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Application of Nanostructured Materials in Lasers and Display

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Abstract- It is well known that new nanoscale materials useful for laser, medicine, display, etc. Applications have been carefully studied last decade. In the current paper the search for the effective nanostructured materials has been revealed in two directions: to optimize the mechanical and laser features of the inorganic systems and to improve the surface properties of the organics polaroid films with nanoobjects. It has been testified that the surface mechanical properties of the inorganic materials via nanotubes treatment process can be drastically improved. For example, the surface mechanical hardness of the UV and IR range "soft" inorganic materials can be increased up to 2-10 times under the conditions of oriented nanotubes placement. It has been obtained that the surface mechanical hardness of the organic polaroid films can be increased saving the spectral features.

I. INTRODUCTION

At present time both the fullerenes and carbon nanotubes as well as the quantum dots can be considered as the good candidates to improve the structural, mechanical, spectral, photoconductive and photo refractive features of the different inorganic and organic materials operated in the UV, VIS and IR spectral ranges [1-3]. These nanoobjects have unique energy levels, high value of electron affinity energy, and strong hardness of their C—C bonds. These nanoobjects influence the balk and surface properties of the optical materials. A special accent has been given to carbon nanotubes because the carbon nanotubes imaginary part of the dielectric constant is close to zero in the near and middle infrared spectral range that permits to save or improve the spectral properties of the matrix materials after nanoobjects treatment.

In the current paper some way to improve or optimize the mechanical, spectral and polarization properties of the inorganic and organic materials via nanoobjects treatment have been shown.

II. EXPERIMENTAL CONDITIONS

Different materials of the UV, VIS and IR spectral range, such as model system of MgF_2, have been chosen as inorganic matrixes. The single- and multiwall carbon nanotubes have been used as promising nanoobjects. These nanotubes have been placed on the material surface using IR CO_2-laser with *p*-polarized irradiation at wavelength of 10.6 μm and power of 30 W. Moreover, when nanotubes have been placed at the materials surface, the electric field close to 100-200 $V \times cm^{-1}$ has been applied in order to orient the nanotubes during the deposition. It should be mentioned, that some structures have been additionally treated with surface electromagnetic waves in order to obtain homogeneous surface and to decrease the roughness. The spectral characteristics of the nanotubes-treated materials have been tested using Perkin-Elmer Lambda 9 instrument. Surface mechanical hardness has been revealed using the CM-55 instrument, when the test has been made applying the silicon glass K8 as etalon. This etalon permits to obtain abrasive hardness close to zero at 3000 cycle with forces on indenter close to 100 g.

Iodine-polyvinyl alcohol films coated with carbon nanotubes has been chosen as matrix systems to develop and study new thin film polarizers with high relation between transmission level of parallel and orthogonal part of the electromagnetic wave.

III. RESULT AND DISCUSSION

It is the complicated complex task to modify the optical materials operated as output window in the UV lamp and laser resonators, as polarizer in the telecommunications, display and medicine systems. Many scientific and technological groups have made some steps to reveal the improved characteristics of optical materials to obtain good mechanical hardness, laser strength, and wide spectral range. Our own steps in this direction have been firstly shown in paper [4]. In order to reveal the efficient nanoobjects influence on the materials surface it is necessary to choose the model system.

It should be noticed that magnesium fluoride has been considered as good model system. For this structure the spectral characteristics, atomic force microscopy data, measurements to estimate the hardness and roughness have been found in good connection. The main aspect has been made on interaction between nanotubes (their C—C bonds) placed at the MgF_2 surface via covalent bonding [5]. Table 1 presents the results of surface mechanical hardness of MgF_2 structure after nanotubes placement; Table 2 shows the decrease of MgF_2 roughness.

