Proceedings of the 46th International School and Conference on the Physics of Semiconductors "Jaszowiec" 2017, Szczyrk

# Electrical Transport Properties of $Yb_{8-x}Y_xV_2O_{17}$ ($x = 0, 2, 8$)

B. Sawicki[a], M. Piz[b], E. Filipek[b], T. Groń[a,*] and H. Duda[a]

[a]University of Silesia, Institute of Physics, Uniwersytecka 4, 40-007 Katowice, Poland

[b]West Pomeranian University of Technology Szczecin, Faculty of Chemical Technology and Engineering, Department of Inorganic and Analytical Chemistry, al. Piastów 42, 71-065 Szczecin, Poland

The UV-vis-NIR and electrical properties of $Yb_{8-x}Y_xV_2O_{17}$ for $x = 0$, 2, and 8 were investigated. The band energy gap of 2.6 eV determined for $Yb_6Y_2V_2O_{17}$ ($x = 2$) and comparable for the remaining compounds with $x = 0$ and 8 is characteristic for insulators. Low electrical conductivity with a characteristic minimum shifting to higher temperatures from 322, via 360 to 370 K in the sequence $x = 0$, 2 and 8, which decreases with increasing content of ytterbium was observed. Temperature dependence of thermoelectric power showed $n$–$p$ transition at 410 and 467 K for $x = 0$ and 2, respectively, and $n$-type conductivity for $x = 8$, indicating mainly $n$-type electrical conductivity. A breakdown voltage of 26 V/mm is mainly observed for the $I$–$V$ characteristics at 400 K and showing a varistor-like behavior.

DOI: 10.12693/APhysPolA.132.363

PACS/topics: 72.20.Pa, 72.80.Ga, 75.20.–g

## 1. Introduction

Complex oxide systems based on rare earth metal oxides are of great interest for creation of new materials for production e.g. of plasma displays, electroluminescent diodes, or fluorescence lamps [1–5].

Preliminary studies of the ternary oxides $V_2O_5$–$Yb_2O_3$–$Y_2O_3$ system have shown that, in one of its sections, i.e. in the system $Yb_8V_2O_{17}$–$Y_8V_2O_{17}$, a previously unknown phase of the formula $Yb_6Y_2V_2O_{17}$ is formed [6]. The new phase $Yb_6Y_2V_2O_{17}$ was obtained by heating a mixture of the three oxides, i.e. $Yb_2O_3$, $V_2O_5$ and $Y_2O_3$ in a molar ratio (3:1:1) in air, between temperatures 873 and 1823 K [6]. The X-ray powder diffractogram showed that $Yb_6Y_2V_2O_{17}$ is isostructural with $Yb_8V_2O_{17}$ which crystallizes in the triclinic systems [7]. This result is contrary to the literature data [8]. According to the results of our research the elementary cell parameters of new phase $Yb_6Y_2V_2O_{17}$ which were refined with the use of the program REFINEMENT are as follows: $a = 0.8972$ nm, $b = 0.9292$ nm, $c = 0.9824$ nm, $\alpha = 77.668°$, $\beta = 106.301°$, $\gamma = 116.291°$ [7].

In the present study the electrical and optical properties of $Yb_{8-x}Y_xV_2O_{17}$ for $x = 0$ and 8 [7–9] as well as for a new phase ($x = 2$) were carried out.

## 2. Experimental details

The powder diffraction patterns of the samples obtained were recorded with the aid of the diffractometer EMPYREAN II (PANalytical, Netherlands) using Cu $K_\alpha$ with graphite monochromator. Ultraviolet–visible and near-infrared (UV–vis–NIR) diffuse reflectance spectra were recorded at room temperature and in the wavelength range of 200–900 nm using a JASCO-V670 spectrophotometer equipped with an integrating sphere. In order to determine the energy gap, $E_g$, these spectra were transformed using the Kubelka–Munk function: $F(R) = (1-R)^2/2R$, where $R$ is reflectancy [%] [10, 11]. The sample morphology was observed on SEM images. Scanning electron microscopy study was performed on JSM-1600, JEOL, Japan with an X-ray energy dispersive analysis — EDX (ISIS-300, Oxford).

