Analysis of Structural and Optical Features of Nanosized ZnO Films by Modulation Polarimetry Methods

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Introduction

The stimulated interest in the search for new nanomaterials, whose properties are determined by their morphology, leads to their wide application in various practical fields. There are many methods for their detection, which are listed in detail in [1]. However, there is no information on the use of modulation polarimetry (MP), which has demonstrated significant information content on examples of various materials at the nanoscale [2]. Among the available diagnostic methods, surface plasmon resonance (SPR) is a unique phenomenon that underlies the most sensitive methods used to detect changes in the dielectric characteristics of a medium. The use of polarized light modulation to detect SPR in oxide materials with nanograins becomes a logical and effective approach. We have previously studied nanocluster films of tin dioxide [3]. The use of modulation polarimetry turned out to be effective for determining some of the optical constants of the material and elucidating its internal structure. Therefore, our research goal includes two aspects: firstly, to test the ability of the MT to detect the optical properties of nanosized ZnO films with metallic and dielectric characteristics and to interpret their topological properties, taking into account the experience and results of studies in [2]...

Methods

Film samples for research were obtained by thermal decomposition of a fairly simple zinc-containing organic compound—zinc acetate.

Samples were obtained using an aqueous solution of zinc acetate (Zn(O2CCH3)2) with a concentration of 0.25 mol. The glass substrates were immersed in an aqueous solution of zinc acetate, then dried at room temperature in air until the moisture evaporated, and then immersed in the solution again. After that, the resulting film samples were annealed in air at a temperature of 310°C for 20–60 minutes. During this time, zinc acetate in the air decomposed into zinc oxide. Thin transparent films formed on the glass surface..

The use of the modulation polarimetry method in the variant of internal reflection at the film-environment interface, in particular, the Kretschmann geometry, made it possible to obtain detailed information about the optical properties and structural features of the films ZnO. The theoretical basis and method of the experiment for measuring internal reflection is described in detail in [4]. In this technique, sample is successively illuminated by constant intensity s- and p-polarized light. Differential signal, which is the difference between the squared reflectance of s- (R) and p-polarizations (R), □R=R -R , is then recorded. Using the system shown in Fig.1 R s, R p and □R are measured simultaneously.

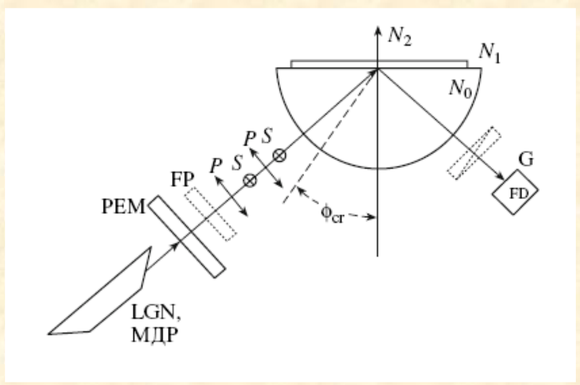

Figure 1 Experimental setup. LGN-Helium-Neon Laser, PEM- photoelastic polarization modulator, FP- phase plate, p,s –linear polarizators, azimuths are parallel and perpendicular to the plane of incidence, G – Glann's prism, FD – photo detector, ϕ – critical angle for the total internal reflection, N , N and N - refraction indices of glass, films and air, respectively.

A 1/3 m monochromator associated with a halogen lamp is used as an unpolarized light source, which is replaced by a Helium-Neon laser whenever a linear polarize light at a fixed wavelength is required. The REM polarization modulator is a dynamic phase plate, the functioning of which can be controlled in two modes. In both cases, by rotating the modulator around the optical axis of the measuring device, its position is selected, in which the polarization azimuths of the outgoing radiation are alternately parallel and perpendicular to the plane of incidence (p- and s-polarization, respectively). After interaction with the half-cylinder and the resonance-sensitive film of ZnO on its working surface, the radiation was directed to the FD photodetector (Si or Ge photodiode), which, after absorbing the radiation, generates a signal with a variable component proportional to the difference in the reflection coefficients of the detected radiation of p- and s-polarizations.

