Electrical properties of p-$CuCoO_2$/n-Si heterojunction

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Introduction

Delafossite ($CuCoO_2$) oxides have been testified to be used in the fields of translucent conductive oxides (TCO), solar cell devices, photocatalysis, and other optoelectronic devices as p-type semi-conductive materials [1]. The development of p-type TCO will give us possibilities that cannot be used with n-type materials alone, such as transparent *p-n* heterojunction, diodes, transistors [2]. Therefore, it was of interest to fabricate an p-$CuCoO_2$/n-Si heterostructure. As well as the deposition of thin $CuCoO_2$ films on *n*-Si crystalline substrates, made by the method of RF magnetron sputtering.

Experimental technique

Thin $CuCoO_2$ films (~ 200 nm thick) were obtained by RF magnetron sputtering on glass substrates (for optical studies) and on plane-parallel n-Si plates (for obtaining heterostructures). A stoichiometric mixture of CuO and CoO_2 was used to make the target. Substrate temperature $t°_S$ = 380 °C, spraying was carried out in two stages t_1 = 15 min, P_1 = 180 W, t_2 = 15 min, P_2 = 200 W (t - spraying time, P - magnetron power). Studies of the optical transmission spectrum of thin $CuCoO_2$ films were carried out on an SF-2000 spectrophotometer in the wavelength range of incident radiation λ = 0.2–1.1 μm. The surface resistance of $CuCoO_2$ films was studied using the four-probe method. At a film thickness of 200 nm, its resistivity was ρ = 20 Ω·cm. The fabrication of ohmic contacts to $CuCoO_2$ films and *n*-Si substrates was performed using a silver-based conductive paste.

I-V-characteristics of p-$CuCoO_2$/n-Si heterostructures were measured using Arduino-based hardware and software, Agilent 34410A digital multimeter and Siglent SPD3303X programmable power supply, which were controlled by a personal computer using software created by the authors in the LabView environment. Light *I-V*-characteristics were measured under integrated light under standard lighting conditions close to AM1.5, and with lighting power density of 80 mW/cm^2.

Experimental results and their discussion

The dependence of the transmittance for $CuCoO_2$ thin films applied by high-frequency magnetron sputtering on the wavelength range λ = 0.5-1.1 μm takes the value of T ~ 16 %. In the region of wavelengths λ < 0.4 μm, a sharp decrease in the transmission coefficient is observed due to the intrinsic absorption edge of $CuCoO_2$ films.

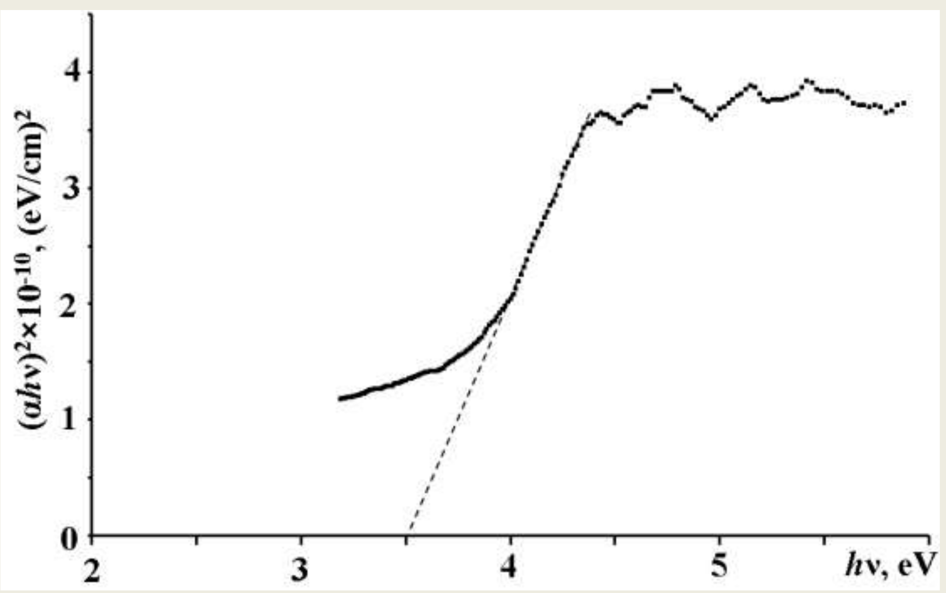

Fig. 1. Spectral dependence of the absorption coefficient $(\alpha h\nu)^2$ = f($h\nu$) of $CuCoO_2$ films.

