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SCOPE OF ELECTRON TRANSPORT STUDIES BY THERMALLY STIMULATED DISCHARGE CURRENT MEASUREMENT

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Abstract

A logical approach to electron transport studies for barrier conduction in layered structures was adopted by thermally stimulated discharge current (TSDC) measurement. The scope and applicability of this technique to the evaluation of the thermoelectric parameters of relaxation time, detrapping energy and depolarization rates are demonstrated here. These are characterized by the controlling factors of layer resistance and the resultant thermal and voltage gradients which apply to the drift of electrons arising from both dipolar and interfacial charges. The methodologies used in this study are suitable for parametric evaluation of structured electronic devices.

Keywords: depolarization rate, detrapping energy, electron transport, layer resistance, relaxation time, TSDC

Introduction

Transport of electrons through a given medium forms the basis for any electrical phenomenon. The medium itself has been much studied for mechanistic understanding of electron mobility between a source and a drain in modern electronics. The barrier properties emanating from insulator/conductor interface is of particular interest in controlled phase device functions such as in metal–insulator–semiconductor (M–I–S) operations. The insulator is usually a material which can exhibit both insulating and conducting states by such mechanism as hopping or tunneling of electrons across the two regions for current conduction. Change to conduction from insulation has been confirmed for both pyrolyzed polyimide [1] and heat treated polyimide [2]. Since a thermal component is a necessary precursor in such phenomena, opportunities exist for evaluation of electron transport parameters across dissimilar interfaces by thermally stimulated discharge current (TSDC) measurement [3]. An example has been provided [4] for such evaluation for epoxy/silicone structural interfaces for some

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practical applications. The parameters evaluated were for interfacial polarization beyond the glass transition region where Maxwell–Wagner mechanism [5, 6] is operative. The purpose of this study is to investigate the scope of such evaluations in the glass transition region for multilayer interfaces, using modular instrumentation and single point data collection. The glass transition region is the area where both dipolar and interfacial discharges occur from multilayer interfaces.

A second part of this investigation will be reported separately for data evaluation in the insulator/semiconductor interface using laboratory-designed equipment for experimental studies and continuous data collection.

Experimental

Three interlayer samples providing multiple interfaces were investigated. The layout of the samples are reported in Table 1. The polyester is the same in samples 2 and 3, but different for sample 1.

Table 1 Data of interlayer samples

No.	Sample composition	Composite thickness/cm
1	polyester/polysilicone/polyester	$2.286 \cdot 10^{-2}$
2	polyester/silicone/polyetherimide/polyester	$2.362 \cdot 10^{-2}$
3	Polyester/acrylic ester/polyester	$1.524 \cdot 10^{-2}$

The theoretical and experimental aspects of the TSDC technique have been described before [3]. In this work, stainless steel electrodes were fixtured inside a thermal test chamber using a teflon cage and chromel wires for making the voltage and ground connections. A Spellman UHR30P10/100 high voltage power supply and a Keithley 617 programmable electrometer were used for voltage application and data collection, respectively. Data plotting was done by a computer program. For uniform comparison, all samples were subjected to the same experimental regimen. The poling temperature was 50°C, poling voltage was 5 kV DC, heating rate was 5°C min^{-1} and annealing time was 1 h at 150°C.

Results and discussion

Figure 1 shows the individual depolarization thermograms for all three samples.

It can be seen that the magnitude of depolarization in terms of current release and transfer efficiency is lowest for sample #2 which has a higher number of interfaces than the other two samples. For all samples, the initial discharge up to 100°C mainly from near surface dipole orientation and decay of instantaneous charge due to electrode polarization associated with the poling voltage is a low energy surface phenomenon. The peak is due to drift across the layer boundaries of trapped electrons injected from the charging electrode and localized dipolar charges. The end-stage rise

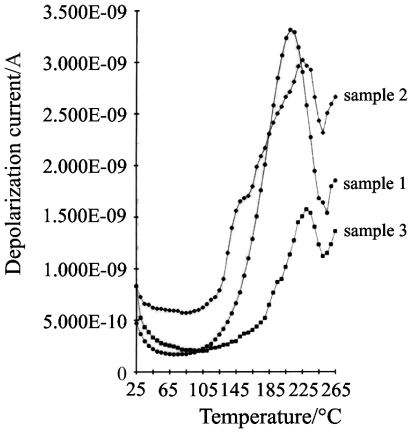

Fig. 1 Depolarization current *vs*. temperature

in current is due to the onset of Ohmic conduction which is strongly influenced by interfacial charge crowding. It is not observed in homogeneous media.

