T2 and T3 for simplicity. As shown in the table, samples deposited at high temperature of 250°C. Such high deposition temperature supposes to result in low sp^3 content and high stress inside the deposited films. The obtained sample has been annealed in temperature range 300-500°C in nitrogen atmosphere to reduce film material loss die to oxidation of carbon b oxygen according to;

$$C + O_2 \rightarrow CO_2 \qquad\qquad (3)$$

FTIR, SEM, optical transmission (reflection) and sheet resistance measurement has been recorded before and after annealing of the sample to detect the changes brought in the films upon annealing. Figure 6(a) shows the FT-IR spectra of, as deposited and annealed, T2 group. As shown two main absorption peaks at 2850 and 2920 cm^{-1} are recorded.
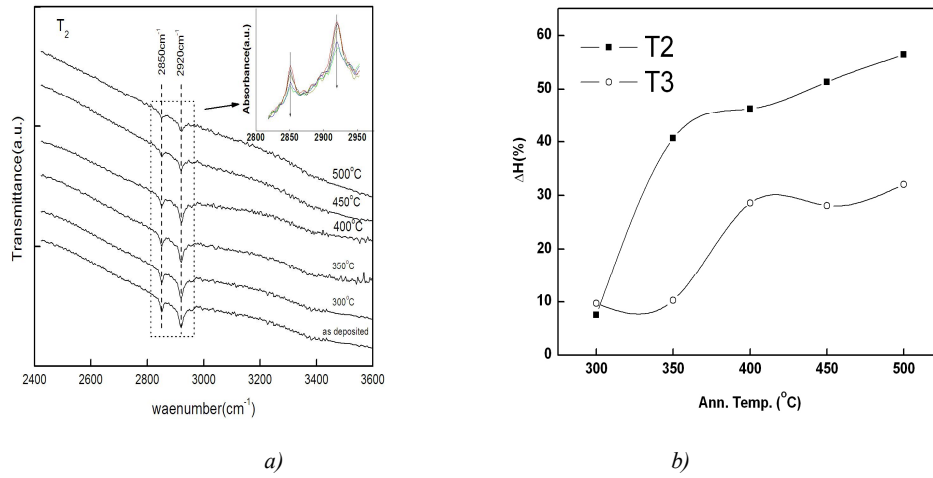
Figure 6: a) FT-IR spectra of DLC samples T2 as deposited and annealed.

b) Hydrogen loss in DLC films against annealing temperature

Table 1: Deposition condition of DLC films on glass substrate

Deposition conditions	T2	T3
Substrate type	Glass substrate	
pre-treatment gas	N_2	
deposition gas mixture (C_7H_8:N_2)	90:10	90:20
working pressure(Pa)	10^{-3}	
Deposition time	80 min	
Thickness of as-deposited films	550 nm	480 nm
Substrate Temperature	250^oC	

The recorded peaks could be attributed to the H-atom connected to C-sp^3 structure. No other peaks are recorded in the spectra. By annealing the sample at different temperatures, the intensity of the absorption peaks were found to reduce which indicated a reduction in the hydrogen content upon annealing. The inset curve in figure 6(a) shows the absorbance of the samples which shows reduction as the annealing temperature increases. The recorded FT-IR spectra were used to determine the bonded hydrogen content in the material according to the following equation;

$$N = A \int \frac{\alpha(\omega)}{\omega} d\omega \qquad (4)$$

where A is the absorption strength. There is another question of whether all hydrogen is bonded at C-H sites. Figure 6(b) shows the estimated hydrogen losses in the films against the annealing temperature. As observed by increase the annealing temperature the hydrogen loss increases significantly after 350°C in T2 group while the losses starts at 400°C for T3 group.