Table 1

Structures	Abrasive surface hardness (number of cycles before visualization of the powder from surface)	Remarks
Pure organic glasses	200-400 cycles	CM-55 instrument has been used. The test has been made using silicon glass K8 as etalon. This etalon permits to obtain abrasive hardness close to zero at 3000 cycle with forces on indenter close to 100 g.
organic glasses+nanotubes	1500-3000 cycles	
MgF_2	1000 cycles	
MgF_2+nanotubes	3000 cycles	
MgF_2+vertically oriented nanotubes	more than zero hardness	

Table 2

Parameters	Materials	Roughness before nano treatment	Roughness after nano treatment	Remarks
R_a	MgF_2	6.2	2.7	The area of 5000×5000 nm has been studied via AFM method
S_q	MgF_2	8.4	3.6	The area of 5000×5000 nm has been studied via AFM method

One can see from Table 1 that the nanostructured samples reveal the better surface hardness. For example, after nanotubes placement at the MgF_2 surface, the surface hardness has been better up to 3 times in comparison with sample without nanoobjects. It should be noticed that for the organic glasses this parameter can be increased up to one order of magnitude. Moreover, the roughness of the MgF_2 covered with nanotubes and treated with surface electromagnetic waves has been improved essentially. Really, R_a and S_q roughness characteristics have been decreased up to three times. One can see from Table 2 that the deposition of the oriented nanotubes on the materials surface and surface electromagnetic waves treatment decreases the roughness dramatically. Indeed this process is connected with the nature of the pure materials; it depends on the crystalline axis and the defects in the volume of the materials.

In order to explain observed increase of mechanical hardness we compared the forces and energy to bend and to remove the nanotubes, which can be connected with magnesium fluoride via covalent bond MgC. Thus, the full energy responsible for destruction of the surface with nanotubes should be equal to the sum of W_{rem} (energy to remove the layer of nanotubes) and of W_{destr}

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(energy to destroy the magnesium fluoride surface). Due to the experimental fact that nanotubes covering increases drastically the surface hardness of MgF_2 [5], the values of W_{rem} and W_{destr} can be close to each other. Under the conditions of the applied forces parallel to the surface, in order to remove the nanotubes from MgF_2 surface, firstly, one should bend these nanotubes, and secondly, remove these nanotubes. In this case W_{rem} are consisted of W_{elast} (elasticity energy of nanotube) plus W_{MgC} (energy to destroy the covalent MgC binding). The energy of elasticity can be estimated as follow:

$$W_{elast} = F^2_{rem} \times L^3/6E \times I \qquad (1)$$

where E=1.5 TP [3,6] is the modulus of elasticity, $I = \pi \cdot r^3 \cdot \Delta r$ – is the inertion moment of the nanotube cross section at its wall thickness Δr=0.34 nm, r=4 nm; and L=50 nm is the nanotube length. The force F_{rem} can be estimated as follows:

$$F_{rem} = F_{MgC} \times 2r/L, \qquad (2)$$

where F_{MgC} is close to 2 nN.

Based on our calculation we should say that in order to broke the relief with nanotubes, we should firstly bend the nanotubes with energy that is 5 times more than the one, which can be applied to simply remove the nanotubes from surface after the destroying MgC binding. This fact is in good connection with the experimental results.

This calculation can be used to explain the results of dramatically increased mechanical surface hardness of the MgF_2 covered with nanotubes. The experimental data testified that the surface mechanical hardness of MgF_2 materials covered with nanotubes can be compared with the hardness of etalon based on silicon glass K8.

As a result of this process, the refractive index can be modified which explains the increase in transparency in the UV. Moreover, the spectral range saving or increasing in the IR range can be explained based on the fact that the imaginary part of dielectric constant of carbon nanotubes, which is responsible for the absorption of the nanoobjects, is minimum (close to zero) in the IR range. The UV-VIS and near IR-spectra of the magnesium fluoride is shown in Fig. 1.

