Vanadium Complex (VO_2(3-fl)) Films Based Resistive Temperature Sensor

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Abstract

A resistive-type temperature sensor based on vanadium complex (VO_2(3-fl)) film is reported in this study. Silver electrodes were deposited on the glass substrates in a co-planar structure. A thin film of vanadium complex (VO_2(3-fl)) was coated as a temperature-sensing material on the top of the pre-patterned electrodes. The temperature-sensing principle of the sensor was based on the conductivity change of coated sensing element upon heating or cooling processes. The resistance of the temperature sensor, measured at 100 Hz, decreased exponentially with increasing the temperature in the range of 25−80 °C. The overall resistance of the sensor decreases in 3.7−4.5 times. The resistance temperature coefficients of the sensor were in the range of 3.2 to 3.6%. The properties of the sensor studied in this work, make it beneficial to be used in the instruments for environmental monitoring of temperature.

Keywords: Vanadium complex, thin film, teperature sensor, resistance;

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1. Introduction

Development of the sensors for application in monitoring various parameters such as humidity, temperature and chemical gases have gathered considerable attention in recent years. A number of sensors have been fabricated on the basis of vanadium oxides [1-6]. Vanadium oxides (VO_2) show the large reversible change of electric, magnetic and optical properties at temperatures around 68−70 °C [7-9]. Transition of semiconductor to metal is also observed in these smart materials. At transition temperature, the optical properties of vanadium dioxide are quickly changed: the optical transmission is decreased and reflectivity is increased. Due to this behavior, vanadium dioxide is an attractive material for smart windows for solar energy control and electrical and optical switches. Microstructure and crystallinity of the films effect hysteresis of the transition. By the addition of transition metals such as niobium, molybdenum or tungsten, the transition temperature of vanadium dioxide may be decreased.

It was found that VO_2 films demonstrate holographic storage and bit recording properties at using a near-infrared laser [10, 11]. Switching time of about 30 ns and writing energy of the order of a few mJ/cm^2 were reported [12]. The vanadium dioxide is an interesting candidate for modern applications of active thin films in optical or electric switches as well [13].

Vanadium oxide is considered as an n-type semiconducting material [7]. Due to the semiconducting properties, vanadium oxides and their complexes have been reported to be used in different kind of sensor. The lamellar nature of vanadium oxide makes it possible to modulate the adsorption and conduction properties. The electrical conductivity in vanadium oxides can be enhanced by formation of oxygen vacancies. Therefore it is important to introduce different metal based materials into existing technology which may bring in considerable improvements in functionality and/or cost of organic electronics [14]. A vanadium complex (VO_2(3-fl)) and CNT composite film based temperature sensor was reported in Ref. [15].

This paper reports the fabrication of surface-type Ag/VO_2(3-fl)/Ag resistive temperature sensor employing vanadium complex VO_2(3-fl) as an active sensing element.

2. **Experimental Procedure**

The molecular structure of the vanadium complex (VO_2(3-fl)) is shown in Fig. 1. The VO_2(3-fl) was obtained from Aldrich and used as received. Commercially available glass slides were used as substrates which were primarily cleaned ultrasonically. In the first go, the silver electrodes were deposited in a co-planar structure by masking on the glass substrate using Edwards AUTO 306 vacuum evaporation technique. The pressure inside the chamber was maintained at 10^{-5} mbar. The thickness of the silver electrodes was 200 nm. It was measured in the process of the thin film deposition by quartz crystal oscillator, FTM5, which was fitted in the vacuum evaporator chamber. The gap between the silver electrodes was 40 µm. It was measured by optical microscope with built-in scale. Later, 5 wt.% solution of VO_2(3-fl) in benzol was drop casted on the pre-patterned Ag surface-type electrodes. The device was kept at room temperature for 10 hrs to let the moisture evaporate from the films. The VO_2(3-fl) film thickness was in the range of 20–30 µm. The cross sectional view of the fabricated resistive type temperature sensor is shown in Fig. 2. The temperature measurements were carried out in a self-made chamber which has been designed and developed in our laboratory. The temperature range of 25 ˚C to 80 ˚C was selected due to its practical importance in domestic and industrial applications. Resistance measurements were carried out using ESCORT ELC-132A meter at a frequency of 100 Hz in ambient atmosphere. The temperature was measured by multi-meter FLUKE 87. The experimental error for the measurement of the temperature was equal to ±1 ^{o}C and the accuracy of electric resistance measurement was equal to ±2% (it was estimated as described by Dally et. al. [16]).

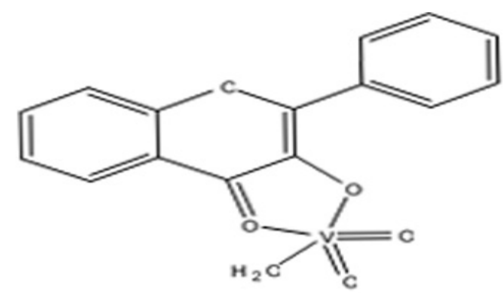

Fig. 1: Molecular structure of the vanadium complex VO_2(3-fl).