Figure 7 shows two SEM photos for sample T2 before and after annealing. As shown in the figure the particle size recorded before annealing is about 50 nm. Sample deposited at the same deposition parameters was measured by IR-Raman spectroscopy, in another work of our lab, and particle size of sp^2 structure was found to be 28nm. After annealing, the
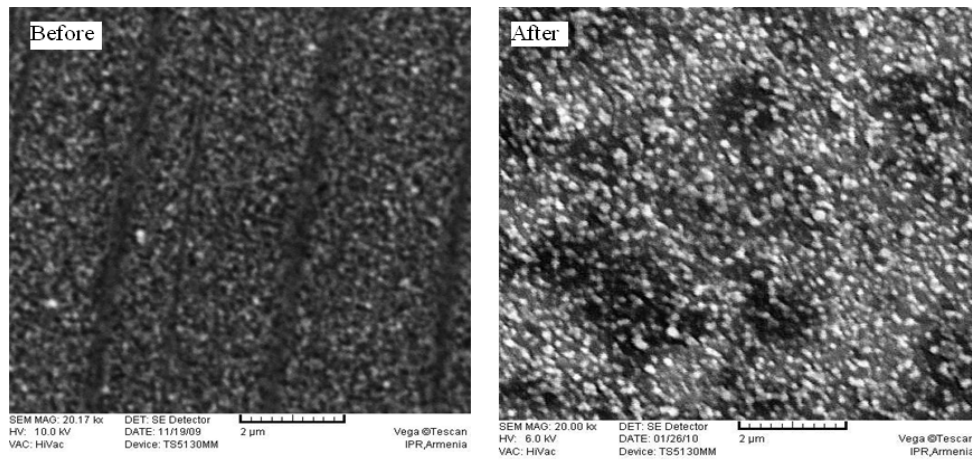

Figure 7: SEM pictures of T2 sample recorded before and after annealing at 500°C.

particle size was found to be 200nm in size. Such results suggest an increase in the sp^2 particle size upon annealing. Before annealing straight lines crossing the samples can be attributed to the absence of homogeneity in the chemical composition of the substrate. Such inhomogenity in the substrate chemical composition results in a different charge distribution on the surface causing preffential landing spots on the surface of the substrate.

Measuring the thickness before and after annealing at different temperature gives data represented in figure 8. As shown in the figure thickness reduction is observed as the annealing temperature increases. Such result could be attributed to increase in the effusion of the film materials or increase in the film density. Table 2 shows the estimated band gap values of all single layer deposited samples on glass substrate as deposited and annealed. As observed in the table in the beginning of annealing, an increase in the recorded band gap is
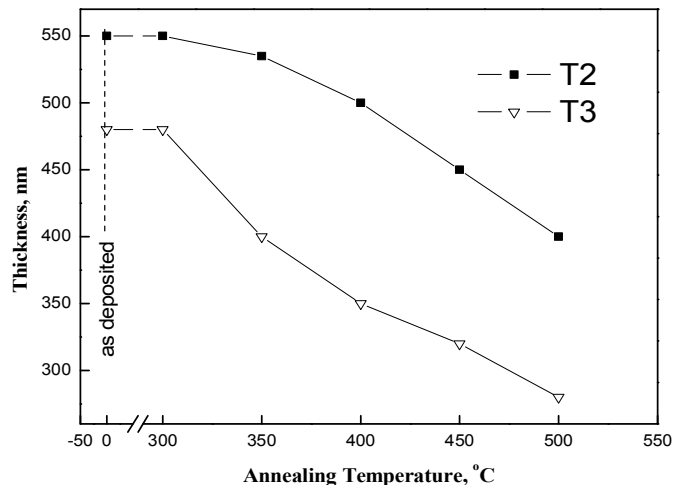
Figure 8: Variation in film thickness with annealing temperatures

observed as a result of a reduction in the defects in the material. After that a reduction in the band gap is observed due to the increase in the sp^2 ratio in the films.

Table2: Band gap variation for all films

Annealing temp. (°C)	Band Gap (E_g) (eV)	
	T2	T3
as-deposited	3.3	3.3
300	3.73	3.13
350	3.73	3.54
400	3.74	3.41
450	3.85	3.41
500	3.27	3.52

Figure 8 shows the variation of the recorded sheet resistance of all samples before and after annealing. As shown in the figure, the sheet resistance decreases when increasing the annealing temperature and it becomes as minimum for sample T2 annealed at 500°C. The reduction in the sheet resistance could be attributed to reduction in the defect density of the films, increase in the sp^2 content its corresponding cluster size.

From the above mentioned results, we can summarize the effect of the thermal treatment on the properties of DLC as;

1) Structure changes, hydrogen loss and increase in sp^2 content,

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2) Thickness changes, reduction in thickness values by annealing

3) Optical performance instability

4) Reduction in sheet resistance value.

Such irreversible changes in the behavior of DLC against thermal treatment form real obstacles against uses of DLC in many application fields.

In an attempt to enhance the thermal stability of DLC an intermediate layer of zinc oxide has been deposited using magnetron source and introduced between film and substrate. The deposited zinc oxide layer was 45 nm thick. The deposited samples show no significant losses in thickness or transmission against annealing.