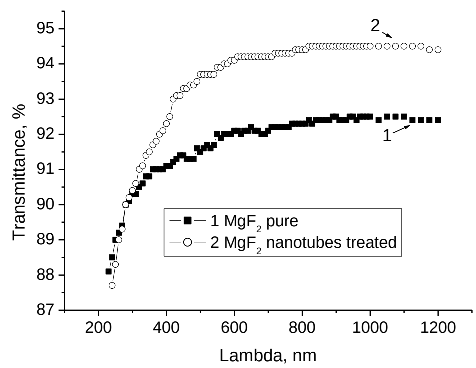

Fig.1. UV-VIS-near IR spectra of MgF_2 before (curve 1) and after single wall nanotubes deposition (curve 2). The thickness of the sample close to 2 mm.

It should be noticed that the drastic increase in the transparency at wavelength of 126 nm has been observed. Really, for the 5 units of MgF_2 sample, the transparency *T* has been changed after nanotubes deposition as follows: sample №1. *T*= 61.8% → *T*=66.6%l №2. *T*=63.6% → *T*=69%; №3. *T*=54.5% → *T*=65.8%; №4. *T*=58.1% → *T*=67.5%; №5. *T*=50.9% →*T*=65%.

Regarding polarizers based on iodine-polyvinyl alcohol thin films, one can say that we have obtain increase of transmission for parallel light component and good relation between transmittance of parallel and orthogonal light component. The results are shown in Fig.2.

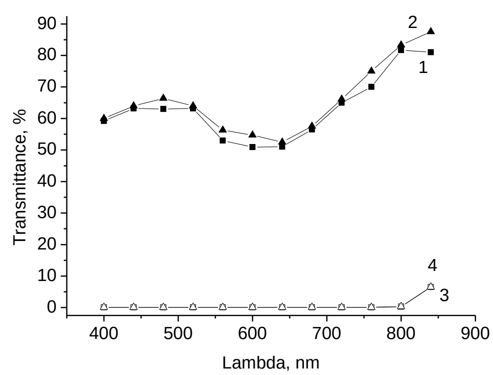

Fig.2. Dependence of transmittance on wave length for parallel (curve 1 and 2) and orthogonal (curve 3 and 4) components of electromagnetic wave. Curves 1 and 3 correspond to non-treated polarizer films; curves 2 and 4 connected with polarizer films covered by carbon nanotubes.

Analyzing results, it should be notices that the transmittance of the parallel component of the electromagnetic wave can be increased up to 2-5% in the VIS spectral range. It can be explained via small value of refractive index of nanotubes that is close to 1.1. This process decreases the Fresnel loses from one and second polarizer film surfaces. Really, the refractive index of the polyvinyl matrix structure is located in the range of 1.49-1.53. Let us to choose the middle value close to 1.5. The Fresnel loses from one pure surface can be calculated as follow:

$(n-1)^2/(n+1)^2=(1.5-1)^2/(1.5+1)^2=0.04$, thus 4% from one surface and approximately ~ 8% from two pure surfaces.

After nanotubes placement on the films surfaces the Fresnel loses can be:
$(n-1)^2/(n+1)^2=(1.1-1)^2/(1.1+1)^2=0.00226$, thus 0.2% from one surface and approximately ~0.4% from two nanotubes-treated surfaces.

Thus, it permits to develop the effective nanotubes coating with eliminated interface between matrix structure and coating with effective value of refractive index.

It should be mentioned that saving or improving the spectral range, the mechanical hardness of the polaroid films increases that provokes to use nanotreatment process instead famous lamination one. That can be useful in spatial light modulator technique and to optimize the display elements [7] operated in the crossed polarizers.

IV. CONCLUTION

In conclusion, the influence of the nanoobjects based on carbon nanotubes on mechanical, spectral and polarization features of some model optical materials have been shown The dramatic increase of surface mechanical hardness has been observed via nanotubes placement under condition of spectral range saving or improvement. As the result of this investigation, new area of applications of the nanoobjects-treated materials can be found in the optoelectronics and laser optics, for example, for development of transparent UV and IR window, for gas storage and solar energy accumulation, as well as in telecommunications systems and in display and medicine.

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