Changes in optical parameters of vanadium dioxide microstructures during resistive switching

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The parameters of electrical and optical switching in two-contact microstructures based on polycrystalline VO_2 films synthesized by chemical vapor deposition were investigated. The parameters of the semiconductor-metal temperature phase transition in the obtained two-contact microstructures with a width of 10 microns and a contact distance of 4 microns are measured. Measurements of the temperature dependences of the resistance showed a sharp jump in resistance by about three orders of magnitude at a direct phase transition temperature of about 65 °C. The formed structures exhibit pronounced resistive switching with a current surge of about 20 times at a threshold voltage of ≈ 19.5 V, due to the formation of a local metal filament between the contacts. The optical response of structures under temperature- and electrically-initiated semiconductor–metal phase transitions in VO_2 has been studied by spectral ellipsometry and microellipsometry. It was found that at a wavelength of 633 nm, during the temperature phase transition, the parameter Δ changes by 4.2° and the parameter Δ by 6.5°, whereas during resistive switching, jumps of Ψ by 2.4° and Δ by 3.4° are observed. For quantitative interpretation of the changes in ellipsometric parameters, numerical calculations of the reflection coefficients for transverse magnetic and transverse electric polarizations in the wavelength range of 400−1000 nm were performed, taking into account the geometry of the probing beam, gold contacts and metallic filament. The calculated changes in Ψ and Δ agree with the experimental values in order of magnitude. It is shown that during resistive switching, the change in the optical parameters of VO_2 is influenced by additional heating of the surrounding VO_2 region from the metal filament. The results obtained demonstrate the possibility of modulating optical parameters of VO_2 by an electric signal and contribute to understanding the mechanisms of electro-optical effects in microstructures, which is promising for creating tunable electro-optical structures and photonic devices.

Keywords: vanadium dioxide, semiconductor-metal phase transition, microstructures, two terminal switches, ellipsometry, optical response.

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1. Introduction

Vanadium dioxide (VO_2) relates to a class of correlated oxides of transition metals and is one of the most studied materials with a reversible phase transition of semiconductor–metal [1]. This transition may be initiated by thermal heating (68 °C), electric exposure (field/current), mechanical deformations, and also optical pumping, which makes VO_2 a promising platform for the development of functional elements in electrical and optical devices [2,3]. Besides, the phase transition in VO_2 is accompanied with dramatic changes in the fundamental parameters: electroconductivity increases by up to five orders of magnitude, the lattice parameters vary to 1% (the transition happens from the monoclinic phase to the rutile one), and the infrared (IR) range demonstrates the significant readjustment of the spectral response (n and k vary many fold) [2,4].

As it is known, the temperature phase transition in VO_2 causes a gradual change in the share of the metal (rutile) phase in the total volume of the film, whereas the electrically initiated transition develops with the formation of a narrow conducting area between the contacts at the expense of the local Joule heating [5,6]. For two-terminal switches this manifests itself in the resistive switching: upon achievement of the threshold voltage/current, a localized Joule heating occurs, then a current-conducting metal filament is formed in VO_2 between the contacts, which causes a current surge and pronounced non-linearity in the current-voltage curve. Control of the contact geometry makes it possible to purposefully change both the threshold electric parameters and the integral optic response, since the share of the metal phase in the total volume directly specifies the effective optical constants in the field of measurements.

Recently together with the studies of kinetics and mechanism of phase transition in the VO_2 structures, the applied area is developing actively, which is oriented at the integration of VO_2 into micro- and nanophotonic devices:

metasurfaces, tunable cavities, tunable waveguide components and electrooptic modulators of near and medium IR ranges [3,7]. In such systems it is fundamentally important to be able to electrically control the optical constants of VO_2 [8,9]. For the practical applications, the important requirements are high stability and reproducibility of the parameters of devices in multiple switchings in VO_2, and high speed of response of the devices compliant with the current requirements of photonics [10,11].

To develop the electrically controlled optical switches based on VO_2 microstructures, the fundamentally important is the study of interconnection between the parameters of the electrically initiated resistive switchings and the change of the optical constants of the material, including in dynamics. This requires using the methods capable of recording the spectral readjustment of the optical response directly in the process of electrically initiated switchings. One of such methods is ellipsometry, which is highly sensitive to the changes in the optical properties of materials [12]. At the same time, despite a wide use of ellipsometry for the study of the temperature-initiated transition in VO_2 and for the extraction of the spectral dependences $n(\lambda)$ and $k(\lambda)$, the application of *in situ* spectral and microellipsometry namely to the electrically initiated phase transition occurs very rarely. In most papers the optical response in electrical excitation is recorded by the methods of reflection/transmission at a single wavelength, microscopy of the domain structure or through the integration of VO_2 into the finished nanophotonic elements, which complicates the quantitative separation of the contributions of partial metallization, geometry of the filament and parasitic effects of the contacts [9,13,14].

