

Nonlinear I-V characteristics of semiconducting paints

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Abstract

Tin oxide-based high resistivity semiconducting paints can be used on high voltage insulators for improved performance. They were found to exhibit nonlinear I-V characteristics which are reported here. The paints exhibited power law relationship and a sharp transition in mechanism of conduction at a critical voltage.

Key words: Conducting paints, electrical properties.

1. Introduction

Semiconducting glazes are employed on high voltage insulators for improving their performance in several respects¹⁻⁴ such as reduction in radio interference (R.I.) and corona, suspension of pollution flash over (F.O.), uniform voltage distribution, prevention of condensation of fog, moisture and ice, etc.

Recently semiconducting paints have also been reported to be useful in suppression of R.I. and corona and pollution F.O. under laboratory as well as severe outdoor conditions⁵⁻⁶. Some of their interesting properties have been reported earlier⁷. During further work on development of such paints they were found to exhibit interesting nonlinear I-V characteristics which are reported here.

2. Experimental

Three varieties of semiconducting paints were prepared by using antimony-doped semiconducting tin oxide as the basic semiconducting material and three types of oil media, viz., linseed oil, karanja oil and cottonseed oil. The semiconducting tin oxide

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was prepared by doping the material with antimony oxide at $1200 \pm 10^\circ \text{C}$ for 5 hr. The fine powder (-150 mesh) of this doped semiconducting tin oxide was then intimately mixed with the above oil media, to obtain three varieties of semiconducting paints.

Silver paste contacts were painted on glass specimens and fired at 600°C for 30 min to achieve good adhesion. Electrical contact leads were then soldered on to the fired silver contacts. The desired semiconducting paint was then spray painted on these specimens and these specimens were then cured in an electrical oven at 105°C for 500 hr to stabilise the electrical resistivity of these samples. The I-V characteristics of such cured paint samples were then measured using ac voltages in the range 100-1500 V. The details regarding the specimens and the circuit diagram used for the measurement of I-V characteristics are shown in Fig. 1.

The resistance of the paint samples was found to be a function of applied voltage. The resistance values at various applied voltages were therefore inferred from the I-V characteristics.

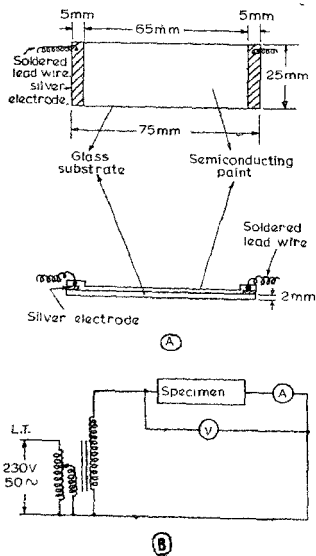


FIG. 1. (A) Details of specimen painted with semiconducting paint. (B) Circuit diagram for the measurement of I-V characteristics.

3. Results and discussion

From the typical I-V characteristics exhibited by the paints, shown in Fig. 2, it can be seen that these paints do not exhibit linear ohmic I-V characteristics. The typical resistance vs. voltage characteristics of such paints are shown in Fig. 3. From this figure it can be seen that the resistance of the paints initially increases with increase in the applied voltage and attains a maximum at a critical applied voltage. Above this critical voltage, the resistance starts decreasing with further increase in the applied voltage.

Some typical log-log plots for the I-V characteristics of these paints are shown in Fig. 4. It can be seen from this figure that the log-log plots of I-V characteristics of such paints are linear which indicates that the paints exhibit power law relationship of the type

$$V = K \cdot I^\beta \quad (1)$$

where

V = applied voltage

I = current

K = a constant depending on composition and dimensional properties

β = the exponent—constant indicating the extent of nonlinearity in I-V characteristics.

Further, it can be seen from Fig. 4 that the paints exhibit same relationship below and above a critical voltage, but the slope of the line changes at the critical voltage. This indicates that the values of the constants K and β are abruptly changing at the critical voltage. This indicates that there is a transition in the mechanism of conduction at the critical voltage V_c . The values of the exponent β below and above V_c for various paint samples are given in Table I. It can be seen from this table that the

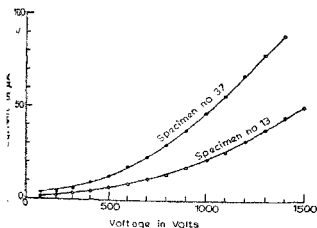


FIG. 2. The typical I-V characteristics of tin oxide-based semiconducting paints.

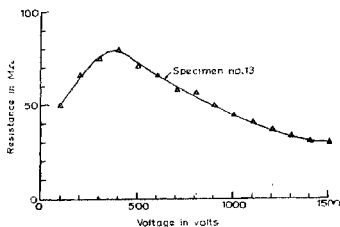


FIG. 3. Typical resistance-voltage characteristics of the tin oxide-based semiconducting paints.

values of β are more than unity for voltages below V_c and less than unity for voltages above V_c . The mechanism of conduction above V_c therefore seems to resemble the mechanism of conduction observed in SiC voltage dependent resistors⁹⁻¹¹. The mechanism of conduction at low fields below V_c may be controlled by the diffusion of charge carriers through the nonconducting medium. The values of β below and above V_c seem to be dependent on the nature of the nonconducting organic medium.