The electrical conductivity $\sigma(T)$ and the $I$–$V$ characteristics have been measured with the aid of the DC method in the temperature range 300–400 K using a KEITHLEY 6517B Electrometer/High Resistance Meter. The thermoelectric power $S(T)$ was measured in the temperature range 300–600 K with the aid of a Seebeck Effect Measurement System (MMR Technologies, Inc., USA). For the electrical measurements, the powder samples were compacted in a disc form (10 mm in diameter and 2 mm thick) using a pressure of 1.5 GPa and then they were sintered during 2 h at 1073 K. The electrical and thermal contacts were made by a silver lacquer mixture (Degussa Leitsilber 200).

## 3. Results and discussion

Figure 1 shows a fragments of diffraction pattern (XRD) of $Yb_8V_2O_{17}$ (Fig. 1a), $Yb_6Y_2V_2O_{17}$ (Fig. 1b) and $Y_8V_2O_{17}$ (Fig. 1c) obtained in the context of this paper, which are almost identical to that shown in [7].

The SEM image of new polycrystalline phase is presented in Fig. 2.

The morphology of $Yb_{8-x}Y_xV_2O_{17}$ for $x = 2$ ($Yb_6Y_2V_2O_{17}$) crystallites is very similar to those of the matrix *i.e.* $Yb_8V_2O_{17}$ [7]. They look like polygons of irregular shapes and different sizes, varying from 0.5 to 9 $\mu$m (Fig. 2).

The UV-vis-NIR measurements and the Kubelka–Munk transformation [10,11] (Fig. 3) have shown that all phases of $Yb_{8-x}Y_xV_2O_{17}$ are insulators for the energy gap of 2.6 eV for $Yb_6Y_2V_2O_{17}$ ($x = 2$), whose value is comparable to that of other samples ($x = 0$ and 8).

*corresponding author; e-mail: Tadeusz.Gron@us.edu.pl

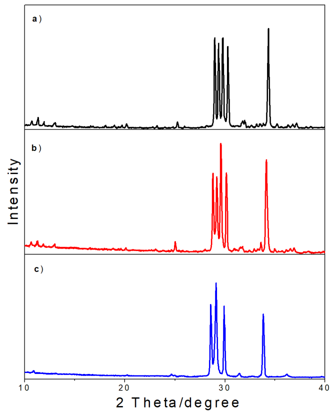


Fig. 1. Fragments of XRD powder patterns of the: a) $Yb_8V_2O_{17}$, b) $Yb_6Y_2V_2O_{17}$, c) $Y_8V_2O_{17}$.

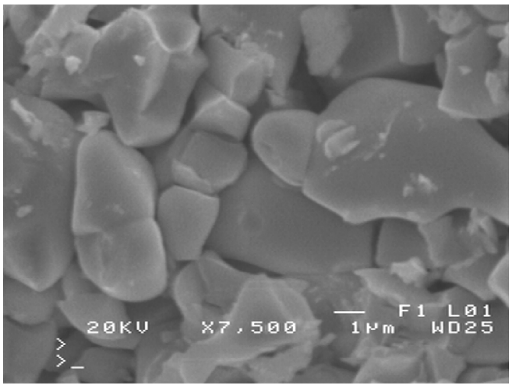


Fig. 2. SEM image of $Yb_6Y_2V_2O_{17}$.

The compounds under study showed low electrical conductivity, $\sigma(T)$, with a characteristic minimum shifting to higher temperatures from 322, via 360 to 370 K in the sequence $x = 0$, 2 and 8 (Fig.4). It is noteworthy that the electrical conductivity decreases with increasing content of ytterbium. The temperature dependence of thermopower, $S(T)$, showed $n$–$p$ transition at 410 and 467 K for $x = 0$ and 2, respectively, and $n$-type conductivity for $x = 8$, indicating mainly $n$-type electrical conductivity (Fig. 5) probably due to predominant contribution of oxygen vacancies. In this case, the thermoelectric power increases as the content of ytterbium increases.