The objective of this paper is to study the change in the ellipsometric parameters of VO_2 microstructures at the temperature phase transition and electrically initiated resistive switchings, and also the quantitative interpretation of these changes with the account of the real geometry of the microellipsometric measurement. The novelty of the paper consists in the experimental registration of the reversible change of parameters Ψ and Δ at the local electrically initiated phase transition in the two-terminal structure VO_2, accompanied with the formation of the metal filament, and in the numerical estimate of the effective coefficients of reflection of TM- and TE-polarizations for such heterogeneous region. A reversible change was detected for the ellipsometric parameters Ψ and Δ at the local electrically initiated phase transition in VO_2, which makes it possible to mention the modulation of optical coefficients of VO_2 with an electric signal. The results of the study of micro- and nanostructures of VO_2 obtained in the paper are promising for the development of the tunable electric and optical switches, sensors and neuromorphous systems based on VO_2.

2. Experiment method

VO_2 films were synthesized by the method of gas phase deposition on $SiO_2(300\,\text{nm})$/Si substrates. The detailed description of the synthesis parameters is given in papers [15,16]. Two-terminal resistive switches were formed on the basis of synthesized films using photolithography and magnetron sputtering of gold with thickness of 100 nm. The width of the gold contacts was 10 mcm, the gap between the two contacts was 4 mcm. The morphology and composition of the formed structures were studied using scanning electron microscopy (Hitachi SU8220, electron beam energy 5 keV) and X-ray phase analysis (Bruker D8, source CuK_α, detector LYNXEYE XE-T, range 2θ of angles $5-65^\circ$, pitch 0.03°).

For all the formed two-terminal switches VO_2 the temperature and electrically initiated phase transition was studied using the source-meter Keysight B2900. To study the temperature phase transition, the dependence of resistance on the temperature in the range from 30 to 80 °C was studied. To study the electrically initiated phase transition, current voltage curves of VO_2 films were measured in the range of supplied voltages from 0 to 20 V. Therefore, the values of the resistance drop were obtained for the semiconductor-metal transition, as well as the temperature value of direct and reverse phase transition, the value of the threshold voltage and current surge at the electrically initiated transition.

The ellipsometry method was used to study the optical response of the structure in the temperature phase transition. For this purpose, the dependences of the ellipsometric parameters Ψ and Δ on temperature in the range from 30 to 80 °C with the pitch of 1 °C in process of the sample heating and cooling were obtained. The measurements were carried out using a spectral ellipsometer „Spektr 1891“ at the angle of incidence of light 45° with the fixed wavelength of 633 nm. Besides, only the surface of the VO_2 film without the metal contacts was located in the scanning area. To study the dynamics of the optical response in electrical switchings in the thin VO_2 films, the microellipsometry method was used. The measurements were carried out at room temperature with the help of the ellipsometer Microscan-M at the angle of incidence of light of 58.5° and wavelength of 633 nm. The incident beam with the diameter of ~ 10 mcm was focused in the field of the VO_2 film between two gold contacts. To initiate the electrical switchings between the two contacts, direct voltage of 25 V was supplied in pulses, which exceeded the voltage of resistive switchings. The phase transition in VO_2 happened locally as a result of Joule heating with electric current, which caused the change in the optical constants of VO_2. Therefore, the dependences of parameters Ψ and Δ on time were obtained — before and after electrical initiation of the phase transition in VO_2 between the contacts. Besides, it should be noted that for the studied geometry of the switch and the dimensions of the probing beam of light, the studied area of the beam includes both the area of the film VO_2 and part of the gold contacts [17].

