Tr. J. of Physics
23 (1999) , 969 – 976.

# Electrical Switching In Potassium-Boro-Vanadate-Iron Glasses

**Harshvadan R. PANCHAL, Dinesh K. KANCHAN**
*Physics Department, Faculty of science, M.S. University,*
*390 002, Baroda-INDIA*

Received 25.06.1997

### Abstract

Electrical switching has been observed in $20K_2$O : (75-y)$V_2O_5$ : $yB_2O_3$ : $5Fe_2O_3$ glasses which were prepared by a splat quenching method. To investigate switching phenomenon, glass samples of the same dimension from as quenched material were examined for their I-V characteristics at various ambient temperatures. The exponential decrease of switching voltage is observed with increasing ambient temperature indicating the cause of switching due to Joule's heating. It is also observed that the switching voltage can be controlled by varying the ambient temperature and switching temperature by changing the voltage. The dependence of switching temperature on the amount of $V_2O_5$ has also been observed. An increase in $V_2O_5$ enhances the conductivity of these glasses which requires less input power and lower ambient temperature to induce switching in these glasses. When the applied voltage approaches the switching voltage, the sample temperature has been found to be higher than the ambient temperature. The radiation loss from the sample is expected to be a function of input power P= I.V. The switching behaviour in these semiconducting glasses is found to be temperature dependent which may be understood in terms of Joule's heating. The present glass system may be used as voltage as well as thermal switching.

**Key words:** Electrical Conduction, Electrical Switching, Switching Voltage, Radiation loss.

## Introduction

Semiconducting glasses often show marked deviation from normal semiconductor behaviour, i.e., non-ohmic conduction under the influence of high temperature and strong electric field. Electrical switching in transition metal oxide glasses has been investigated by Drake et al. [1] and Mansingh et al. [2-5], and Hosseini et al. [6] and Higgins et al. [7] have reported detailed studies of the dependence of the switching voltage on temperature. The origin of switching has been attributed to the metal-semiconductor transition in $VO_2$ [8], whereas others [9] have attempted to explain the switching phenomenon on the basis of thermal process. Attempts have also been made to present a hybrid model on both thermal and electronic process.

In the present work we have studied the switching behaviour of 20 $K_2O$: (75-y) $V_2O_5$: $yB_2O_3$ : $5Fe_2O_3$ glasses in the composition range 40-75 mole % $V_2O_5$ and ambient temperature range 300-508 °K, with a view to establishing the mechanism of threshold switching in these samples. Measurements of I-V characteristics have been made on bulk samples using full faced silver paint electrodes.