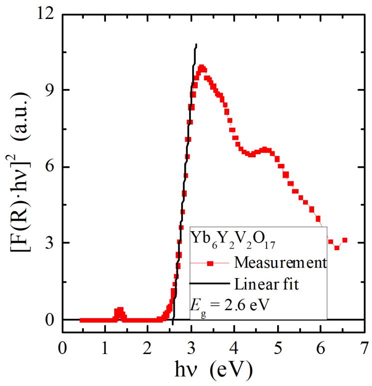


Fig. 3. Plots of $(F(R)h\nu)^2$ vs. the energy of the incident photon $h\nu$ for $Yb_6Y_2V_2O_{17}$. $E_g$ is the band gap energy.

TABLE I

The voltage at the point of breakthrough $V$ [V] and breakdown voltage $V_b$ [V/mm] of $Yb_{8-x}Y_xV_2O_{17}$ for the specimen thickness of 2 mm at 300 K and 400 K.

| x | Compound | $V$ | $V_b$ | $V$ | $V_b$ |
|---|---|---|---|---|---|
| | | 300 K | | 400 K | |
| 0 | $Yb_8V_2O_{17}$ | – | – | 60 | 30 |
| 2 | $Yb_6Y_2V_2O_{17}$ | 92 | 46 | 44 | 22 |
| 8 | $Y_8V_2O_{17}$ | – | – | 54 | 27 |

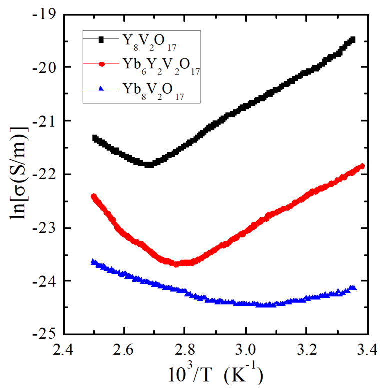


Fig. 4. The electrical conductivity ($\ln\sigma$) vs. reciprocal temperature $T^{-1}$ for $Yb_{8-x}Y_xV_2O_{17}$ ($x = 0$, 2 and 8).

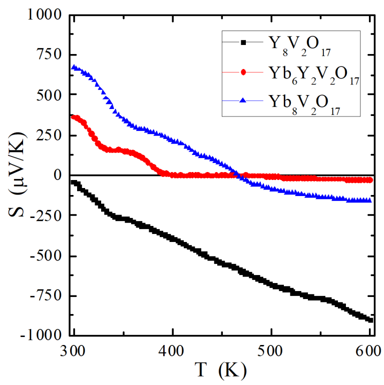


Fig. 5. The thermoelectric power $S$ vs. temperature $T$ for $Yb_{8-x}Y_xV_2O_{17}$ ($x = 0$, 2 and 8).

The most interesting observation concerns the nonlinear $I - V$ characteristics (Figs. 6–8) for all the phases under study, similar to back-to-back Zener diodes but with much greater current and energy handling capabilities [12]. A breakdown voltage $V_b$ ~26 V/mm (Table I) is mainly observed for the $I$–$V$ characteristics at 400 K and it is almost twice lower than the value of $V_b$ at 280 and 300 K, showing a varistor-like behavior. From the physics research of varistors follows that the non-linearity $I-V$ characteristics in this case may be due to the phenomenon of grain-boundary where a barrier to majority charge carriers exists in the depletion layers of the adjacent grains [12].

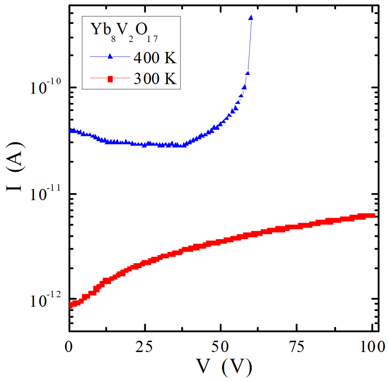


Fig. 6. The $I-V$ characteristics at 300 and 400 K for $Yb_8V_2O_{17}$.

