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Study of the dc electrical properties of Bijoypur White Clay of Bangladesh

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Abstract : The current-voltage (I–V) characteristics of washed Bijoypur White Clay (BWC) samples, heat treated at 1273 K were investigated. It is found that Space Charge Limited Conduction (SCLC) mechanism is operative in these materials. The dc conductivity measurements of the different BWC samples prepared at 2000, 3000 and 3500 psi pressures were performed in the temperature range 300 to 673 K The temperature dependence of the dc electrical conductivity shows electrolytic behaviour below 380 K and semiconducting above The temperature dependence of electrical conductivity at the higher temperature region (above 380 K) indicates that the conduction is due to the thermally activated variable range hopping of charge carriers in the localized states.

Keywords : DC conductivity, hopping conduction, white clay

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1. Introduction

Bijoypur White Clay (BWC) found in the Netrokona district of Bangladesh is a white burning clay. BWC is being used in ceramics, insulators and sanitary industries. The chemical analysis of BWC has been reported by several authors [1–3]. Chowdhury and Bhuiyan [4] carried out an investigation on the structural modification of BWC on heat treatment and found that BWC modifies on heat treatment to a possible mullite phase. Sharif and Mian [5] reported preliminary results of the ac and dc electrical studies of graphite powder mixed BWC prepared at temperature 1073–1123 K in air. Rahman and Haque [6] prepared resistors from the mixtures of BWC and graphite powder in the proportion 1 : 3 by weight and investigated the I–V characteristics up to the applied voltage of about 10 V. It is seen from the different investigations on BWC that it is possible to prepare composite type passive electronic components of desirable electrical properties. Before going for useful applications of BWC, it is very much essential to know its electrical behaviour.

To the authors knowledge, the detail dc electrical properties of washed and heat treated BWC have not yet been reported. The potentials of BWC for electrical and other technological applications are uncertain without a fundamental understanding of its electrical properties. In this paper, an attempt is made to report the dc electrical properties of as-collected, washed and heat treated BWC.

2. Experimental details

2.1. Sample preparation :

The uncompressed hard and solid BWC was collected after removing the overburden of 5 m thickness from mine. The as-collected BWC was washed in the laboratory using a process that has been described earlier [7]. The washed clay suspension was dried in an electric oven at 378 K for 24 hours. This dried sample is labelled as washed BWC. The washed BWC was then ground and was passed through a 200 mesh sieve. The BWC was then placed inside a die punch of diameter 0.01 m. The washed BWC pellets were obtained with 2000, 3000 and 3500 psi pressures by using a hydraulic press unit. After removing the sample from the die punch, its upper and lower edges were polished and then a thin coating of conducting silver paste was applied which act as electrode for electrical measurements. Some of the prepared samples were heat treated in air at 773 and 1273 K for 6 hours before the silver paste coating was applied. The samples are designated as :

	Samples	Prepared at pressure (psi)
	A1	2000
As-collected BWC (A)	A2	3000
	A3	3500
	B1	2000
Washed BWC (B)	B2	3000
	B3	3500
Washed BWC heat treated at 773 K (C)	C1	2000
	C2	3000
	C3	3500
Washed BWC heat treated at 1273 K (D)	D1	2000
	D2	3000
	D3	3500

2.2. Measurement techniques :

The current and dc resistance was measured by a digital Keithley Electrometer (model 614, Keithley Instrument Inc., Cleveland, Ohio, U.S.A.). A pressure contact specimen holder, housed in a steel chamber, with an inbuilt heater was employed for these measurements at 303, 373, 423, 473 and 523 K. A transistorized power supply, model 6181C, of Hewlett Packard was used for constant voltage supply across the samples and the dc conductivity was calculated from the measured dc resistance at different measuring temperatures from 303 to 673 K. The I–V characteristic measurements were performed upto 100 V. The temperature was recorded by a Cr-Al thermocouple by measuring the emf with a microvoltmeter (model 197 A of Keithley Instrument Inc., Cleveland, Ohio, U.S.A.). All the measurements were performed in air.