The depolarization curves of Fig. 1 were analyzed for transport properties. The initiation of the transport process is characterized by the finite relaxation time (τ) for conversion of charge carrying electrons from the bound state to the free state. Progressive changes in relaxation time with temperature were calculated by the relationship: $\tau=KT^2/[H_r\Delta H_{a\ exp}(\Delta H_a/KT)]$, where K is Boltzmann constant (eV K^{-1}), T is the absolute temperature and H_r is the heating rate (K s^{-1}). The required activation energy, ΔH_a, for the interfacial polarization process was determined from the initial rise in current [7] by the Arrhenius plot of I_n *vs*. $1/T$ according to the method of Perlman [8]. The activation energies have been determined to be 0.48, 0.41 and 0.49 eV for samples 1, 2 and 3 respectively.

The linear relationship of relaxation time with temperature, shown in Fig. 2, indicates that only a single type of dipole is involved in depolarization for all three samples. Otherwise the data would be scattered.

Under the poling field, the initial polarization is brought about by an induced charge shift throughout the material [9]. Polarization itself arises from both oriented dipoles and trapped electrons at various energy levels. Their drift by thermal stimulation across the layer boundaries produce an amount of Joule heat which is characteristic of the ratio of dissipated heat due to layer resistance and the emerging current. The calculated voltage drop across the sample has been found to be about 50% of the applied voltage for all samples.

Electron detrapping energy (ξ) i.e. the energy gap between the polarized state and depolarization, expressed in terms of relaxation times, was calculated by the relation:

$$(\xi) = KTI_n(\tau_2/\tau_1)$$

which was developed earlier [2] in another study. Successive relaxation times vary according to: $\tau_2=\tau_{1\ exp}(\xi)/(KT)$, where τ_1 is the relaxation time at a given temperature and τ_2 is the relaxation time at the next incremental temperature. Figure 3 shows the

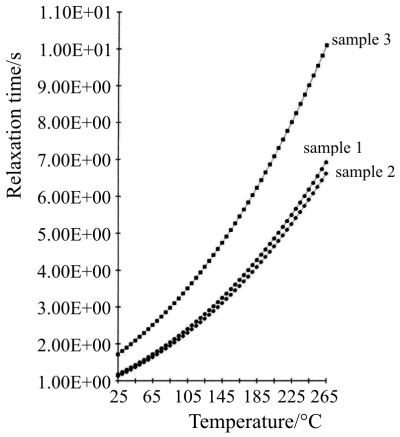

Fig. 2 Relaxation time *vs.* temperature

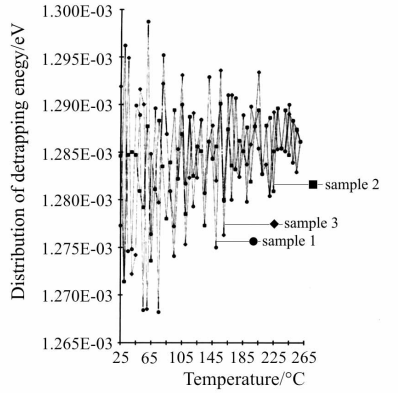

Fig. 3 Detrapping energy *vs*. temperature

energy distribution of trap levels which reflect the influence of thermoelectric coefficient of electrons on the thermal and voltage gradient in the material.

The resulting differentiation in conductivity produces the discharge current pattern of the depolarization curves in Fig. 1.

Finally, the rate of depolarization is a better measure of electron transport since it takes into account the retardation effect of the above factors on the discharge current. A previously developed equation [10], given below, was used for calculating temperature-dependent depolarization rates:

$$\text{depolarization rate} = [4\pi di(T)]/[\alpha(T)VA]$$

where $i(T)$ is the discharge current, $\alpha(T)$ is the transport frequency, V is the voltage drop. d and A are the sample thickness and electrode contact area respectively. The plots of depolarization rates *vs.* temperature in Fig. 4 for all three samples show relative dispersions and thermal shifts.

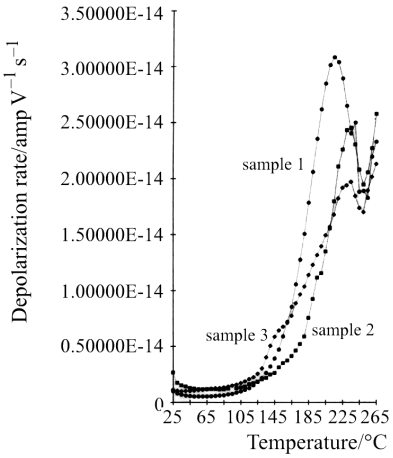

Fig. 4 Depolarization rate *vs*. temperature

Conclusion

The factors influencing the transport of electrons through layered barrier interfaces were investigated by thermally stimulated discharge current measurement. Thermoelectric parameters of relaxation time, detrapping energy and depolarization rates are reported here. These are mainly characterized quantitatively by the controlling factors of layer resistance and the resultant thermal and voltage gradients which apply to the drift of electrons arising from both dipolar and interfacial charges. The methodologies used in this study are suitable for parametric evaluation of structured electronic devices.

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