International Journal of Nanoscience
Vol. 1, No. 1 (2019) 1–4
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PHOTOCURRENT HYSTERESIS OF SOL-GEL DERIVED STRONTIUM TITANATE FILMS ON SILICON

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Received 25 January 2019; accepted 16 February 2019

$SrTiO_3$ and $SrTiO_3$:Nd films of 110 and 210 nm thickness were fabricated using the sol-gel technology on silicon. Their current-voltage characteristics were investigated with and without illumination. The film structures are photosensitive and exhibit the hysteresis on the forward and reverse bias with loop broadening at the reverse part.

Keywords: strontium titanate, photocurrent, sol-gel.

1. Introduction

Over the past quarter century, an interest in the fabrication and study of electrophysical properties of strontium titanate ($SrTiO_3$, ST) has grown significantly. By doping, electronic properties of ST can be changed from dielectric to semiconductor, metal, and even superconductor.[1,2] There are many data on photoelectric properties of this material, however, the effect of nonequilibrium charge carriers on dielectric features of ST is almost not studied.

Properties of ST depend on the manufacturing technology. So, the dielectric constant of ST films can range from 150 to 475 at the frequency of 100 kHz. The thickness increase of the sol-gel derived ST films after heat treatment at 750 °C causes the growth of porosity, which leads to the band gap (E_g) and refractive index change from 3.96 eV to 4.2 eV and 2.33 to 1.87, respectively. The value of $E_g = 4.63$ eV can be achieved by reducing the annealing temperature down to 500 °C.[3]

ST also exhibits photoelectric and resistive switching properties.[4,5] The hysteresis required for the resistive switching elements is observed on the current-voltage characteristics. Usually, ST films are polycrystalline. The resistance of the polycrystalline structures includes bulk resistance of polycrystal grains, the resistance of the interfaces, the so-called double Schottky barrier, and the resistance at the metal/semiconductor interfaces (Schottky barriers).[2] Therefore, their capacity is determined by the volume capacity of the grains, the capacity of the double Schottky barriers and the capacity of the Schottky barriers. The main factor determining the resistive switching of ST films was shown to be the change of the Schottky double barriers with a concomitant change in the voltage polarity.[5] Despite the fact that there are many works on this topic, interest in further research on morphological and structural features of ST films do not fade away.