In the 5th chapter the antireflection behavior of DLC film(s) had been discussed. When light incident on a surface separating two different media, i.e. have different refractive index values, part of the light is reflected. This reflected portion increases as the refractive index increase. For example for silicon with refractive index ~ 3.5 the reflection becomes about 30% which form a huge loss in the incoming optical energy. If it is possible to coat the surface with a material have lower refractive index a minimization of such losses is possible.
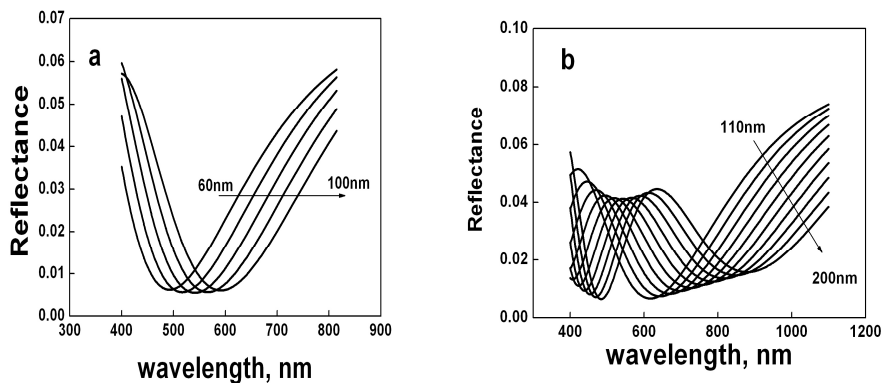

Figure 9: Calculated antireflection behavior of two DLC layers on PMMA surface at different values of second layer thickness.

DLC single and multilayer antireflection theoretical and experimental study has accomplished on different types substrates. The theoretical study was done based on transfer matrix method and a mathematics based program was written from this purpose. The reflectance and transmittance is estimated according to this method based on the following equation for single layer coating;

$$r = \frac{\gamma_o m_{11} + \gamma_o \gamma_1 m_{12} - m_{21} - \gamma_s m_{22}}{\gamma_o m_{11} + \gamma_o \gamma_s m_{12} + m_{21} + \gamma_s m_{22}} \qquad (5)$$

$$t = \frac{2\gamma_o}{\gamma_o m_{11} + \gamma_o \gamma_s m_{12+} m_{21} + \gamma_s m_{22}} \qquad (6)$$

Reflectance spectra obtained from the created program is presented in figure 9 for double DLC layer coating. The thickness of the second layer changes from 60 to 200 nm. In thickness range 110-200 nm shows two minima with central peak between them. In both cases the minimum reflectance wavelength is shifted toward higher value by increase the thickness. The total coating thickness was kept above 150 nm to simplify the deposition process. As shown in the figure two antireflection behaviors have been recorded; single wavelength antireflection and broadband antireflection with two minima.
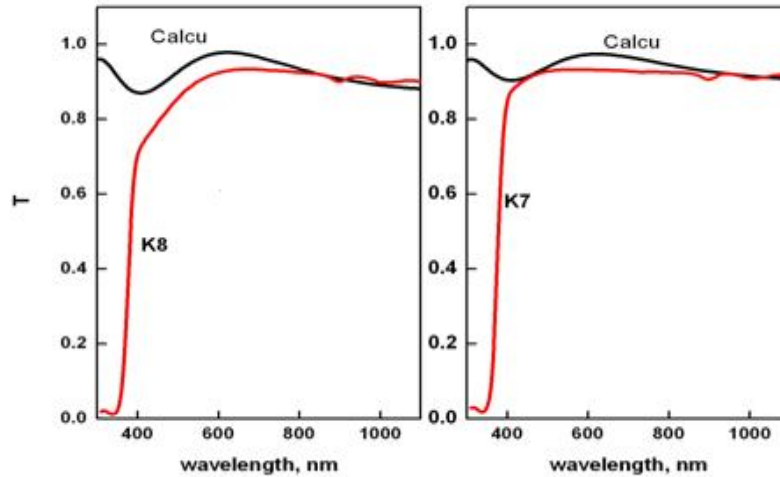

Figure 10: experimental and calculated transmission spectra of double DLC layer on PMMA substrate