For the quantitative interpretation of the change in the ellipsometric parameters at resistive switchings, the numerical calculations were conducted by the finite element

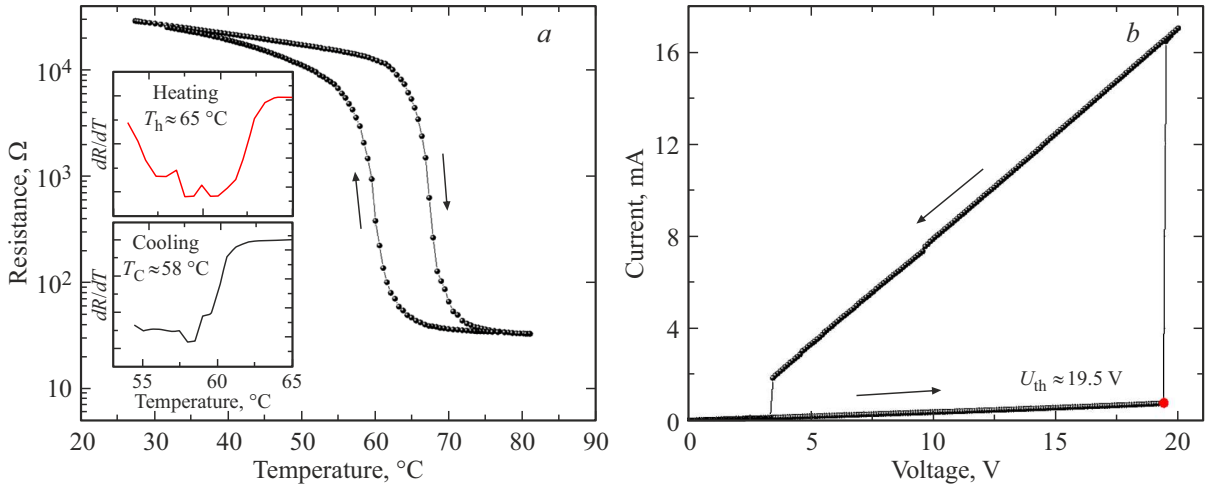


Figure 1. *a* — dependence of resistance on the temperature of the switch based on a polycrystalline film of VO_2. The insert shows the dependence of the derivative of resistance by temperature on the temperature in process of heating and cooling. *b* — electrical characteristics in the mode of the voltage source of the switch based on a solid polycrystalline film of VO_2.

method for the reflection coefficients of the electromagnetic wave of TM- and TE-polarizations. The calculation was carried out in the range of wavelengths 400–1000 nm at the angle of incidence 58.5° for the thin layers of VO_2 and Au on the SiO_2/Si substrate. After calculating the reflection coefficients of the individual regions of the structure, the effective reflection coefficients of the illuminated area were determined: effective coefficients of reflection of the illuminated area with the account of the probing beam diameter, the area of the gold contacts in the measurement area, and the surface area of VO_2, changing into the metal state in process of filament formation.

3. Experimental findings and discussion

The gas phase synthesis produced polycrystalline VO_2 films with the thickness of ~ 300 nm, which have a pronounced polycrystalline morphology of the surface (see *Annex*, Figure, *a*). Based on the diffraction measurements, it was obtained that all synthesized structures contained peaks of VO_2 M1 (011) and VO_2 M1 (022) of higher intensity and a weak peak V_2O_5 (002), which indicates the significant predominance of the crystalline phase of VO_2 M1 (see *Annex*, Figure, *b*).

Figure 1, *a* presents the dependence of the resistance on temperature for the formed switches based on polycrystalline VO_2 films. The obtained dependence clearly shows a sharp drop in resistance ~ 500 times at temperature ~ 65 °C, happening as a result of the phase transition of semiconductor–metal. The reverse phase transition of metal-semiconductor happens at ~ 58 °C.

Figure 1, *b* shows the current-voltage curve for the formed switches. The obtained electric characteristics clearly show the drastic current surge ~ 20 times at threshold voltage of $U_{th} \approx 19.5$ V. This surge is due to the formation of the current-conducting filament occurring as a result of the local phase transition in VO_2 between the contacts when heated with electric current [18,19]. The reverse current surge upon voltage decrease down to ~ 2 V is due to the damage to this filament as a result of VO_2 film cooldown.

As a result of ellipsometric measurements, the dependences of parameters Ψ and Δ in VO_2 films on temperature were obtained (Figure 2, *a*). These dependences show a clear loop of temperature hysteresis with a surge in parameters Ψ and Δ at phase transition in VO_2 at temperature of ~ 65 °C, which agrees well with the temperature measurements of resistance of the same films. As a result of the direct phase transition, the value of parameter Ψ decreased from 31.2 to 27°, and the value of parameter Δ increased from 147.8 to 154.3°. At reverse phase transition at temperature of ~ 59 °C the value of parameter Ψ increased from 27.4 to 30.7°, and the value of parameter Δ decreased from 154.2 to 148.1°. In dielectric state of VO_2 the value of parameter Ψ also depends on the interference between the VO_2 film and the SiO_2 substrate, whereas in the metal state of VO_2 there is practically no penetration of radiation into the VO_2 film, and the reflection from it plays a significant role. Let us emphasize that the values of temperatures, at which the most dramatic surge of ellipsometric parameters occurs (65 and 59 °C), coincide with high precision with temperatures of direct (65 °C) and reverse (58 °C) phase transition obtained from the resistance behavior upon heating and cooling (Figure 1, *a*).