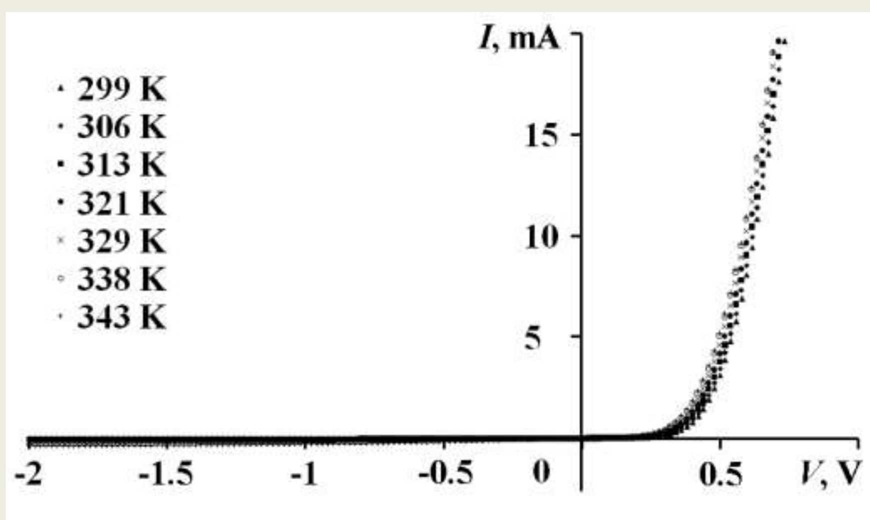

Fig. 2. *I-V*-characteristics of the heterostructure of p-$CuCoO_2$/n-Si in the temperature range from 293 K to 343 K.

The method of independent measurement of transmission and reflection coefficients was used to determine the absorption coefficient of $CuCoO_2$ thin films. The light reflection coefficient R in the studied region of the spectrum for films $CuCoO_2$ is $R \approx 20\%$.

In Fig. 1 shows the spectral dependence $(\alpha h\nu)^2 = f(h\nu)$ for the $CuCoO_2$ film. The presence of a rectilinear region near the region of intrinsic absorption edge on the obtained dependences confirms the fact that the process of absorption of light photons takes place by means of direct optical transitions. For the studied films, the optical width of the band gap was determined by extrapolating the rectilinear sections to the energy axis. As a result, we obtained the following value of E_g = 3.5 eV for $CuCoO_2$ thin films.

From the *I-V*-characteristics of the p-$CuCoO_2$/n-Si heterostructures presented in Fig. 2, it is seen that in the temperature range T = 299 - 343 K, these heterostructures have rectifying properties. The current rectification ratio is determined at T = 294 K and voltages $|V|$ = 0.7 V is equal to RR ~ 10^3.

The height of the potential barrier $q\varphi_k$, which corresponds to a sharp increase in direct current, was estimated by extrapolation of linear sections of *I-V*-characteristics in the region of forward biases to the voltage axis. At room temperature, the height of the potential barrier of the p-$CuCoO_2$/n-Si heterojunction is equal to $q\varphi_k$ ~ 0.5 eV. With increasing temperature from T = 299 K to T = 343 K there is a linear decrease in energy $q\varphi_k$ from 0.54 eV to 0.4 eV. The temperature coefficient of change of the height of the potential barrier and its height at 0 K were determined, which are equal to $d(q\varphi_k)/dT = -1.54\cdot10^{-3}$ eV/K and $q\varphi_k(0\text{ K})$ = 1 eV respectively.

To determine the mechanisms of current transfer through the p-$CuCoO_2$/n-Si heterojunction at forward biases, the *I-V*-characteristics were constructed in the coordinates ln$I$ = $f(V)$ (Fig. 3). In Fig. 3 there are two rectilinear sections with different angles of inclination to the voltage axis. According to the tangents of these angles, the non-ideality factor of heterojunctions n were determined.

