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ABSTRACT

A deep level transient capacitance spectroscopy (DLTS) system, modified for the measurement of transient conductance, has been used to observe γ-ray induced defect centres in the gate junction of 2N4416 Si field effect transistors. The defect concentrations increased linearly with γ-dose in the range 50 kGy to 10 x 10^3 kGy (5-1000 Mrad) for the common E_c - 0.17 eV level, and in the range 500 kGy to 10 x 10^3 kGy (50-1000 Mrad) for the levels E_c - 0.22 eV and E_c - 0.44 eV. Another common level, a hole trap at E_v + 0.42 eV, was the only minority trap observed. The technique may be useful for measuring γ-fluxes in situations inaccessible to standard dosemeters (e.g. flux-mapping).

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EMISSION SPECTROSCOPY; VACANCIES; RADIATION EFFECTS; GAMMA RADIATION; FIELD EFFECT TRANSISTORS; SILICON; DOSEMETERS

CONTENTS

1. INTRODUCTION

The technique of deep transient capacitance spectroscopy (DLTS) [Lang 1974] is standard for analysis of defect levels in semiconductors. By periodically reducing the reverse bias on a diode, trapping centres are filled, and their emission is monitored as a function of temperature by measuring transient changes in the device capacitance. In this way, individual defect levels may be observed.

The fundamental limit to the sensitivity of the technique is reached for semi-insulating devices, or for those in which capacitance change with bias is very small. In this case, transient current or conductance measurements may be performed. For field-effect transistor (FET) structures, the drain conductance may be monitored as detrapping from defect states modulates the channel depletion depth. This report describes observation of the common deep level A- and E-centres in γ-irradiated silicon FETs, using a modified transient capacitance spectroscopy system.

2. APPARATUS

The capacitance bridge used in the system is a Boonton model 71A L-C meter and signal processing is by an electronic correlator [Miller et al. 1975]. To convert to the conductance mode, the sample RF signal voltage into the phase detector of the bridge is interrupted and the phase of the signal shifted 270° to enable observation of the real component of device impedance. This is effected by using a Canberra 1457 delay amplifier and a calibrated coaxial cable acting as a phase trimmer. The phase is optimised by noting the maximum response when a resistor is placed across the test terminals (or alternatively a null response if a capacitance is added). The modifications to the bridge and setting up of the system are minor [Williams et al. 1980], so any standard DLTS apparatus without a transient conductance capability may be converted.

3. EXPERIMENTAL

The experiment involved six groups of three FETs selected from different batches. One set was used as a control group and the others received doses of 50, 250, 500, 5 x 10^3 and 10 x 10^3 kGy (5, 25, 50, 500 and 1000 Mrad), respectively, at 21 kGy h^{-1} (2.1 Mrad h^{-1}). Irradiations were performed in a cobalt-60 irradiation facility at ambient temperature, fluxes being calibrated by the AAEC's Isotope Division. The current-voltage (I-V) characteristics of each FET were recorded before irradiation so that each group contained FETs of similar transconductance (g_m). Transient conductance scans were performed over the temperature range 77-300 K by locating the FETs in a brass holding block which was mounted in a continuous flow cryostat (Oxford Instruments CF-100). The FET gate was pulsed towards or into forward bias to obtain the majority or minority defect level spectrum. A 500 µs bias reduction pulse was used, supplied by a Systron-Donner 100A pulse generator. The drain voltage was 1.35 V; this voltage is not critical as long as the FET is below pinch-off and above zero volts, since the I-V characteristic is linear in this region.

4. RESULTS

Figure 1(a) shows a typical majority carrier spectrum. The E_c - 0.17 eV level is the A-centre, oxygen-vacancy (O-V), and has been studied after irradiation of silicon by protons [Kimerling et al. 1978], neutrons [Whan 1966] and electrons [Kimerling 1977]. The E_c - 0.22 eV level is commonly assigned to a divacancy (V-V) defect, and the E_c - 0.44 eV level to phosphorus-vacancy (P-V) [Kimerling 1977]. Apart from the three dominant defects, there is evidence for levels estimated as E_c - 0.19 eV and E_c - 0.36 eV respectively. These are probably levels E4' and E6 of Kimerling et al. [1978]. When our results are compared with those of Kimerling [1977] it can be inferred that the starting material for the FETs is low oxygen content, float-zoned, phosphorus-doped silicon.

Figure 1(b) shows the appearance of the hole trap E_v + 0.42 eV when the gate is forward biased. This is commonly thought to be either a higher charge state of the A-centre, or an interstitial related defect [Kimerling 1977]. From Figure 1(c) it can be seen that at a dose of 50 kGy (5 Mrad), the A-centre is visible, but it is not until 500 kGy (50 Mrad) that the other levels are clearly defined.

Cross sections were measured from the dependence of correlator output signal on trap filling time. The results correlate closely with those of Kimerling [1977]. Figure 2(a) shows the reduction in relative correlator output signal as a function of bias reduction pulse width (during which time the traps are filled).