3. Results and discussion

3.1. Current-voltage (I–V) characteristics :

I–V characteristic curves of sample D, for measurement temperatures 303, 373, 423, 473 and 523 K are presented in Figure 1. It is seen that current falls first and then increases

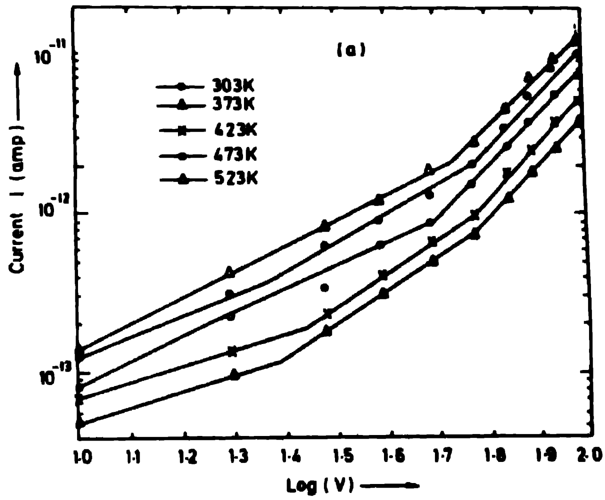

Figure 1(a). Current *versus* voltage at different temperatures for washed and heat treated at 1273 K BWC samples at 2000 psi.

gradually with measurement temperature. This fact will be discussed in the next section. It is observed that the I–V curves fit to a relation $I \propto V^n$, where n is a power factor. It is seen that first three temperature curves (303, 373 and 423 K) for D1 and D2 have three different slopes at low, intermediate and high voltage regions while there are two different slopes in the remaining two high temperature (473 and 525 K) curves. However, there are only two different slopes for all the temperatures in case of D3. The values of n for all the curves are depicted in Table 1.

In Table 1, it is seen that the low voltage region is ohmic and the intermediate and high voltage region follow a square law and a cube law with trap respectively. It is seen that the ohmic region is not present in the high temperature curves of samples D1 and D2. There are also two slopes over the voltage range employed for all the temperatures in the sample

D3, which corresponds to the region containing traps. When the transport is slower than the generation of carriers then the conduction is known to be due to Space Charge Limited Conduction (SCLC) [8]. The above results suggest that the SCLC mechanism is operative in these materials. At low voltages, the I–V characteristics are ohmic which may be related to adsorbed water, water of crystallization *etc*. In the intermediate and high voltage regions,

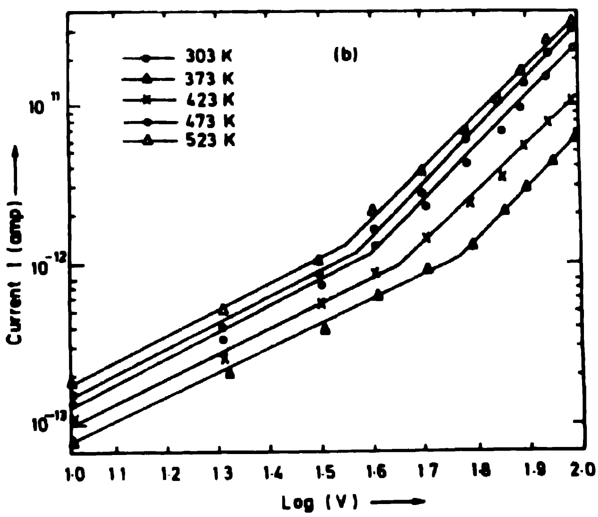

Figure 1(b). Current *versus* voltage at different temperatures for washed and heat treated at 1273 K BWC samples at 3500 psi.

the SCLC may be due to the higher concentration of the injected free carriers than that of the carriers due to the presence of water in the clay [8]. It is clearly seen that the temperature affects the SCLC behaviour which manifests the presence of traps in the material. Porosity plays an important role in deciding the concentration of the trap centre in a material. The absence of the ohmic region in sample D3 may be due to less porosity (low trapping centre) compared with that in the less pressurized samples D1 and D2 [9], resulting higher concentration of free carriers than that of the carriers related to water in the material even at low voltages.

Table 1. Values of power factor *n* for sample D at different measurement temperatures.

Pressure in psi	Voltage range	*n* values below 423 K	*n* values above 423 K
	Low	0.95	1.46
2000	Intermediate	2.16	×
	High	3.22	3.22
	Low	0.70	1.42
3000	Intermediate	2.30	×
	High	3.01	3.01
3500	Low	1.46	1.46
	High	3.23	3.23

3.2. Temperature dependence of dc electrical conductivity :

Generally, clay adsorbs water and that affect the electrical properties. To observe the effect of water on dc electrical conductivity σ_{dc}, σ_{dc} of sample D3 was measured for successive cycles. It is observed that after the first cycle of measurement, σ_{dc} becomes almost stable with lower values and on further heating, there is not appreciable change in the σ_{dc}. So, second cycle data are presented in this paper.