At small forward biases of 0.05 V < V < 0.4 V, the slope to the voltage axis of linear dependences ln$I$ = $f(V)$ is characterized by the value of the non-ideality factor $n \approx$ 2.2-2.5, the generation-recombination current transfer mechanism predominates. With increasing forward bias to voltage V > 0.4 V, the non-ideality factor $n \approx$ 3.4-4.7, the tunneling mechanism of current transfer prevails. Weak temperature dependence of the non-ideality factor is characteristic of tunneling mechanisms of direct current formation, with the participation of surface states at the heterointerface and defects in the space charge region.

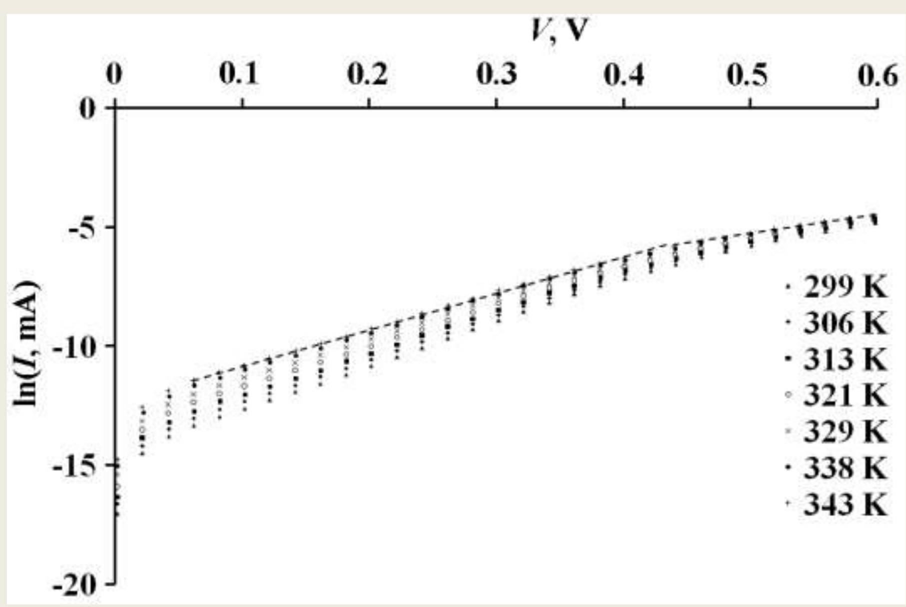

Fig. 3. Dependences ln$I$ = $f(V)$ at forward biases applied to the p-$CuCoO_2$/n-Si heterostructure at different temperatures.

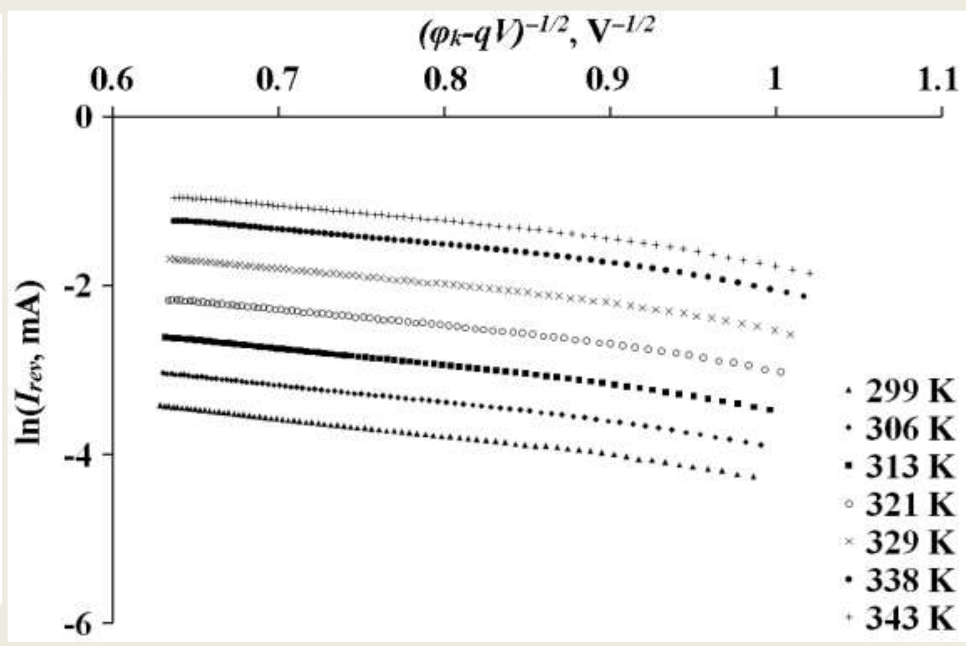

Fig. 4 Temperature dependences of reverse *I-V*-characteristics for p-$CuCoO_2$/n-Si heterostructure.