To study the electrically initiated change of the optical response using microellipsometry, the dependence of ellipsometric parameters Ψ and Δ on time was obtained when the electric voltage of 25 V was supplied to the VO_2 switch (Figure 2, *b*).

The obtained dependences clearly show a dramatic surge of ellipsometric parameters related to the local phase transition in VO_2 and change of its optical coefficients (signature of „semicond. → metal“ in Figure 2, *b*). The value of parameter Ψ when switched varies from 51.2 to

48.8°, and the value of parameter Δ varies from 146.6 to 150°. After removal of the supplied electric voltage the ellipsometric parameter Ψ changes in a surge-like manner from 48.2 to 48.9°, parameter Δ from 153.1 to 151.6°, and then they gradually return to the initial value within ∼ 10 s. The obtained results of the surge-like change of ellipsometric parameters and hysteresis nature of the change are explained by the change of optical constants — refractive and absorption indices — at the local phase transition in VO_2.

Let us consider in more detail the obtained changes of ellipsometric parameters Ψ and Δ at resistive switchings in VO_2. Thus, when switching with the formation of the metal filament the change of parameter Ψ is 2.4° (from 51.2 to 48.8°), and parameter Δ changes to 3.4° (from 146.6 to 150°). At the same time it was obtained that at temperature phase transition of the VO_2 film the parameter Ψ decreases by 4.2°, and Δ increases by 6.5° (Figure 2, *a*). A smaller change of Ψ and Δ at resistive switchings may be explained by local nature of the process — at resistive switchings, contrary to the temperature transition, not the entire VO_2 film changes to the metal state, but only a narrow metal filament. Therefore, the effect of modulation of effective optical constants of VO_2 at resistive switchings turns out to be less than in the temperature phase transition.

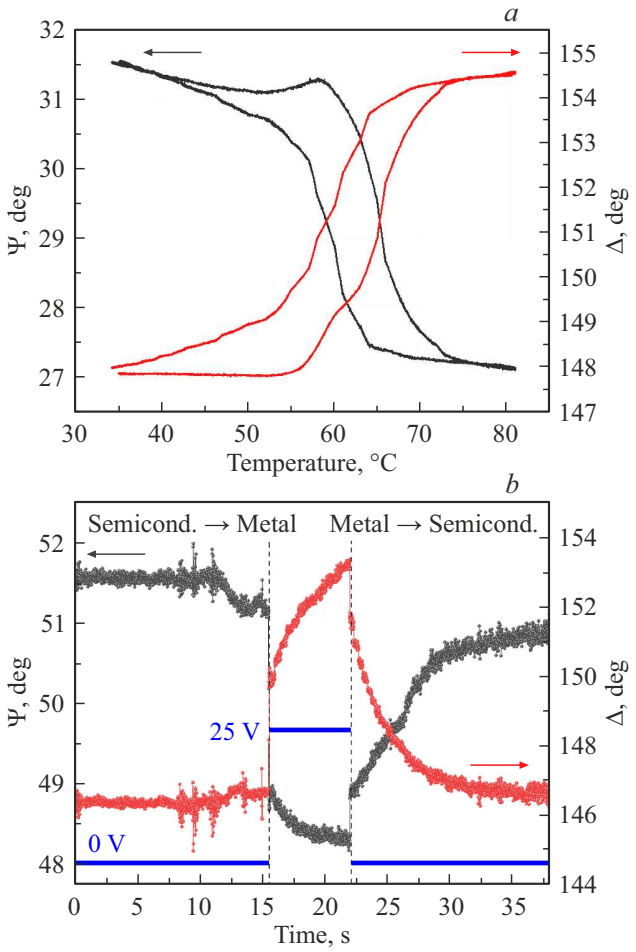


Figure 2. *a* — experimental dependences of ellipsometric parameters Ψ (black curve) and Δ (red curve) on VO_2 film temperature. *b* — dependence of ellipsometric parameters Ψ (black curve) and Δ (red curve) on time at resistive switchings in two-terminal microstructures of VO_2, the blue line shows the value of the supplied voltage depending on time.