Two double layer DLC films have been deposited on PMMA substrates where antireflection behavior has been recorded. The samples named K7 and K8 to be distinguished. Both samples show about 2% higher transmission with respect to uncoated PMMA glass in some spectral ranges. The obtained optical parameters from ellipsometery measurements have been loaded inside the program and represented together with experimental spectra in figure 10. Some difference between the experimental and calculated data is observed in the spectral range below 400nm due to the assumption, during
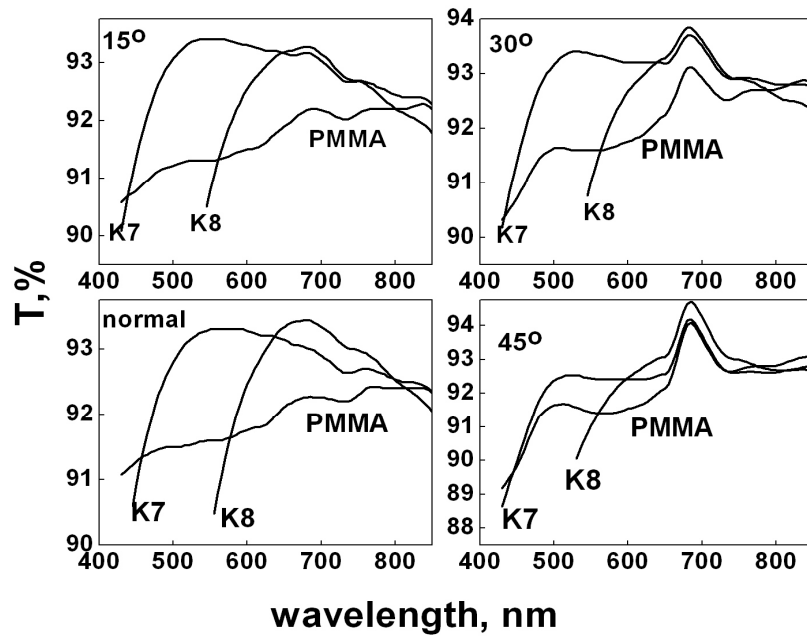
Figure 11: Transmission spectra of Tri-layer DLC/PMMA and bare PMMA substrate at different angle of incident

Table 3: Variation of AR-range and maximum transmission wavelength with the incident angle of DLC

	angle(^{o})	AR-range (nm)	λ_m (nm)
	0	456-805	565
	15	438-850	570
K7	30	433-800	530
	45	443-667	523
	0	575-805	685
	15	561-800	680
K8	30	563-776	680
	45	559-800	648

calculations, of the zero extinction coefficient of PMMA while the absorption in this range is very big.

The effect of incident angle on the performance of the antireflection coating has been also investigated used multi-incident angle transmission head attached to our spectrophotometer. Samples K8 and K7, were tested at different incident angles. As shown in figure 11 the performance is stable by increasing the incident angle up to 30°. But at incident angle of 45° the transmission suffers from a significant reduction but still higher

than uncoated PMMA glass. Table 3 shows the recorded variation in the optical performance where the AR-range refers to the wavelength range where the transmission of the coated samples is higher than the uncoated PMMA and λ_m is the wavelength corresponding to the maximum recorded transmission. Broad band antireflection of tri-DLC layer was also recorded for two other samples on PMMA.

On inorganic glass, we introduce coatings on the same deposition conditions of broad band antireflection with different features as recorded and represented in figure 12. The difference in transmission between uncoated and coated glass for sample K7 is less than 1% at some spectral ranges and only higher than uncoated glass in wavelength lower than 630nm.
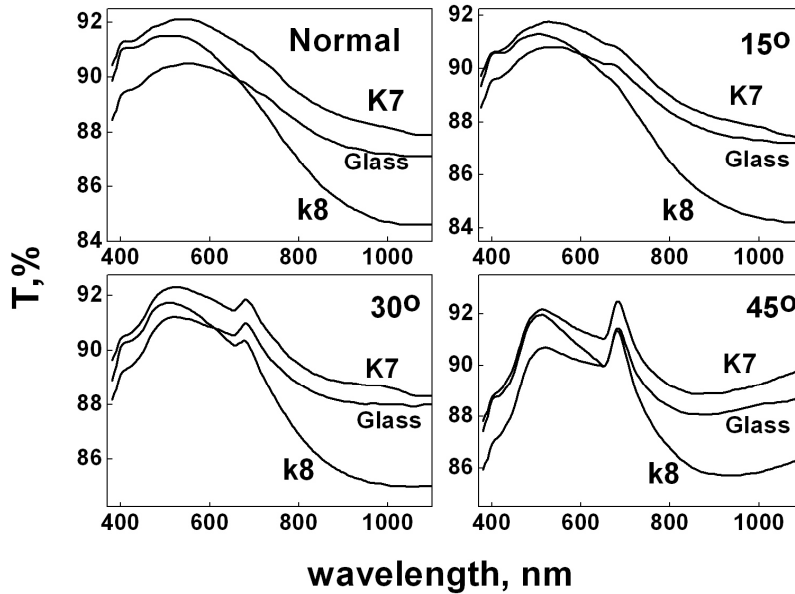