The σ_{dc} of all samples were measured over the temperature range 300 to 673 K. The plots of σ_{dc} against $1/T$ are shown for samples A and D in Figure 2. It is found that the room temperature σ_{dc} value is lower for washed samples than that of as-collected BWC and decreases further on heat treatment from 10^{-11} to 10^{-12} $(\Omega\text{–m})^{-1}$. The effect of pressure of pellet preparation on the σ_{dc} is not much significant within the applied pressure range used in this investigation. It is observed that there is an initial increase of σ_{dc} up to 310 K in samples A and B and that up to 320 K in samples C and D and then starts decreasing up to 380 K in all the samples and again σ_{dc} increases with increasing temperature.

The initial increase in σ_{dc} is probably due to the motion of hydroxyl ions and/or other species. The decrease of σ_{dc} value above 310 K may be attributed to the compensation effect of outgassing adsorbed water molecules, thereby decreasing the hydroxyl ion source and/or any other migratory ions. This initial increase and then fall of σ_{dc} is a behaviour of solid electrolyte. Above 380 K, the increase of σ_{dc} may be due to the increased movement of adventitious ions and/or electrons within the bulk of the material.

It is observed that the curves do not fit fairly to straight lines over the whole temperature range above 380 K for all the samples except for D. In sample D, there is a considerable departure from straight line above 500 K. The activation energies are calculated from the slope of the best fit straight lines of log σ_{dc} – $1/T$ plots. The values of σ_0, obtained by extrapolation of log σ_{dc} – $1/T$ plots to $1/T = 0$, are of the order of 10^{-10} to 10^{-8}. The activation energies and the pre-exponential factors of all the BWC samples are summarized in Table 2. The observed temperature dependence of conductivity and the activation energies calculated from the Arrhenius plots suggest that thermally activated conduction of charge carrier may be operative in electrical conduction in BWC.

Table 2. Activation energy E_r in eV and pre-exponential factor σ_0 in $(\Omega\text{–m})^{-1}$.

Sample	Temperature in K	Pressure 3500 psi		Pressure 3000 psi		Pressure 2000 psi	
		E_r	σ_0	E_r	σ_0	E_r	σ_0
A	373–673	0.308	2.0×10^{-10}	0.278	1.4×10^{-10}	0.238	1.1×10^{-10}
B	373–673	0.255	1.4×10^{-10}	0.230	1.0×10^{-10}	0.227	5.0×10^{-11}
C	373–673	0.226	2.5×10^{-10}	0.211	2.0×10^{-11}	0.199	5.0×10^{-11}
D	373–523	0.225	1.4×10^{-11}	0.197	1.3×10^{-11}	0.181	1.1×10^{-11}
	523–673	0.497	1.7×10^{-9}	0.411	5.0×10^{-10}	0.375	2.0×10^{-10}

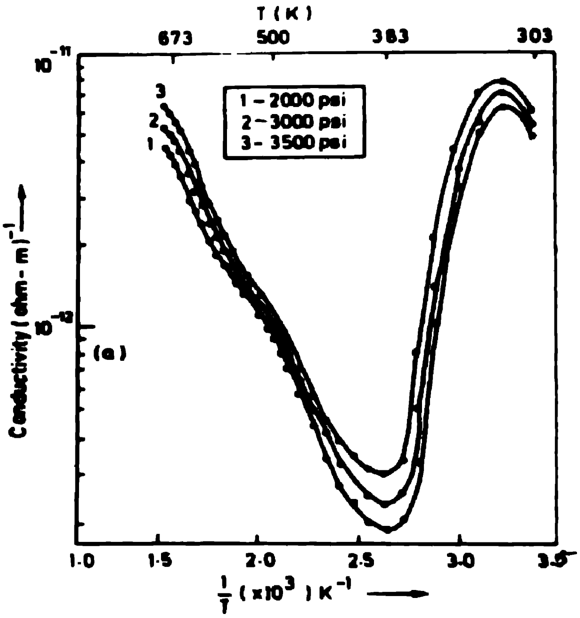

Figure 2(a). DC conductivity against inverse absolute temperature of as-collected BWC sample.