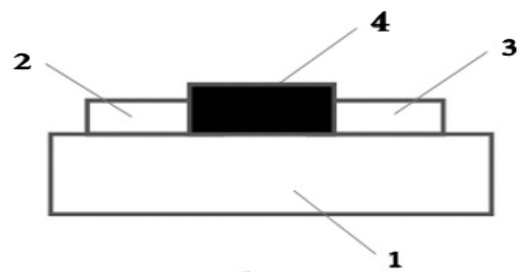

Fig. 2: The cross sectional view of the fabricated resistive type temperature sensor: Glass substrate (1), Silver electrodes (2 and 3), VO2(3-fl) film (4).

3. Results and Discussion

Fig. 3 shows resistance versus temperature relationships for two Ag/VO_2(3-fl)/Ag surface–type resistive temperature sensors. It can be observed that the resistances show sharp decrease with increase of temperature that is actually characterize semiconductor based thermistors [16]. The resistance of the temperature sensors decreases 3.7–4.5 times with increasing the temperature in the range of 25–80 ^{o}C. At heating or cooling processes, resistance-temperature curves of the sensors show good repeatability. The resistance temperature coefficient (S) of the samples can be calculated by [16]:

$$S = \frac{\Delta R \times 100\%}{R_o \Delta T} \quad (1)$$

where R_o, ΔR and ΔT are initial value of the sensor's resistance, changes in the resistance and temperature, respectively. It was found that the resistance temperature coefficients of the sensors were in the range of 3.2 to 3.6% .The value of the resistance temperature coefficients are in the range of that of conventional semiconductor thermistors [16].

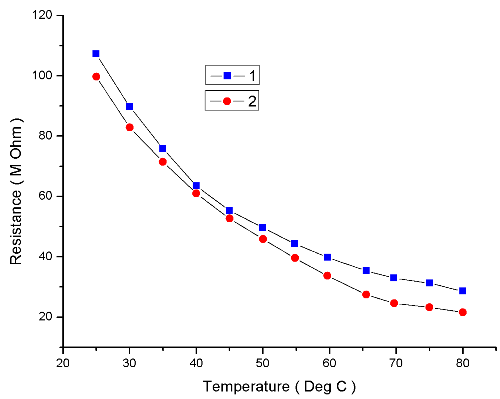

Fig. 3: Resistance versus temperature relationship for two Ag/VO_2(3-fl)/Ag surface–type resistive temperature sensors.

For simulation of the resistance-temperature relationships, we can use an exponential function given in Eq. (2) [17] by method of substitution.

$$f(x) = e^{-x} \quad (2)$$

The relative resistance –temperature relationships can be expressed by the following equation:

$$\frac{R}{R_o} = e^{-\Delta TK} \quad (3)$$

where R is the sample's resistance at elevated temperatures (T), K is the resistance temperature factor. Average value of K was determined from the experimental data shown in Fig. 3, which is 2.6×10^{-2} °C^{-1}. Fig. 4 shows the experimental and simulated (by using Eq. (3)) results, which are in good agreement.

The mechanism of conductivity in the VO_2(3-fl) samples can be considered as transitions between spatially separated sites that can be attributed to the Percolation theory [18,19]. According to Percolation theory, the effective conductivity (σ) of the samples can be calculated as:

$$\sigma = \frac{1}{LZ} \quad (4)$$

where L is a characteristic length, which depends on the concentration of sites, Z is the resistance of the path with the lowest average resistance. With an increase in temperature, the sample is heated that may cause the reduction of Z due to generation of charge carriers, increase of their concentration and mobility. The conductivity of the VO_2(3-fl) samples increases and the resistance decreases with increase of temperature accordingly, as observed experimentally (Fig. 3).

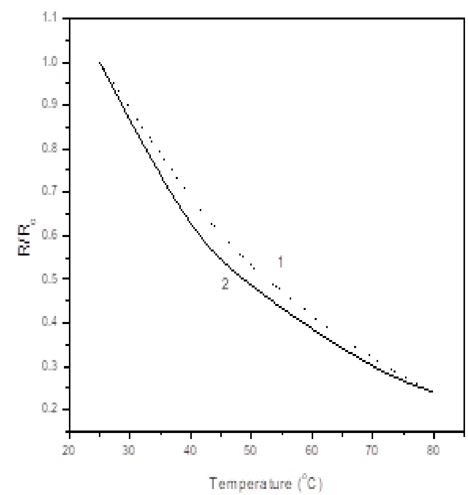

Fig. 4: Simulated (1) and experimental (2) resistance versus temperature relationship for Ag/VO_2(3-fl)/Ag surface–type resistive temperature sensor.