Figure 12: Transmission of double layer DLC-antireflection coating on inorganic glass

Single wavelength antireflection behavior is obtained by coating Si surface with single DLC layer deposited at high substrate voltage with respect to PMMA where all samples have been deposited at negative 150 volt. The antireflection layer refractive index and thickness were calculated using the well known equation of single layer antireflection layer;

$$n_1 d_1 = \frac{\lambda}{4} \qquad (7)$$

and

$$n_1 = \sqrt{n_0 n_s} \qquad\qquad (8)$$

where n_1 and d_1 is the refractive index and thickness of the layer, n_0 is the air refractive index and n_s is the refractive index of the substrate, listed in table 4. Figure 13 shows the single layer antireflection coating which gives single wavelength minimum reflection.
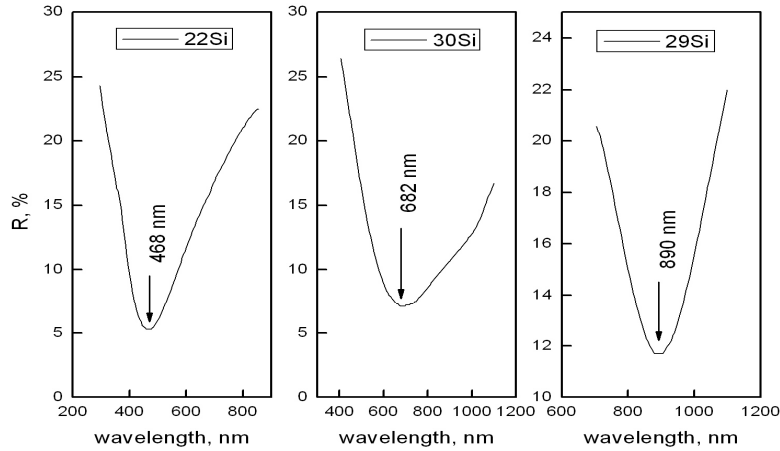

Figure 13: Single wavelength antireflection behavior of single DLC on Si substrate

Table 4: Refractive indexes, thickness, anode cathode voltage U ac, bias voltage Ub and current density

sample code	U_{ac} KV	I_{ac} mA	U_b	I_p mA/cm^2	N%	d_{ex} (nm)	n_{ex}	d_{th} (nm)	n_{th}
22	2.5	30	-200	0.2	10	90	2.2	55	2.12
30	2.6	35	-300	0.25	14	110	2	89	1.9
29	2.8	40	-400	0.3	10	125	2.5	123	1.8

At lower substrate voltage and higher temperature another antireflection behavior, broad band one, has been recorded by for single DLC-layer. Figure 14 shows the recorded reflection spectra of such samples. All the recorded reflection spectra are lower than bare Si reflection level as represented in figure 15. Such result could be attributed to a formation of refractive index gradient towered the substrate surface as a result of the deposition parameters. The recorded reflection spectra represented in figure 14 shows interference fringes which have been used together with the refractive index values obtained from ellipsometer to calculate the thickness from interference fringes. In table 5 the deposition conditions and the experimental and calculated data for the thickness measurement. Except

Table 5: Deposition parameters of Broad band antireflection single layer DLC on Si

sample	T(^{o}C)	U(kV)	U$_b$	time(min)	A$_p$(mA)	d(nm)	d$_i$(nm)	n
31	180	2.2	-150	15	50	167	389.766	2.7
32	180	2.5	-150	15	60	167	231.632	2.7
28	150	2.4	-150	15	55	152	200.053	2.3
27	150	2.1	-150	15	40	158	194.396	2
25	150	2.5	-150	15	60	156	140.294	1.9
26	150	2.6	-150	15	60	156	134.626	1.98