Note that the direct recovery of the values of indices n and k for the metal phase of VO_2 from microellipsometric data in this case is an unobvious problem, since the probing beam records the effective signal from the heterogeneous area, including gold contacts, VO_2 in the semiconductor state and the local metal filament. Therefore, for the quantitative assessment of the change in the ellipsometric parameters, a geometric model of the studied structure was used with the contribution of gold contacts, vanadium dioxide film in the semiconductor and metal phases:

$$\delta\Psi = \operatorname{arctg}\left|\frac{S_{\mathrm{Au}}\cdot R_p^{\mathrm{Au}} + S_{\mathrm{VO}_{2s}}\cdot R_p^{\mathrm{VO}_{2s}}}{S_{\mathrm{Au}}\cdot R_s^{\mathrm{Au}} + S_{\mathrm{VO}_{2s}}\cdot R_s^{\mathrm{VO}_{2s}}}\right| - \operatorname{arctg}\left|\frac{S_{\mathrm{Au}}\cdot R_p^{\mathrm{Au}} + (S_{\mathrm{VO}_{2s}} - S_{\mathrm{VO}_{2m}})\cdot R_p^{\mathrm{VO}_{2m}} + S_{\mathrm{VO}_{2m}}\cdot R_p^{\mathrm{VO}_{2m}}}{S_{\mathrm{Au}}\cdot R_s^{\mathrm{Au}} + (S_{\mathrm{VO}_{2s}} - S_{\mathrm{VO}_{2m}})\cdot R_s^{\mathrm{VO}_{2m}} + S_{\mathrm{VO}_{2m}}\cdot R_s^{\mathrm{VO}_{2m}}}\right|$$

$$\delta\Delta = \operatorname{Arg}\left(\frac{S_{\mathrm{Au}}\cdot R_p^{\mathrm{Au}} + S_{\mathrm{VO}_{2s}}\cdot R_p^{\mathrm{VO}_{2s}}}{S_{\mathrm{Au}}\cdot R_s^{\mathrm{Au}} + S_{\mathrm{VO}_{2s}}\cdot R_s^{\mathrm{VO}_{2s}}}\right) - \operatorname{Arg}\left(\frac{S_{\mathrm{Au}}\cdot R_p^{\mathrm{Au}} + (S_{\mathrm{VO}_{2s}} - S_{\mathrm{VO}_{2m}})\cdot R_p^{\mathrm{VO}_{2m}} + S_{\mathrm{VO}_{2m}}\cdot R_p^{\mathrm{VO}_{2m}}}{S_{\mathrm{Au}}\cdot R_s^{\mathrm{Au}} + (S_{\mathrm{VO}_{2s}} - S_{\mathrm{VO}_{2m}})\cdot R_s^{\mathrm{VO}_{2m}} + S_{\mathrm{VO}_{2m}}\cdot R_s^{\mathrm{VO}_{2m}}}\right)$$

where S_{Au}, $S_{\mathrm{VO}_{2s}}$, $S_{\mathrm{VO}_{2m}}$ — surface areas of golden electrodes, vanadium dioxide in semiconductor and metal states, accordingly, R_p^{Au}, R_s^{Au}, $R_p^{\mathrm{VO}_{2s}}$, $R_s^{\mathrm{VO}_{2s}}$, $R_p^{\mathrm{VO}_{2m}}$, $R_s^{\mathrm{VO}_{2m}}$ — reflection coefficients of p- and s-waves from gold, vanadium dioxide in semiconductor and metal states, accordingly. The beam diameter was accepted to be equal to 10 mcm, the surface area of the gold contacts illuminated with laser - to 15 μm^2. According to this estimate, the change of parameter Ψ is ∼ 2.5°, and Δ ∼ 4.5°, which by the order of the magnitude agrees with the change obtained experimentally in this paper Ψ by 2.4° and Δ by 3.4°.

Figure 3 presents the calculated spectral dependences of the effective reflection coefficients of the studied area for TM- and TE-polarizations before (OFF State) and after (ON State) resistive switching. You can see that the formation of the metal area of VO_2 causes a change in the reflection coefficients for both polarizations. The most pronounced change is observed in the long-wavelength part of the spectrum, which is related to the high contrast of optical constants of VO_2 in semiconductor and metal phases. Oscillations in the short-wavelength part of the spectrum are due to interference effects and rereflections in the SiO_2 layer.