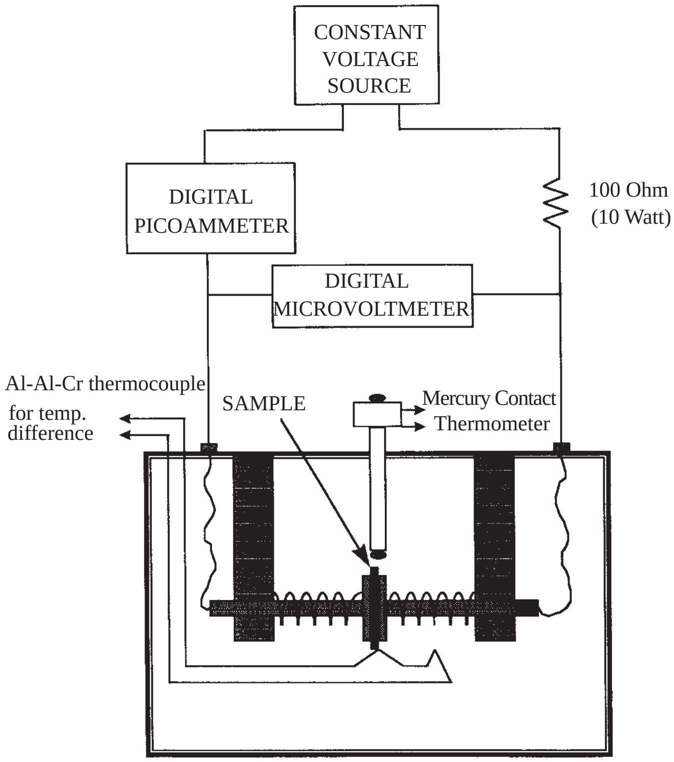

**Figure 1.** Experimental arrangement for electrical switching study.

## Experimental

Weighed amounts of analytical grade chemicals $V_2O_5$, $H_3BO_3$, $K_2CO_3$ and $Fe_2O_3$ were well mixed and melted in a porcelain crucible at 950 °C and maintained for about 4 hours. These melts were quenched on to a cleaned copper plate at room temperature and subsequently pressed by another plate to provide faster cooling. X-ray diffraction analysis showed the amorphous nature of ceramic sample. The electrical measurements were made by usual two probe method. The samples of convenient shape and size were cut and polished with very fine quality lapping papers. With painted silver paste, good ohmic contacts were formed. As shown in Fig. 1, the samples were pressed between two electrodes for good thermal and electrical contacts. The cell was placed in a heating furnace. The temperature of the furnace (ambient temperature) was controlled with mercury contact thermometer and relay. For I-V characteristics, a constant voltage source was connected in series with the sample and a fixed resistance of 100 ohm, 10 watt. A digital picoammeter was used for measuring the current through the sample and digital microvoltmeter across the sample to measure the voltage. The temperature difference between the sample and the ambient was measured by a thin Al-Al-Cr wire thermocouple, which was attached to the sample at a point along the thickness of the sample. The e.m.f. of the thermocouple was measured by digital microvoltmeter.

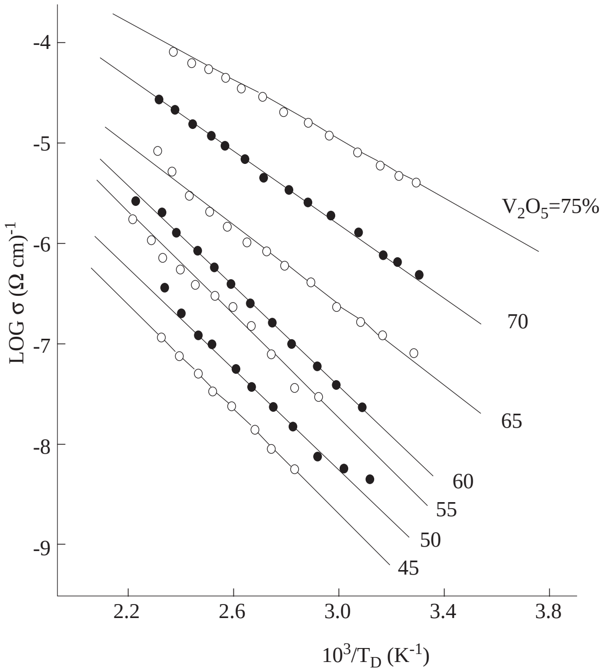

**Figure 2.** Plot of Log$\sigma$ versus $10^3/T_D$

## Results and Discussions

The conductivity of the present glasses (from $7.53\times 10^4$ to $8.43\times 10^9\Omega^{-1}cm^{-1}$) follows the exponential law