Results

Figure 2 shows the dependencies of the reflection coefficients R for s-polarized radiation of the group A sample and the polarization difference ρ on the angle of incidence of light Θ for the group A sample (Figure3). It can be seen that the parameter ρ = Rs-Rp is the result of a physical subtraction and is devoid of errors that accompany this operation in a mathematical operation.I.

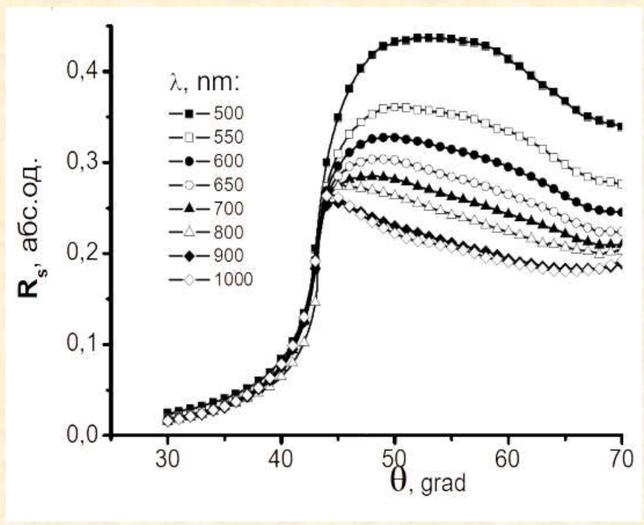

Fig. 2. Dependencies of reflection coefficients R s for s-polarized radiation for a zinc oxide film.

It was found that the experimental characteristics are characterized by the presence of plasmon-polariton resonance (PPR) not only for p-polarized radiation, which is characteristic of homogeneous solid films, but also for s-polarized radiation. The last circumstance reflects the cluster structure of the obtained films. The experimental results are in good agreement with the AFM phase topology of the surface of the samples. This model is based on the real fact that in the case of clusters isolated by a dielectric, the s-polarized wave also has a field component oriented in the general case along the normal to the surface of the cluster.

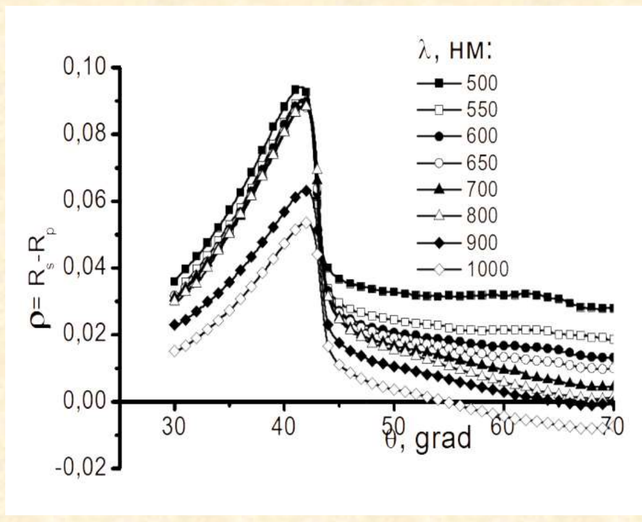

Fig. 3. Polarization difference ρ = Rs-Rp from the angle of incidence of light □ for a zinc oxide film.

Conclusion

The studies performed have shown that the obtained ZnO thin films can be effectively used as optical plasmonic sensors. An analysis of the spectral and angular dependences of the Stokes vector components confirms the presence of a cluster structure in ZnO films and resonant dipole interaction with an electromagnetic wave. As it turned out, in isolated dielectric clusters, the field is oriented along the normal to the cluster surface. The cluster structure of ZnO films detected by modulation polarimetry is confirmed by the results of atomic force microscopy (AFM).

Particular attention should be paid to the fact that the studied films exhibit a dipole resonant interaction independent on the light incidence angle, which indicates the versatility of the method and its potential for use in various areas of electronics and photonics.

The results obtained indicate the possibilities of using the studied nanosized ZnO films in various practical applications, in particular, in optical sensors. The use of polarization modulation can make it possible to create sensitive elements with high resolution and sensitivity to properties' changes.

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