2. Experimental

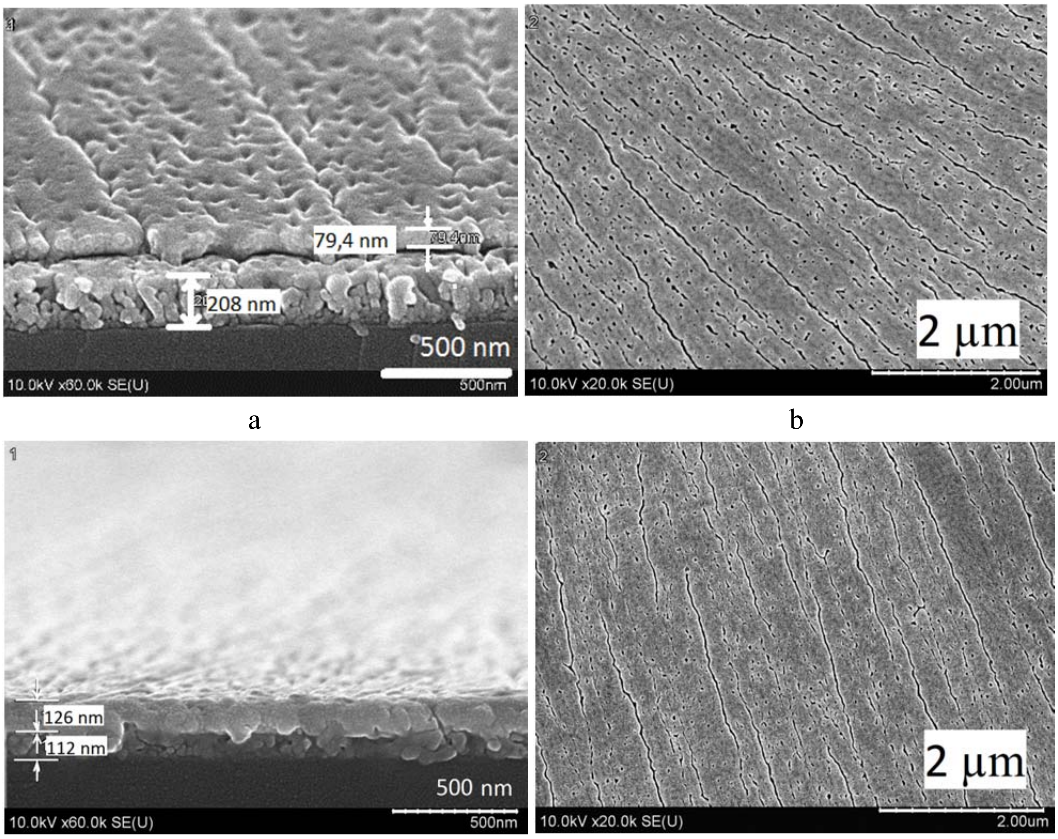
Titanium isopropoxide, strontium acetate and neodymium nitrate were used for fabrication of $SrTiO_3$:Nd films. Acetic acid was used as a solvent. First, titanium isopropoxide was dissolved in a mixture of acetic acid and acetylacetone, then strontium acetate was added to the solution and stirred until complete dissolution. Neodymium nitrate was dissolved in a mixture of acetone and distilled water. The resulting solutions were combined and thoroughly mixed. The sols were spun on silicon substrates. The final heat treatment of the samples was carried out at 1000 °C for 40 min.

Current-voltage characteristics (I-V) of the structures were measured at room temperature within the voltage range $U = \pm 15$ V using a stabilized TEC-23 power source. The measurements required to use a voltmeter with high internal resistance and nichrome conductors. Voltage and current were monitored with electronic digital devices: V7-23 voltmeter and V7-27A ampermeter. First, dark I-V characteristics were obtained, and then the measurements were done under white light illumination with the intensity of 39 mW/cm^2.

3. Results

Fig. 1 shows $SrTiO_3$ and $SrTiO_3$:Nd capacitor structures with nickel electrodes on monocrystalline silicon. Deposition of single layer of the sol with concentration of ST 62 mg/ml after annealing results in formation of the $SrTiO_3$:Nd (Fig. 1a,b) and $SrTiO_3$(Fig. 1c,d) xerogel films with the thickness of 208 and 112 nm, respectively. The Ni contact thickness amounted to 79.4 and 126 nm, respectively.

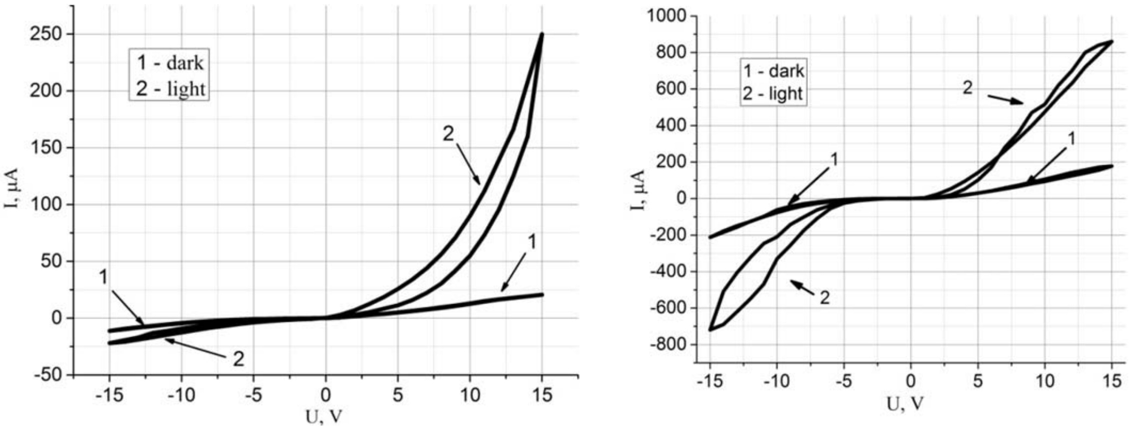
I-V measurements of this capacitor structure show that illumination of the samples leads to significant changes in the forward and reverse branches of the I-V curves (Fig. 2). At the forward bias voltage +15 V (voltage increase from 0 to 15 V) the current for $SrTiO_3$:Nd structure is –45 μA without illumination, and at the same voltage under illumination, the current