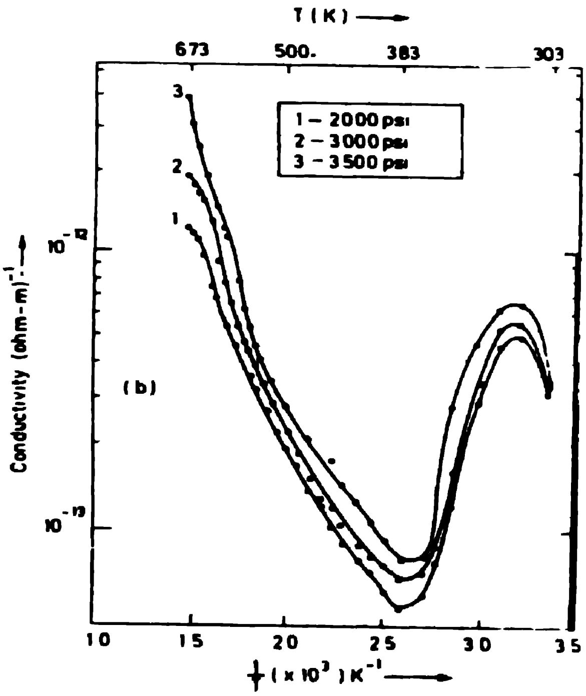

Figure 2(b). DC conductivity against inverse absolute temperature of washed and heat teated at 1273 K BWC sample.

As the curves illustrated in Figure 2 do not fit to simple straight lines, the same data are presented in Figure 3 as log σ_{dc} *versus* $T^{-1/4}$. The plots show fairly straight line behaviour. These results are typical of transport in disordered and amorphous materials [10]. Here, the variable range hopping between localized states leads to a temperature

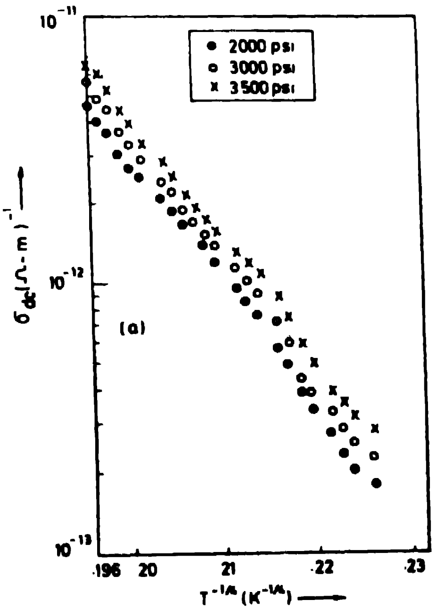

Figure 3(a). Electrical conductivity *versus* $T^{-1/4}$ of as-collected BWC sample

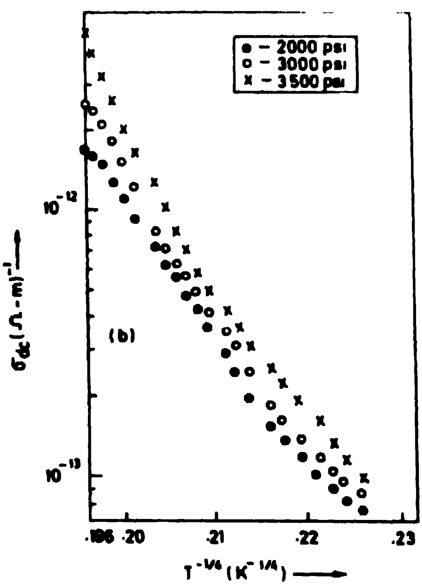

Figure 3(b). Electrical conductivity *versus* $T^{-1/4}$ of washed and heat treated (at 1273 K) BWC sample.

dependence of the form $\sigma = \sigma_0 \exp [-(T_0 / T)^{\frac{1}{d+1}}]$, where d is the dimensionality of transport (*e.g.*, $d = 3$ for three dimensional motions, *etc.*) [11]. Therefore, thermally activated variable range hopping of charge carriers in localized state is responsible for electrical conduction in these materials.

4. Conclusions

From n values, it is evident that SCLC with traps occurs in heat treated BWC which is dependent on porosity. The dc conductivity of washed samples is lower than those of as-collected samples. The σ_{dc} decreases on heat treatment and its value varies from 10^{-11} to 10^{-12} $(\Omega\text{-m})^{-1}$. The initial increase of σ_{dc} values below 320 K is due to adsorbed water and/or of hydroxyl ions; and this adsorbed water or hydroxyl ions decrease on increasing temperature above 320 K. As a result, σ_{dc} decreases. The further increase of σ_{dc} above 380 K is probably due to increased movement of ions/electrons within the material. It is found that thermally activated variable range hopping conduction between the localized states is operative in these materials.

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