for sample 31, where big difference between the two thicknesses values is recorded, the other samples show a reasonable matching especially samples 25 and 26. For these sample an equivalent layer have been deposited on inorganic glass substrate in an attempt to prove that reduction in the reflection level not because the film material becomes absorptive. Sure the difference between Si and glass must be taken in consideration.
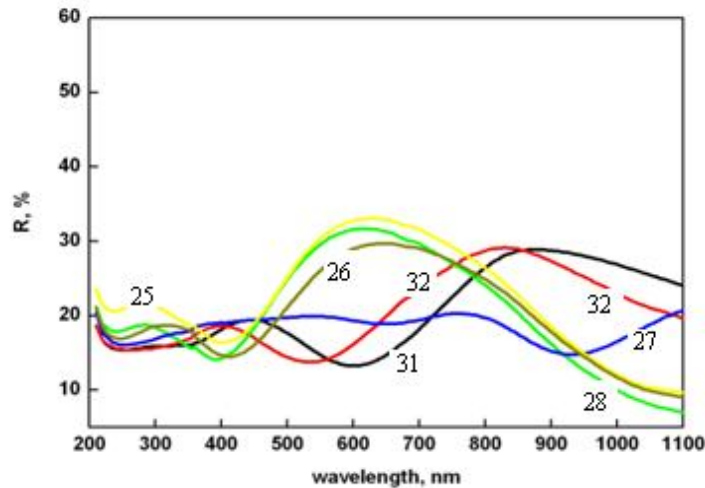

Figure 14: Reflection of single DLC layer on Si

Among a large number of attempts to get tri-layer antireflection behavior on Si surface only one sample gives the required behavior. Such results reflect the obstacles we get during deposition of multilayer films on the surface. Figure 15 presents reflection spectra of tri-layer DLC film deposited on Si substrate. The deposited layer was designed, according to the modeling, to have low refractive index for the top layer. As can be observed two minimum reflections were found at 460nm and 900nm matching will with the theoretical model. The overall reflection is less than 1% in the spectral range 400 – 1000nm

with two zero reflectance around 480 and 900 nm. The obtained behavior shows excellent matching with the calculated spectra. The upper layer refractive index was measured to be
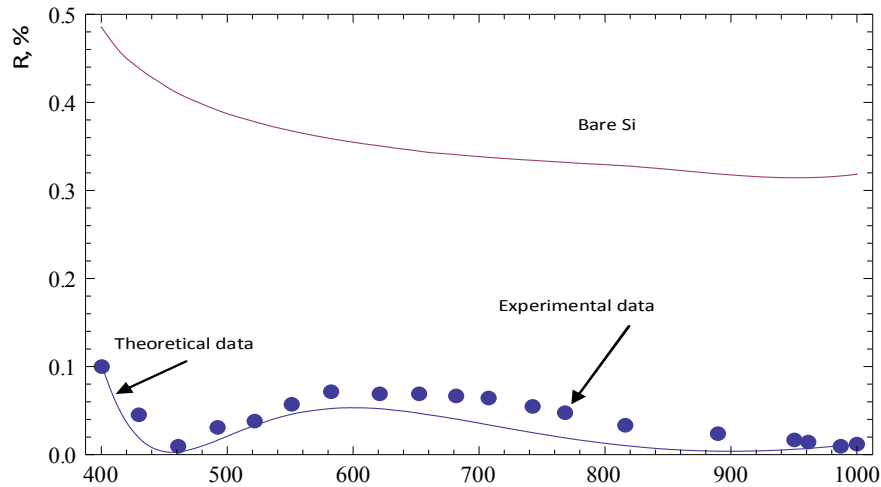

Figure 15: Spectral reflectance of triple layer ARC on Si

n_1=1,5, while the middle and last refractive index are n_2=1.8 and n_3=2.5 respectively. The corresponding thickness for these layers are d_1 = 50nm, d_2 = 30 nm and d_3 = 98nm.

COMMON CONCLUSIONS

1. PECVD technology has been modulated for deposit DLC films, with different transparency levels, on the surface of different types of substrates to work as a protective coating against destructive effects, which have a wide application area on Fresnel lenses, PV converters and other optoelectronic devices.

2. For the first time antireflection multi-layer DLC has been obtained on the surface of PMMA which have been based on theoretical calculations before deposition.

3. Single and multi-layer DLC protection coating against humidity has been tested for 1000 hours at humidity level of 60% and temperature of $80^{o}C$ which corresponding to the international testing standers.