The mechanism of electrical conduction in silicon carbide voltage dependent resistors has been explained on the basis of two types of hypothesis. In the first case, it is proposed that every p -type grain of SiC has a coating of a thin layer of n -type material. The sintered polycrystalline compacts therefore act like a large number of p - n junction diodes connected in series and parallel in random directions. Two p - n junction diodes connected in parallel but in reverse direction would indeed give a symmetric nonlinear behaviour. The SiC VDRs, it is suggested, are a result of a number of such pairs of diodes connected in series and parallel to each other. This theory obviously cannot explain the mechanism of conduction in the semiconducting paints, because sintered products of n -type SnO_2 do not show this type of behaviour and hence the formation of p - n junctions has to be ruled out. Another mechanism suggested is based on the fact that each SiC grain has a thin protective layer of SiO_2 on its surface. This layer protects it from further oxidation and is responsible for the high temperature withstand capability of the SiC products. In case of sintered VDRs, this protective layer acts as an insulating barrier and electrons have to tunnel through this barrier in order to reach the bulk of the adjacent grain. This tunnelling across the SiO_2 insulating barrier at the surface of each grain is suggested to be responsible for the nonlinear

Table I

Typical values of the exponent β for various compositions

Sl. No.	Composition in gm/litre	Organic medium	Value of β	
			below V_c	above V_c
1.	710	Linseed oil	1.724	0.7042
2.	1000	Linseed oil	1.429	0.6757
3.	1600	Linseed oil	1.538	0.6757
4.	710	Karanja oil	1.600	0.5495
5.	1000	Cotton seed oil	1.379	0.4926

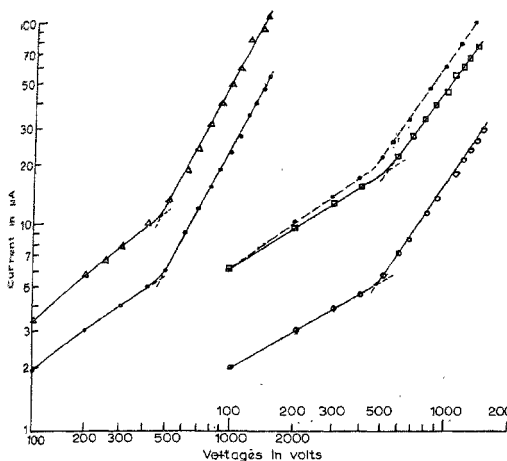


FIG. 4. Typical I-V characteristics on log-log scale.

behaviour of the SiC voltage dependent resistors. It is possible to explain the non-linear behaviour of the semiconducting paints on the basis of this model. The thin dielectric insulating layer, provided by the organic medium, coats the surface of the semiconducting tin oxide grains. The electrons therefore have to overcome this insulating barrier in order to be able to reach the bulk of the adjacent tin oxide grains.

4. Conclusion

The semiconducting paints based on the oxide as the basic semiconducting material exhibit nonlinear I-V characteristics and follow the power law relationship.

The mechanism of conduction in such paints exhibits a sharp transition at a critical voltage V_c and the mechanism of conduction above V_c seems to be similar to that exhibited by silicon carbide nonlinear voltage dependent resistors.

The nonlinearity as indicated by the value of the exponent ' β ' is dependent on the nature of the organic insulating medium.

5. Acknowledgement

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References

1. CLARK, C. H. W. Semiconducting glaze on high voltage insulators, *Elect. Rev.* 1964, **174**, 740.
2. MORAN, J. H. AND POWELL, D. G. *Trans. IEEE, Power Apparatus and Systems*, 1972, *PAS-91*, 2452-2457.
3. GHARE, D. B. *Semiconducting glazes for high voltage insulators*, Indo-Soviet Conference on Solid State Materials, Bangalore, 1972, Session E, Paper No. 14.
4. FUJIMURA, T., NAITO, K. AND IRIC, T. *Trans. IEEE, Power Apparatus and Systems*, 1978, *PAS-97*, 763-771.
5. PARTHASARATHY, G. AND GHARE, D. B. *Reduction in radio noise level of high voltage insulators by the application of semiconducting paint*, National Seminar on Electrical Insulation, Institution of Engineers, Bangalore, 1974, Session III, Paper No. 6.
6. SRIKANTAN, D. L. AND GHARE, D. B. *Pollution hazards faced on 220 kV electromagnetic potential transformers at Tarapur atomic power station switchyard and the improvements resulting from the application of the semiconducting paint*, Central Board of Irrigation and Power, 45th Annual Research Session, Hyderabad, 1976, **4**, 119-121.
7. GHARE, D. B. Tin oxide based semiconducting paints and their electrical properties, *Indian J. Technol.*, 1977, **15**, 67-70.
8. SCHWERTZ, F. A. AND MAZENKO, J. J. Nonlinear semiconductor resistors, *J. Appl. Phys.*, 1953, **24**, 1015-1024.
9. GOFFAUX, R. Electrical properties of silicon carbide varistors, *Proceedings of the conference on silicon carbide, A high temperature semiconductor*. April 1959, Boston, Pergamon Press, 1960, pp. 462-481.
10. IVANOV, L. I. AND PRUZHININA GRANOVSKAYA, V. I. *Soviet Phy. Tech. Phy.*, 1956, **1**, 216-227.
11. JACQUES SUCHET Nonlinear electric resistors, *U.S. Patent* 2, 714, 096, 26 July 1955.