As experimental resistance-temperature (Fig. 3 and Fig. 4) relationships for the VO_2(3-fl) sensors are quasi-exponential, they can be easily linearized by nonlinear op-amps [20].

4. Conclusion

The resistive-type temperature sensor based on vanadium complex was fabricated by drop-casting method from solution of VO_2(3-fl). It was found that resistive-temperature relationships of the sensors showed exponential behavior. The resistance temperature coefficients of the sensors were in the range of 3.2 to 3.6%. The mechanism of change of conductivity with change of the temperature in the VO_2(3-fl) was considered as transitions between spatially separated sites that can be attributed to the Percolation theory: with an increase in temperature, an increase in the concentration and mobility of charge carriers take place.

Conflict of Interest

None declared

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References

[1]Shimizu, K., Chinzei, I., Nishiyama, H.,Kakimoto, S., Sugaya, S., Matsutani, W., Satsuma, A., (2009) Doped-vanadium oxides as sensing materials for high temperature operative selective ammonia gas sensors. Sens. Actuators B 141, pp. 410-416.

[2]Wang, C. T., Chen, M. T., (2010) Vanadium-promoted tin oxide semiconductor carbon monoxide gas sensors. Sens. Actuators B 150, pp. 360-399.

[3]Carotta, M. C., Ferroni, M., Gherardi, S., Guidi, V., Malagù, C., Martinelli, G., Sacerdoti, M., Vona, M. L. D., Licoccia, S., Traversa, E., (2004) Thin-film gas sensors based on vanadium-titanium oxide powders prepared by sol-gel synthesis. J Europ Ceramic Soc. 24, pp. 1409-1413.

[4]Lavacchi, A., Cortigiani, B., Rovida, G., Bardi, U., Atrei, A., Angelucci, R., Dori, L., Nicoletti, S., Poggi, A., (2000) Composition and structure of tin/vanadium oxide surfaces for chemical sensing applications. Sens. Actuators B 71, pp. 123-126.

[5]Zakharova, G. S., Volkov, V. L., (2003) Intercalation compounds based on vanadium(V) oxide xerogel. Russian chem Rev 72, pp. 311-325.

[6]Schilling, O., Colbow, K., (1994) A mechanism for sensing reducing gases with vanadium pentoxide films. Sens. Actuators B 21, pp. 151-157.

[7]Guzman, G., Vanadium dioxide as infrared active coating. Internet info (http://www.solgel.com/articles/August00/thermo/Guzman.htm)

[8]Chain, E, E., (1991) Optical properties of vanadium dioxide and vanadium pentoxide thin films. Applied Optics 30, pp. 2782-2787.

[9]Parkin, I. P., Binions, R., Piccirillo, C., Blackman C. S. Manning, T. D., (2008) Thermochromic coatings for intelligent architectural glazing. J. Nano Research 2, pp. 1-20.

[10]Roach, W. R., (1971) Holographic Storage in VO_2. Appl Phys Lett. 19, pp. 453-455.

[11]Smith, A. W., (1973) Optical storage in VO_2 films. Appl. Phys. Lett. 23, pp. 437-438.

[12]Eden, D. D., (1981) Vanadium dioxide storage material. Optical Engineering 20, pp. 377-378.

[13]Guzman, G., Beteille, F., Morineau, R., Livage, J. (1996) Electrical switching in VO_2 sol-gel films. J. Mater. Chem. 6, pp. 505-506.

[14]Mitzi, D. B., Chondroudis, K., Kagan, C. R., (2001) Organic-inorganic electronics. IBM J. Research & Devel. 45, pp. 29-45.

[15]Karimov, Kh. S., Tahir, M. M., Saleem, M., Chani, M. T. S., Niaz, A. K., (2015) Temperature sensor based on composite film of vanadium complex (VO_2(3-fl)) and CNT. J. Semicond. 36, pp. 073004-5.

[16]Dally, J. W., Riley, W. F., McConnell, K., G. Instrumentation for Engineering Measurements, 2nd ed., John Willey & Sons, Inc., New York, U.S.A., 1993

[17]Croft, A., Davison, R., Hargreaves, M. Engineering Mathematics. A Modern Foundation for Electronic, Electrical and Control Engineers. Addison-Wesley Publishing Company, Great Britain, 1993

[18]Brabec, C. J., Dyakonov, V., Parisi, J., Sariciftci, N. S., Organic Photovoltaics: Concepts and Realization, Springer-Verlag, Berlin Heidelberg, 2003

[19]Bottger, H., Bryksin V. V., Hopping Conductions in Solids, VCH Publishers, Akademie-Verlag, Berlin, 1985

[20]Irvine, R. G., Operational Amplifiers Characteristics and Applications, Prentice Hall, New Jersey, 1994