Therefore, the numerical modeling of reflection coefficients makes it possible to change from the qualitative description of the change of Ψ and Δ to the quantitative interpretation of the microellipsometry results. Besides, the calculated values must be considered as the effective parameters of the heterogeneous illuminated area, and not as the internal parameters of VO_2. Such consideration complies with the real geometry of the experiment and explains why the change in ellipsometric parameters in

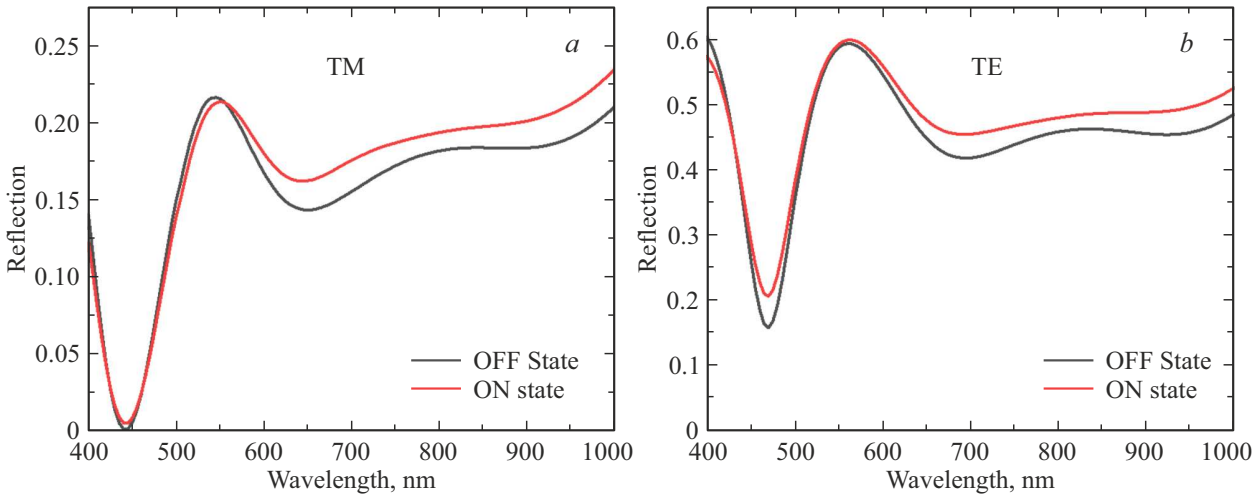


Figure 3. Calculated spectral dependences of effective reflection coefficients of the studied area in the VO_2 microstructure with account of geometry of contacts for TM- (*a*) and TE- (*b*) polarizations. The black curve corresponds to the state prior to the resistive switching (OFF State), the red one — after the resistive switching (ON State).

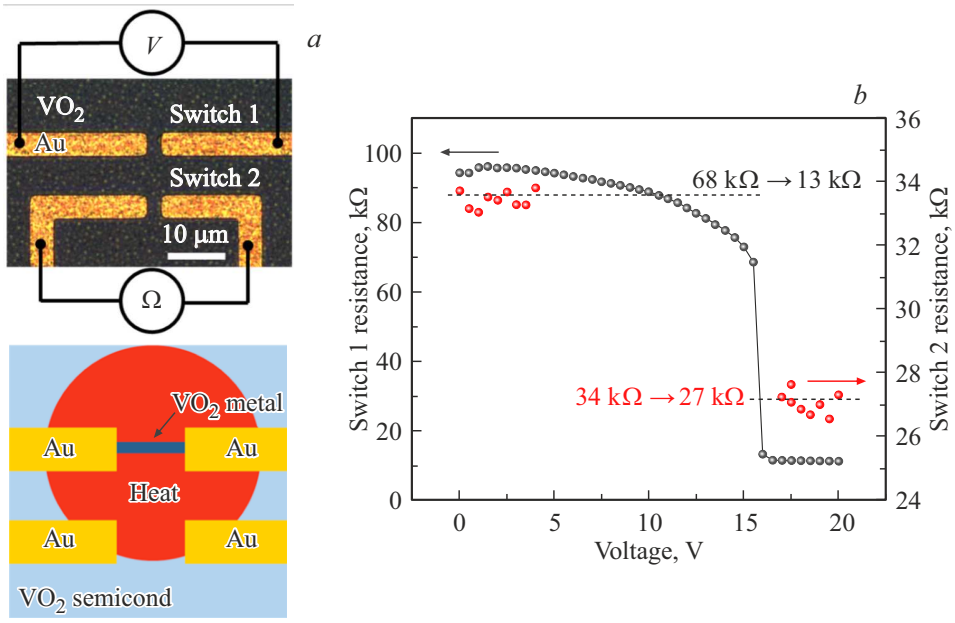


Figure 4. *a*) top — optical image of two closely located VO_2 switches with the schematic designation of the source of voltage V and meter of resistance Ω, bottom — schematic image of heat distribution after resistive switching with the formed metal filament. *b* — dependence of resistance of the first (black dots) and second (red dots) VO_2 switch on the voltage applied to the first switch.

resistive switching is smaller than in the temperature phase transition of the entire film.