4. Multi-layer DLC coating on PMMA shows a good protection level against particle erosion carried on a fast air where the coated PMMA transmission always higher than uncoated one.

5. Deposition of the same DLC multi-layer, i.e. at the same deposition conditions used for PMMA, on glass also results in an antireflection behavior with some differences according to the different used substrates.

6. By annealing of DLC layer deposited on glass substrate at high temperatures up to 500°C, the hydrogen content loss and conductivity increase are observed. At the same time the optical band gap shows reduction at 500°C. and also the particle size of the sp^2 structures is observed to increase by annealing.

7. Also by annealing, the thickness of the annealed films decreased by increasing the annealing temperatures. The reduction in the films thickness and the known increase of sp^2 fraction in the films result in the recorded behavior of the films transmission where these two factors are competing with each other.

8. Insertion of zinc oxide layer between the substrate and the deposited films, higher transmission spectra is obtained and better stability against annealing is observed.

9. Antireflection property of single and broad band wavelength single DLC layer have been deposited on silicon substrate.

10. Technological regimes have been elaborated for depositing DLC films of corresponding refractive indices which require obtaining antireflection multi-layer DLC with very low reflection level.

The principal results of the dissertation are published in the following scientific papers:

1. ***A.Abdul-Nagy***, "Effect of deposition parameters on the refractive index of DLC films on PMMA", Bulletin of state engineering university of Armenia (polytechnic), Yerevan 2010, Part 2, no 1, p 50-52.

2. Zh. Panosyan, A. Gharibyan, Ye. Yengibaryan, ***A. Abdul-Nagy***, Preparation of new type of Antireflection Coatings on the Surface of Si PV Cells, Procedings of EU PVSEC, Spain, pp. 567-569 (2010)

3. *A. Abdul-Nagy*, D.B. Hayrapetyan, Zh. Panosyan, Structural changes in diamond like carbon films upon thermal treatment. Bulletin SEUA, Part 3, N 1, pp. 38-41 (2011)

4. *A. Abdul-Nagy*, D.B. Hayrapetyan, Zh. Panosyan, Annealing effects on the optical and structural properties of DLC films. Journal of Material Science and Engineering B, V. 2 (4), pp. 298-299 (2012)

Ա Մ Փ Ո Փ Ո Ւ Մ

ԱՐԵՎԱՅԻՆ ՖՈՏՈՎՈԼՏԱՅԻՆ ԿԵՐՊԱՓՈԽԻՉՆԵՐԻ ՄԱԿԵՐԵՎՈՒՅԹՆԵՐԻ ԼՈՒՍԱՊԱՅԾԱՌԱՑՈՒՄԸ ԵՎ ՊԱՇՏՊԱՆՈՒԹՅՈՒՆԸ ՔԱՅՔԱՅՈՂ ԱԶԴԵՑՈՒԹՅՈՒՆՆԵՐԻՑ

Ահմեդ Աբդել Նագի Աբուդ Մուստաֆա

Ներկայացվող աշխատանքի հիմնական եզրակացությունը կարող են ներկայացվել հետևյալ կերպ.

- Գլորոշային պլազմաքիմիական աճեցման տեխնոլոգիան մոդիֆիկացվել է տարբեր թափանցելիություններով ԱԱԹ-ներ աճեցնելու համար, որոնք աշխատում են որպես պաշտպանիչ թաղանթներ քայքայող ազդեցությունների նկատմամբ և որոնք ունեն լայն կիրառության ոլորտ ֆրենելային ոսպնյակների մակերնույթներում, ՖՎ փոխակերպիչներում և այլ օպտոէլեկտրոնիկական սարքերում:

- Առաջին անգամ ՊՄՄԱ-ի մակերնույթին ստացվել է լուսապայծառացնող ԱԱԹ, որը հիմնված է նախշան աճեցումը տեսական հաշվարկների վրա:

- Միաշերտ և բազմաշերտ ԱԱԹ պաշտպանիչ շերտը փորձարկվել է 1000 ժամ 60% խոնավության և 80°C ջերմաստիճանի պայմաններում, որը համապատասխանում է միջազգային ստանդարտներին:

- ՊՄՄԱ-ի մակերնույթին ԱԱԹ ծածկույթը ցուցաբերում է լավ պաշտպանության աստիճան արագ օղով իրականացվող մասնիկների էրոզիայի նկատմամբ, որտեղ ՊՄՄԱ-ի թափանցելիությունը միշտ ավելի բարձր է քան չծածկվածինը:

- Միևնույն բազմաշերտ ԱԱԹ-ի աճեցումը ՊՄՄԱ-ի և ապակու համար օգտագործվող միևնույն աճեցման պայմաններում հանգեցնում է լուսապայծառացնող վարքի որոշակի տարբերությունների՝ համաձայն օգտագործվող տարբեր հարթակների:

- Ապակու վրա աճեցված ԱԱԹ-ի շերտը մինչև 500°C ջերմամշակելով դիտվում է ջրածնի կորուստ և հաղորդականության աճ: Օպտիկական արգելված գոտին ցուցաբերում է նվազում 500°C ջերմաստիճանի դեպքում: Միևնույն ժամանակ ջերմամշակելով դիտվել է sp^2 կառուցվածքների մասնիկների չափերի աճ:

- Ջերմամշակման ժամանակ կախված ջերմաստիճանի աճից նվազել է ջերմամշակվող թաղանթների հաստությունը:

- Թաղանթների հաստության նվազեցումը և թաղանթներում sp^2 կառուցվածքի չափաբաժնի մեծացումը բերում է թաղանթների թափանցելիության չափված վարքի, որտեղ այդ երկու ազդեցությունները մրցակցում են իրար հետ:

- Աճեցվող թաղանթի և հարթակի միջև ցինկի օքսիդի ներմուծմամբ ստացվել է ավելի մեծ թափանցելիություն և դիտվել է ավելի մեծ կայունություն ջերմամշակման հանդեպ:

- Սիլիցիումային տակդիրի վրա աճեցվել են հակաանդրադարձնող ԱԱԹ թաղանթներ ինչպես ալիքի երկարությունների լայն, այնպես էլ նեղ տիրույթներում:

- Համապատասխան բեկման ցուցիչներով ԱԱԹ-ներ աճեցնելու համար մշակվել են տեխնոլոգիական ռեժիմներ, որը պահանջվում է ցածր անդրադարձման գործակիցներ ունեցող բազմաշերտ ԱԱԹ ստանալու համար:

З А К Л Ю Ч Е Н И Е

АНТИОТРАЖЕНИЕ И ЗАЩИТА ПОВЕРХНОСТЕЙ СОЛНЕЧНЫХ ФОТОВОЛЬТАИЧЕСКИХ ПРЕОБРАЗОВАТЕЛЕЙ ОТ РАЗРУШИТЕЛЬНЫХ ВОЗДЕЙСТВИЙ

Ахмед Абдел Наги Абуд Мустафа

Основные выводы работы могут быть представлены следующим образом:

- Паровая плазмохимическая технология была модифицирована для выращивания алмазоподобных углеродных пленок с различными пропускающими способностями, которые являются защитными пленками против разрушительных влияний и которые имеют широкие области применения на поверхностях френелевых линз, солнечных батарей и в других оптоэлектрических приборах.

- Впервые, на основе предварительных теоретических расчетов, на поверхности ПММА получены антиотражающие АУП.

- Однослойные и многослойные защитные АУП были испытаны при условиях: 1000 часов при влажности 60% и при температуре 80°С, которые соответствуют международным стандартам.

- АУП покрытия на поверхности ПММА проявляют хорошие защитные свойства против эрозии песочной струи, где пропускание ПММА с АУП было всегда больше, чем без покрытий.

- Выращивание одинаковых АУП на поверхности ПММА и стекла при одинаковых условиях приводит к некоторому различию в поведениях антиотражения, в зависимости от подложки.

- Наблюдались потери водорода и рост проводимости слоя АУП при термической обработке до 500°С. В то же время оптическая запрещенная

зона проявляет уменьшение при температуре 500ºC. Одновременно с термической обработкой наблюдается увеличение размеров структуры sp^2.

- С увеличением температуры термической обработки наблюдается уменьшение толщины пленок, которые подвергаются термической обработке.

- Уменьшение толщины пленки и увеличение части структуры sp^2 в пленках приводит к измеряемому поведению пропускания, где эти два эффекта конкурируют друг с другом.

- С внедрением оксида цинка между выращенными пленками и подложкой получались большие значения для пропускания и большая стабильность относительно термической обработки.

- На подложке из кремния выращивались антиотражающие АУП как для широких, так и для узких областей длин волн.

- .Для выращивания АУП с соответствующими коэффициентами преломления разработаны технологические режимы, которые требуются для получения многослойных АУП с низкими уровнями отражения.