The reverse branches of the *I-V*-characteristics of the p-$CuCoO_2$/n-Si heterostructure at temperatures T = 299 - 343 K in the voltage range from – 1 V < V < – $3kT/q$ in the coordinates $\ln(I_{rev}) = f(\varphi_k - qV)^{-1/2}$ are linear. Therefore, the dominant mechanism of current transfer through the p-$CuCoO_2$/n-Si heterojunction at reverse biases is tunneling with the involving of surface states.

As can be seen from Fig. 5 p-$CuCoO_2$/n-Si heterostructures have low photosensitivity at reverse biases under AM1.5 radiation.

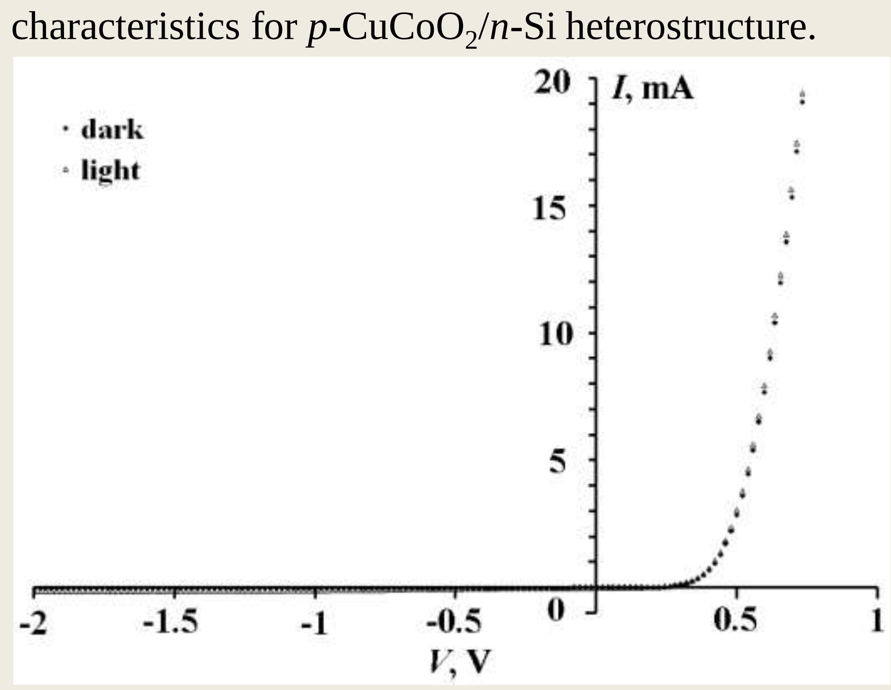

Fig. 5 Light *I-V*-characteristics of the heterojunction p-$CuCoO_2$/n-Si at T=295 K.

Conclusions

Thin $CuCoO_2$ films (~ 200 nm thick) were applied to glass substrates and plane-parallel *n*-Si plates by RF magnetron sputtering. $CuCoO_2$ films have a transmittance $T \approx 16\%$ in the wavelength range λ = 0.5-1.1 μm. Analysis of the absorption spectra of films indicates direct optical transitions. The optical band gap of the obtained $CuCoO_2$ films is E_g = 3.5 eV. The resistivity of the films at room temperature is ρ = 20 Ω·cm. An anisotypic p-$CuCoO_2$/n-Si heterostructure with a current rectification ratio of RR ~ 10^3 was fabricated. The diode characteristics of the heterostructure are due to the energy barrier $q\varphi_k$ ~ 0.5 eV from the *n*-Si side. At forward biases of 0.05 V < V < 0.4 V in the structure of p-$CuFeO_2$/n-Si the generation-recombination mechanism of current transfer prevails. At V > 0.4 V the tunnel mechanisms of current transfer with participation of surface states prevail. The reverse current at biases – 1 V < V < – $3kT/q$ V is determined by tunneling processes involving surface states. Heterostructures have low photosensitivity at reverse biases under AM1.5 radiation.

References

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