Let us now consider the dynamics of optical and electric parameters of the studied structures of VO_2 after the resistive switching. Thus, as a result of the local phase transition of semiconductor–metal, a metal filament is produced between the two contacts, which changes the conductivity of the structure in a surge-like manner (Figure 1, *b*). This causes a dramatic change of optical constants, which is expressed in the surge of parameters Ψ and Δ in Figure 2, *b*. As the time of measurements increases, and the electric voltage is maintained, parameters Ψ and Δ continue to change gradually (area from ≈ 15 to 22 s in Figure 2, *b*). This gradual change of parameters Ψ and Δ, in our opinion, may be related to heating of a portion of the VO_2 film left in the semiconductor state, and gradual change of its optical constants, and also to the increase of the lateral dimensions of the metal filament.

To study this effect of local heating of VO_2 after the resistive switching, lithographic structures were made with two pairs of contacts located at the distance of 10 μm from each other (top Figure 4, *a*). In such structures a phase transition was initiated between one pair of contacts („Switch 1“ on the top Figure 4, *a*), and resistance was measured between

the other one („Switch 2“ on the top Figure 4, *a*). Measurement of the resistance of the second switch happened through application of voltage 100 mV, which is much lower than the threshold value of voltage of resistive switchings. Therefore, the resistive switchings are only possible between the first pair of contacts („Switch 1“ on the top Figure 4, *a*). At the same time the area of VO_2 between the second pair of the contacts is heated with the heat from the metal filament formed between the first pair of the contacts (bottom Figure 4, *a*). As a result of such measurements, the dependence of resistance of the first and second VO_2 switch on the supplied voltage to the first switch was obtained (Figure 4, *b*). It was established that after resistive switching and formation of the metal filament in the first switch, the resistance of the second switch starts decreasing in a surge-like manner. Besides, the resistance of the first switch changes ≈ 5.2 times, from 68 to 13 kOhm, whereas the resistance of the second switch changes only ≈ 1.3 times, from 34 to 27 kOhm. Such change in the resistance of the second switch may be explained by its heating by heat from the metal filament of the first switch. According to our estimates, with account of the experimentally obtained dependence of resistance on temperature of VO_2 (Figure 1, *a*), the abrupt decrease in resistance of the second switch from 34 to 27 kOhm corresponds to the change of its temperature by the value of $\sim 10\,^{\circ}$C. To describe the thermal interaction between the closely located switches, a condition of the independent operation of the adjacent element may be introduced: $T_0 + \Delta T(L) < T_c$, where T_0 — substrate temperature, $\Delta T(L)$ — temperature increase at the distance of L from the metal filament, T_c — temperature of phase transition of VO_2. If this condition is met, the heating of the adjacent structure is not sufficient for its transition to the metal state. In the studied geometry at $L = 10\,\mu$m, and increase of ΔT temperature, according to our estimates, is $\sim 10\,^{\circ}$C. Accordingly, at room temperature such thermal impact does not result in switching of the adjacent element, but noticeably changes its resistance and optical parameters. When the structure operates near the temperature of the phase transition, this distance must be considered as the distance of pronounced thermal coupling. Note that the precise determination of the critical distance requires a separate series of experiments to form and study the structures with various L.

The obtained results of the study of two closely located VO_2 switches make it possible to explain the dynamics of parameters Ψ and Δ after the resistive switching. It was obtained that parameter Ψ continues to slowly decrease after the current surge that occurred and formation of the metal filament (Figure 2, *b*). This decrease may be explained by heating of the portion of the VO_2 film with the heat from the metal filament. Indeed, as it was shown as a result of electric measurements of two pairs of contacts, the metal filament may heat the surrounding VO_2 film, as a result of which a temperature gradient will arise therein, and next to the filament the heating will be the strongest. At the distance of $10\,\mu$m, in the area of the second switch, the change of the temperature, according to our estimates, is $\sim 10\,^{\circ}$C. As a result of this the optical response of this portion of the VO_2 film changes gradually, which results in the change of parameters Ψ and Δ after the resistive switchings. Note also that the change of parameters Ψ and Δ after the resistive switchings provided that the electric voltage is maintained may be explained by the increase in the lateral dimensions of the metal filament.

