The influence of the surface density of oriented nickel networks on the conducting electrode's optical transparency

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Abstract. This study is part of the work on the creation of a transparent conductive coating based on oriented nanonetwork and submicron nickel fibres. It is devoted to finding the optimal values of electrical conductivity and optical transparency of the developed coating. In this work, we study the transmission spectra of oriented nickel networks on a glass substrate in the UV, visible and near-IR regions at different amounts of deposited metal. An exciting feature of the coating was discovered: in the range of 950 nm and above, there is a "bend" of the transmission spectrum downward. This bend (increased absorption of radiation in the near-IR region) is observed only in the presence of nickel nanonetwork and is not typical for a pure submicron network.

1. Introduction

The use of conductive optically transparent coatings has expanded significantly thanks to the development of optoelectronic devices operating on transparent electrodes, such as touch displays and sensors, smart windows and solar panels. The creation of a conductive transparent coating is one of the most urgent problems of modern science, devoted to nanomaterials, composite materials, solar energy, optoelectronics, etc. [1-2]. Indium Tin Oxide (ITO) is now widely used as the primary material in this role because it has low surface resistance and high optical transmittance. ITO is an electrically conductive coating on a glass surface. However, the amount of indium in nature is limited, and the production of ITO is a complex and expensive technological process [2-4]. In this work, we present part of the work devoted to developing and improving an alternative to indium tin oxide (ITO). There are many known methods for producing the transparent conductive coating (TCC). For this, transparent conductive oxides [5-9], conducting polymers [10-13], graphene layers [14-17], carbon nanotubes and nanostructures [18-20], metal nanowires and networks are used. [21-24]. Metals are excellent electrical conductors. Recently, nanowires made of silver, gold and copper are very actively used to create TCC [25-28]. The most relevant direction is the use of structured systems of metal wires: networks and meshes [25-26].

In [29], we developed a technique for creating a transparent electrode based on oriented nickel networks. The basis of the technique is precipitation from the liquid phase by chemical reduction of the nickel salt [30-31]. The forming and adjustment of the transparent conductive layer is carried out
using a micellar template of a surfactant (CTAB) and a magnetic field. We used submicron nickel fibres to implement unity to an array of individual-oriented nickel nano-networks. Oriented nickel nanowire networks and a framework of submicron nickel fibres create an electrically conductive and transparent coating.

Within this study's framework, we investigate the effect of the amount of used nickel on the transmission spectra of the developed coating on a glass substrate in the UV, visible and near-IR regions. The surface density of the metal deposition (mass referred to the substrate's surface area) was taken as the value that determines the amount of nickel used.

2. Results and discussion
In this work, samples of the developed coating on glass with different amounts of metallic nickel were obtained: $0.6 \cdot 10^{-6} - 311 \cdot 10^{-6}$ g / cm$^2$. The smallest value in this range corresponds to a coating consisting only of nickel nanowires. Microscopy images of the coating on a glass surface with different deposition densities of nickel are shown in figure 1.

![Microscopy images of nickel network coatings on the surface of a glass substrate with different deposition densities: 0.6 μg / cm$^2$ (A), 62 μg / cm$^2$ (B).](image)

All obtained samples were examined on a spectrophotometer in the wavelength range of 290-1100 nm. SPECORD 50 (Analytik Jena) was used for all measurements. The averaged transmission spectra for some deposition densities of nickel networks are shown in figure 2. As expected, with an increase in the density of nickel deposition on the glass surface, a monotonic decrease in the transparency coefficient is observed over the entire optical range.

In the research, we discovered an interesting feature of the coating: in the range of 950 nm and above, there is a "bend" of the transmission spectrum downward. This bend (increased absorption of radiation in the near-IR region) is observed only in the presence of nickel nanonet and is not typical for a pure submicron network (figure 3).

This phenomenon may be due to the peculiarities of the transmission of radiation through subwavelength apertures. Bethe's criterion shows that when the aperture size is less than half the wavelength of the radiation passing through it, its strong attenuation is observed already in the near field.
Figure 2. Transmission spectra of oriented nickel networks on a glass substrate in the UV, visible, and near-IR regions at different amounts of deposited metal.

For our case, this means that the material's absorption coefficient increases when the critical value of the wavelength is reached. It should be noted that such an effect is possible only for regular structures such that the scatter of transverse dimensions is small. We believe that the discovered effect may be of interest for applications in the development of nanosensors and near-infrared sensors.

Figure 3. Transmission spectra of the bare glass substrate (red line) and the oriented nickel networks on a glass substrate in the UV, visible, and near-IR regions (the surface density of the metal deposition is 62 mkg/cm²); the dashed line corresponds to the coating without the use of a nanonetwork.
The work studies transmission spectra of oriented nickel networks on a glass substrate in the UV, visible and near-IR regions at different amounts of deposited metal. The results demonstrate a monotonic decrease in the transparency coefficient at a wavelength of 550 nm with an increase in the metal deposition density. An exciting feature of the coating was discovered: in the range of 950 nm and above, there is a "bend" of the transmission spectrum downward. This bend (increased absorption of radiation in the near-IR region) is observed only in the presence of nickel nanonetwork and is not typical for a pure submicron network.

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