a b

c d

Fig. 1. SEM images of $SrTiO_3$:Nd (a,b) and $SrTiO_3$ (c,d) of capacitor structures with nickel electrodes deposited on silicon.



a b

Fig. 2. I-V characteristics of $SrTiO_3$:Nd (a) $SrTiO_3$ (b) capacitor structures under and without illumination.

increases significantly up to 250 μA. When illuminated at the reverse bias voltage 15 V (voltage decrease from 0 to –15 V) the current is –21.9 μA, and at the same voltage without lighting the current is 11.3 μA.

It was also found for this structure that under illumination and voltage increase at the forward bias, a sudden current decrease occurred, which can characterize switching of ST from a low-resistance to a high-resistance state. At forward bias voltage +10 V (from 0 to 15 V) the current is equal to 90 μA; and at reverse bias voltage +10 V (from 15 to 0 V) the current is equal to 55 μA.

At forward bias voltage +15 V the $SrTiO_3$ structure the current is –178 μA without illumination, and at the same voltage under illumination the current increases significantly up to 860 μA. At reverse bias voltage of 15 V (voltage decrease from 0 to –15 V) the current is –212 μA without illumination, and at the same voltage under illumination the current is 725 μA.

It was observed for this sample that under illumination and at the voltage increase at forward and reverse bias, an abrupt current decrease occurred, which can characterize switching of ST from a low-resistance to a high-resistance state. At the increasing reverse bias (from 0 to –15 V) the current is 330 μA at –10 V; and at the decreasing reverse bias (from –15 to 0 V) the current is equal to 210 μA at the same voltage of –10 V, the similar current drop was observed with forward switching on.

4. Conclusion

The experimental studies presented for ST based structures have demonstrated that they are photosensitive and can be prospective for photodetectors and solar energy devices. The structures exhibited hysteresis on the forward and reverse curves of the current-voltage characteristics with loop broadening at the reverse bias. This indicated the weak effect of resistive switching under illumination. The detected resistive properties of ST films may be of additional interest in their production by the sol-gel method with prospects of using nonvolatile memory elements for memristor and optical devices.

Acknowledgments

The work was supported by a joint Russian-Belarusian grant of the Russian Foundation for Basic Research No. 17-52-04127 and BRFFR No. T17PM-122.

References

1. Xiao Lin, C. W. Rischau, L. Buchauer, A. Jaoui, B. Fauque, K. Behnia, *Quant. Mater.* **2**, 41 (2017).
2. M. Kisiel, O. O. Brovko, D. Yildiz, R. Pawlak, U. Gysin, E. Tosatti, E. Meyer, *Nature Communications* **9**, 2946 (2018).
3. N. I. Stas'kov, A. B. Sotskii, L. I. Sotskaya, I. V. Ivashkevich, A. I. Kulak, N. V. Gaponenko, M. V. Rudenko, A. N. Petlitskii, *Opt. Spectrosc.* **125**, 492 (2018).
4. V. M. Poole, S. J. Jokela, M. D. McCluskey, *Scientifics Reports* **7**, 6659 (2017).
5. M. Kubicek, S. Taibl, E. Navickas, H. Hutter, G. Fafilek, J. Fleig, *J. Electroceram* **39**, 197 (2017).