$$\sigma = \sigma_0 \exp(-W/kT_D), \qquad (1)$$

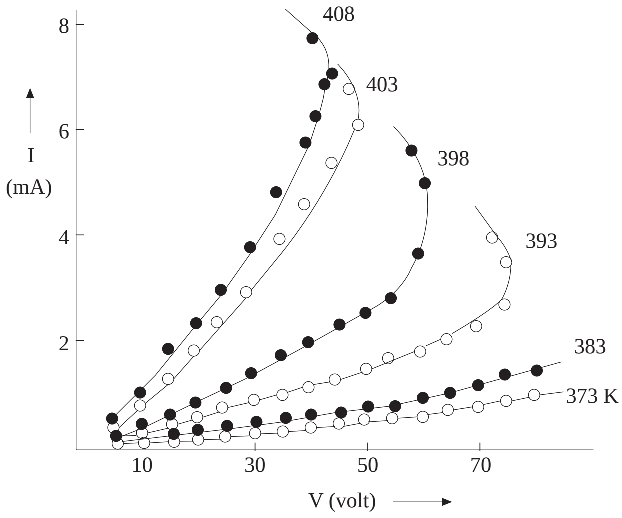

**Figure 3a.** I-V plot for $V_2O_5$=50 mole %.

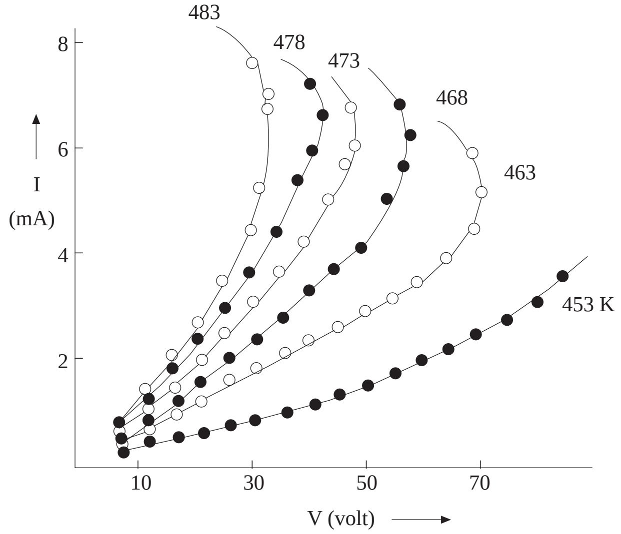

**Figure 3b.** I-V plot for $V_2O_5$=70 mole %.

where, W is the activation energy for electrical conduction and $T_D$ is the sample temperature [10]. The plot of log$\sigma$ versus $10^3/T_D$ (Fig. 2) shows the linear decrease in conductivity with the inverse of sample temperature. Typical I-V characteristics for $V_2O_5$=50 and 70% for different temperatures are shown in Figs. 3 (a) and (b) for low applied voltage; the conduction in these systems is observed to be ohmic up to a particular temperature. When the field is further increased gradually, the current becomes non ohmic. With the rapid increase of current, a decrease in voltage across the sample and an increase across 100 Ω resistance has been observed. This rapid increase in the current without significant increase in the applied voltage is considered as the switching, which is observed in the present glass system at various ambient temperatures. According to