4. Conclusion

This paper studied the optical response in resistive switchings in two-terminal microstructures based on polycrystalline VO_2 films. It is shown that the formed structures demonstrate resistive switchings with the current surge approximately 20 times at voltage of ~ 19.5 V. At the same time the abrupt drop in resistance in the temperature phase transition of semiconductor-metal near $65\,^{\circ}$C is around 3 orders in magnitude. The ellipsometry method studied the dependences of parameters Ψ and Δ on temperature of VO_2 at wavelength of 633 nm. It was found that at temperature phase transition in VO_2 the value of parameter Ψ reduced from 31.2 to 27°, and the value of parameter Δ increased from 147.8 to 154.3°, which is related to the change in the refractive and absorption indices in the VO_2 film. The method of microellipsometry was used to study the change of parameters Ψ and Δ in VO_2 microstructures in resistive switchings. Abrupt changes of Ψ by 2.4° and Δ by 3.4° was found, which was related to the formation of the metal filament between the contacts, and, accordingly, the local change in the optical response of the structure. For the quantitative interpretation of the obtained results, the numerical calculation of reflection coefficients was made for the TM- and TE-polarizations with the account of the geometry of the probing beam, gold contacts and the metal filament. According to the obtained data, the change in the effective reflection coefficients is mostly pronounced in the long-wavelength part of the spectrum, and the calculated changes of Ψ and Δ agree with the experimental values by the order of magnitude. The effect of the gradual change of ellipsometric parameters after the formation of the metal filament was found. It was established that this effect is due to the local heating of the VO_2 film by the heat from the metal filament. It is shown that at the distance of $\sim 10\,\mu$m from the filament the film temperature increases by $\sim 10\,^{\circ}$C, which causes additional modulation of the optical properties of VO_2. To assess the independent operation of the closely located switches, the criterion $T_0 + \Delta T(L) < T_c$ was proposed, according to which the heating of the adjacent element must not result in the achievement of the phase transition temperature. The obtained results make it possible to speak on the possible modulation of the optical constants of VO_2 with an external electric signal, which is very important for the development of electric and optical elements, sensors, modulators on the basis of microstructures of VO_2.

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Conflict of interest

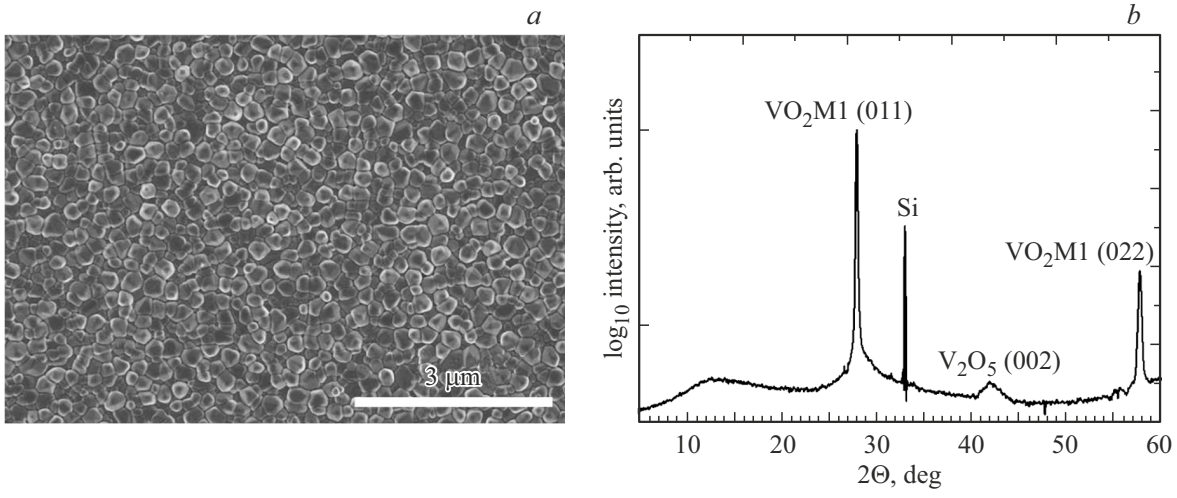
The authors state that they have no conflict of interest.

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Appendix



a — SEM-image of the surface of the synthesized polycrystalline VO_2 film. *b* — diffractogram of the synthesized polycrystalline VO_2 film.