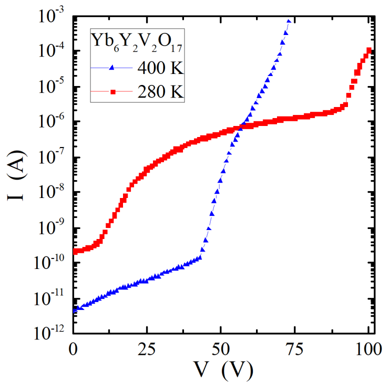


Fig. 7. The $I-V$ characteristics at 280 and 400 K for $Yb_6Y_2V_2O_{17}$.

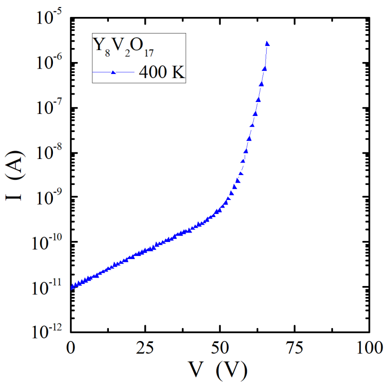


Fig. 8. The $I-V$ characteristics and 400 K for $Y_8V_2O_{17}$.

The studied materials can be used as the voltage stabilizers, the electronic power systems and the transient surge suppression in electronic circuits.

## 4. Conclusions

We have investigated the UV-vis-NIR spectroscopy and electrical properties of $Yb_{8-x}Y_xV_2O_{17}$ phases for $x = 0$, 2 and 8. All samples turned out to be insulators with the band energy gap of 2.6 eV, low electrical conductivity mainly of $n$-type with a characteristic minimum shifting to higher temperatures in the sequence $x = 0$, 2 and 8 which decreases with increasing content of ytterbium and the breakdown voltage of 26 V/mm which is mainly observed for the $I-V$ characteristics at 400 K and showing a varistor-like behavior. The solid solutions under study can be considered as varistors and for applications as the electronic power systems

## Acknowledgments

This work was partly supported by Ministry of Science and Higher Education (Poland) and funded from Science Resources: No. 1S-0300-500-1-05-06 and No. DS-518-10-020-3101.

The authors are also grateful to the team workshop of the Institute of Physics (University of Silesia) for providing practical and technical assistance with a KEITHLEY 6517B Electrometer/High Resistance Meter device.

## References

[1] R.B. Pode, A.M. Band, H.D. Juneja, S.J. Dhoble, *Phys. Status Solidi* **157**, 493 (1996).

[2] J. Chen, F. Guo, N. Zhuang, J. Lan, X. Hu, S. Gao, *J. Cryst. Growth* **243**, 450 (2002).

[3] V. Buissette, A. Huignard, T. Gacoin, J.P. Boilot, P. Aschehoug, B. Viana, *Surf. Sci.* **532**, 444 (2003).

[4] H.Y. Xu, H. Wang, T.N. Jin, H. Yan, *Nanotechnology* **16**, 65 (2005).

[5] Z. Xia, D. Chen, M. Yang, T. Ying, *J. Phys. Chem. Solids* **71**, 175 (2010).

[6] M. Piz, E. Filipek, in: *Proc. 11th Int. Seminar on Thermal Analysis and Calorimetry to the memory of Prof. St. Bretsznajder, Płock (Poland)*, 2016, p. 122.

[7] M. Piz, E. Filipek, *J. Therm. Anal. Calorim.* **130**, 277 (2017).

[8] H. Brusset, R. Mahe, J.P. Laude, *Bull. Soc. Chim. Fr.* , 495 (1973).

[9] J. Lewin, *J. Am. Ceram. Soc.* **50**, 381 (1967).

[10] P. Kubelka, F. Munk, *Z. Tech. Phys.* **12**, 593 (1931).

[11] P. Urbanowicz, M. Piątkowska, B. Sawicki, T. Groń, Z. Kukuła, E. Tomaszewicz, *J. Eur. Ceram. Soc.* **35**, 4189 (2015).

[12] C. Li, J. Wang, W. Su, H. Chen, W. Wang, D. Zhuang, *Physica B* **307**, 1 (2001).