$$V_s = V_o exp(-\beta/kT), \qquad (2)$$

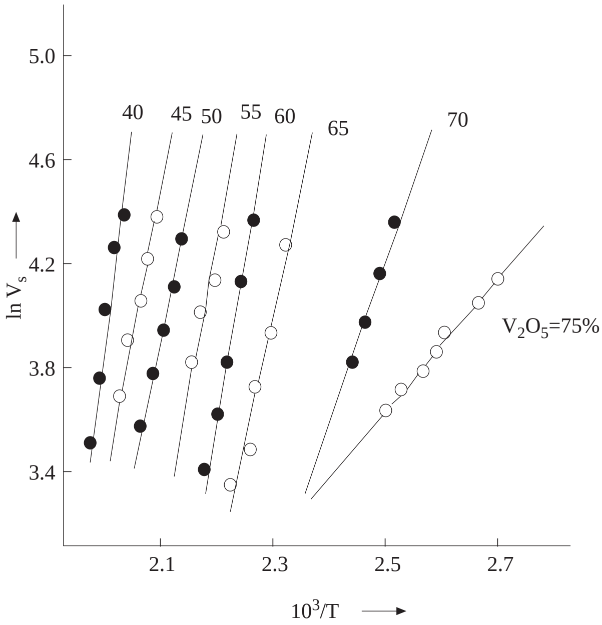

**Figure 4.** Plot of ln$V_s$ versus $10^3$/T.

a plot between ln$V_s$ and $10^3$/T (Fig. 4) shows that the switching voltage, $V_s$, decreases with increasing ambient temperature linearly. It means that it may be possible to have switching at any desired temperature by adjusting applied voltage. The voltage switching is also possible by controlling the ambient temperature. When the applied voltage approaches near the switching voltage, the temperature of the sample is observed to be higher than the ambient temperature, whereas the resistance of the sample near switching decreases rapidly. The decrease of resistance of these semiconducting glasses is dependent on temperature and composition of the glass system as well. Also, as the applied voltage reaches to the switching voltage at a fixed ambient temperature, the current rises significantly in the sample. This results in an increase of the sample temperature which further decreases its resistance. The increase in switching current with ambient temperature means more electrical input power is being required for switching. The more electrical input power will result in an increase in sample temperature and further reduction in the resistance of the sample. It is also observed that much before the switching the ambient temperature is nearly equal to the sample temperature, $T_s$. However, at switching the temperature of the sample is observed to be higher than the ambient temperature due to high input power. Therefore, to observe switching, sufficient input power is to be given to raise the sample temperature from T to $T_s$. With the increase of power input to the sample with the ambient temperature, radiation losses are also expected to increase. To compensate these radiation losses, more power input is required to get switching at a desired temperature. If

$$R = R_o \mathrm{exp}(W/kT_D) \tag{3}$$

to hold, the temperature of the sample at switching, $T_s$, can be given [11,12] as

$$1/T_s = 1/T - (k/W)ln(R/R_s), \tag{4}$$

where $R_s$ is the resistance of the sample at switching and R is the resistance at T for low applied field. It means the temperature of the sample at switching increases with ambient temperature (Table 1).

**Table 1.** Electrical switching data.

| $V_2O_5$% | **T (K)** | $V_s$ **Volt** | $R_s$ **VoltΩ** | $T_D$ **(K)** | $T_s$ **(K)** | **Radiation loss (f)** |
|---|---|---|---|---|---|---|
| 50 | 463.0 | 72 | 14.4 | 540.7 | 463.9 | $3.95\times10^{10}$ |
| | 468.0 | 60 | 9.7 | 545.5 | 479.0 | 4.06 “ |
| | 473.0 | 51 | 8.0 | 557.7 | 481.7 | 4.67 “ |
| | 478.0 | 44 | 6.7 | 565.8 | 487.6 | 5.02 “ |
| | 483.0 | 35 | 4.9 | 578.8 | 498.9 | 5.32 “ |
| 70 | 393.0 | 76 | 21.8 | 434.3 | 386.4 | $1.17\times10^{10}$ |
| | 398.0 | 62 | 12.5 | 439.9 | 403.0 | 1.24 “ |
| | 403.0 | 52 | 9.6 | 448.5 | 409.4 | 1.40 “ |
| | 408.0 | 45 | 6.5 | 451.1 | 425.3 | 1.37 “ |

In thermal equilibrium, following Stefan-Boltzmann's law, the sample temperature $T_D$ can be written as

$$T_D^4 - T^4 = f, \tag{5}$$

where f is a measure of radiation loss from the sample and is expected to be a function of input power P=I.V. From Table 1 it is clear that the radiation loss increases with increasing ambient temperature. Hence the sample temperature $T_D$ should be higher than the ambient temperature, which is true in the present system. A power series for radiation loss f can be written as

$$f = \alpha_o + \alpha_1 P + \alpha_2 P^2 + \ldots \alpha_N P^N. \tag{6}$$

In case where the power input P is zero, it is excepted that $T_D$=T and the constant $\alpha_o$ is expected to be zero. Using Equations (3) and (5), we get

$$f = [(W/k)ln(R/R_o)]^4 - T^4. \tag{7}$$

The value of f can be calculated from experimental value of W, R and $R_o$ for any temperature. The value of f has also been worked out by computer fitting of the above polynomial. Values of the coefficients of $\alpha_1, \alpha_2, \ldots$ were computed for the polynomial given in Equation 6. The coefficient of voltage across the sample for any current I was calculated using

$$V_{cal} = IR_o exp[W/k(T^4 + \alpha_1 P + \alpha_2 P^2 + \ldots)^{1/4}]. \tag{8}$$

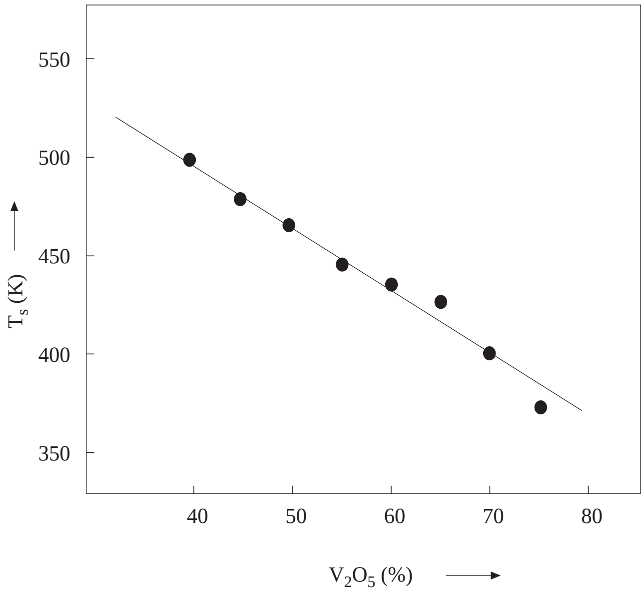

**Figure 5.** Plot of $T_s$ and $V_2O_5$ mole %.

These values of $V_{cal}$ are found to be in good agreement with experimental values. Therefore the above thermal model for thermal switching, which has been attributed due to Joule heating, fits well for the present glass system. Concentration of $Fe_2O_3$ has been kept constant and added as a Mössbauer probe for the study of Mössbauer spectroscopy. Figure 5., shows a variation of switching temperature, $T_s$, with $V_2O_5$ content. In the present glass system, a variation in the amount of glass formers $V_2O_5$ and $B_2O_3$ has been made. With increase of $V_2O_5$ the V-V spacing (calculated from their densities) is found to decrease, which makes polaron hopping between $V^{4+}$ and $V^{5+}$ easier in these glasses, resulting in an increase in conductivity and a decrease in resistance of the sample with $V_2O_5$ content [13-14]. Therefore, the power input required for Joule heating is lower in samples with higher amount of $V_2O_5$ which consequently gives rise to lower switching temperature as well as voltage $V_s$.

Hence, the following observations are made in these semiconducting glasses:
(a) switching temperature is found to be dependent on the sample composition and temperature which may be understood in terms of Joule heating; (b) the input electrical power should be sufficient to compensate for the radiation loss, inorder to initiate the switching. Finally, the present system may be used as a voltage as well as a thermal switch.

## References

[1] C. F. Darke, L. F. Scanlan and Engel A., Phys. Stat. Sol., **32**(1969)193.

[2] A Mansingh., and R Singh., J. Phys. C **13**(1980)5727.

[3] A. Mansingh., R. Singh. and S. B. Krupanidhi, Solid St. Electron, **23**(1980)649.

[4] A. Mansingh., J. K. Vaid and R. P. Tandon., Phys. Stat. Sol. (a), **38**(1976)K1.

[5] A. Mansingh and V. K. Dhavan, Phil. Mag. B., **47(2)**(1983)121-138.

[6] A. A. Hosseini and C. A. Hogarth, J. of Mat. Sci., 20(1985)261-268.

[7] J. K. Higgins and B. K. Temple and J. E. Lewis, J. Non Cryst. Sol. **23**(1977)187.

[8] B. Fisher., J. Phys. C: Solid State Phys. **8**(1975)2072-2076.

[9] H. J. Stocker, C. A. Barlow and D. F. Weirauch., J. Non Cryst. Sol. **4**(1970)523.

[10] I. G. Austin and N. F. Mott, Adv. Physics, **18**(1969)41.

[11] K. Bore., S. R. Ovshinsky, J. Appl. Phy., **41**(1970)2675.

[12] K. Shimakawa, Y. Inagaki and T. Arizumi, Jap. J. Appl. Phys., **12**(1973)1043.

[13] H. R. Panchal, D. K. Kanchan and D. R. S. Somayajulu, J. of Material Science Forum, Vol **223-224** (1996)301-306.

[14] H. R. Panchal, D. K. Kanchan, Solid State Physics(India) Vol. **39C**(1996)218.