The conductivity, g, of a semiconductor in which electrons are the majority carriers, is given by

$$g = e\mu_n n \tag{1}$$

where e = electronic charge, μ_n = electron mobility, and n = net free carrier density (= N_D-N_A where these are the total donor and acceptor concentrations, respectively). A slight increase Δn (<<n) in the free carrier density leads to a slight increase, Δg, in the conductivity of the sample. In this technique the thermal detrapping of electrons from defects provides such an increase, i.e.

$$\Delta n = N_T$$

where N_T is the concentration of the particular defect level. For the condition Δg/g <<1,

$$N_T = \frac{\Delta g}{g} n \tag{2}$$

This equation was used to estimate trap concentrations by measuring Δg_d, the magnitude of the transient conductance change by pulsing to zero bias and g_d, the drain conductance of the FET at the peak temperature. Figure 2(b) shows the dependence of Δg/g on the bias pulse amplitude; the linearity of the plot indicates that the defects are uniformly distributed through the region.

Figure 3 shows a plot of relative defect concentration versus dose received. The slopes are

E_c - 0.17 eV	1.2×10^{-5} kGy^{-1} (1.2×10^{-4} Mrad^{-1})
E_c - 0.22 eV	7.23×10^{-7} kGy^{-1} (7.23×10^{-6} Mrad^{-1})
E_c - 0.44 eV	9.48×10^{-7} kGy^{-1} (9.48×10^{-6} Mrad^{-1})

Absolute defect concentrations require a knowledge of n, which may be obtained from a measurement of the FET pinch-off voltage and a knowledge of the channel depth. It appears that the ultimate sensitivity of this system is approximately 10^{-4} of the net background doping density, which is similar to the capacitance mode operation. Figure 4 shows the Arrhenius plot of the four main levels, these data leading to the activation energies of the traps.

5. DISCUSSION

The homogeneity of the FETs (results within any dose group were within 15 per cent of each other, aided by preselection on the basis of similar g_m* (approx. ± 10 per cent), combined with the linearity of defect concentration with dose suggests that, at least in the range approx. 500 kGy to approx. 10 x 10^3 kGy (approx. 50 to approx. 1000 Mrad), they may be useful as dosemeters. They may be particularly useful in situations where conventional monitoring is difficult, for example where there is a demand for physically small, readily available, mass produced monitors (e.g. flux-mapping). It is intended to use them at the AAEC Research Establishment as a secondary check for flux measurements when irradiating other semiconductor materials for DLTS studies.

For general application, of course, a DLTS system must be available, but as the technique is now standard, 2N4416 FETs are cheap (and widely available) and the levels monitored are well characterised, this may be a simple and novel means of γ-flux measurement.

It may be possible to construct a 'sensitised' FET structure dedicated to flux measurement using DLT conductance spectroscopy. For example, a highly oxygen-doped silicon FET would give improved sensitivity of the O-V level. If it were possible to increase the oxygen content by two orders of magnitude, this would allow measurement of fluxes in the 25 kGy (2.5 Mrad) region, the approximate legal minimum for the γ-ray induced sterilisation of medical items, and the 500 Gy to 5 kGy (50 krad - 0.5 Mrad) dose range used in food processing. Defect introduction rates vary with temperature, particle type and energy [Kimerling et al. 1978], so a prior calibration would be needed before the FET is used as a dosemeter. The FETs would also need a fairly strict (say ± 10 per cent) constancy of the oxygen, and possibly phosphorus (or As or Sb) content. Operation as a dosemeter at elevated temperatures would be no problem as the levels of interest do not begin to anneal out until at least 120°C [Evwaraye 1977; Kimerling 1977].

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* Note that preselection on the basis of g_m (related to $\sqrt{n}$) is essential as the doping density of Texas Instruments 2N4416 JFETs extends over the range $5.3 \times 10^{15} - 1.0 \times 10^{16}$ cm^{-3}.

6. SUMMARY

The common and well-characterised A- and E-centres have been observed in the gate junction of γ-irradiated n-channel silicon FETs using a modified DLTS system to enable transient conductance measurements. The possibility exists of using commercial FETs as dosemeters for the flux range 50 kGy to 10×10^3 kGy (5-1000 Mrad). A dedicated FET structure, suitably doped for more sensitive defect detection, could prove useful in the technologically important flux ranges 500 Gy to 25 kGy (50 krad to 2.5 Mrad).

7. ACKNOWLEDGEMENTS

Dr E.M. Lawson kindly arranged the γ-irradiation performed by Mr J. Gray of the AAEC's Isotope Division. The authors thank Texas Instruments for supplying information on the doping density of the silicon used in the manufacture of the FETs. S.J. Pearton acknowledges the support of an Australian Institute of Nuclear Science and Engineering (AINSE) postgraduate studentship.

8. REFERENCES

Evwaraye, A.O. [1977] - J. Appl. Phys., 48(5)1840.

Kimerling, L.C. [1977] - Radiation effects in semiconductors. Inst.Physics Conf. Series No. 31:222.

Kimerling, L.C., Gibson, W.M. and Blood, P. [1978] - Int. Conf. on Defects in Semiconductors, Nice, France. Inst. Physics Conf. Series No. 46:273.

Lang, D.V. [1974] - J. Appl. Phys., 45:3023.

Miller, G.L., Ramirez, J.V. and Robinson, D.A.H. [1975] - J. Appl. Phys., 46(16)2638.

Whan, R.E. [1966] - J. Appl. Phys., 37(9)3378.

Williams, A.A., Pearton, S.J. and Alexiev, D. [1980] - AAEC unpublished report.

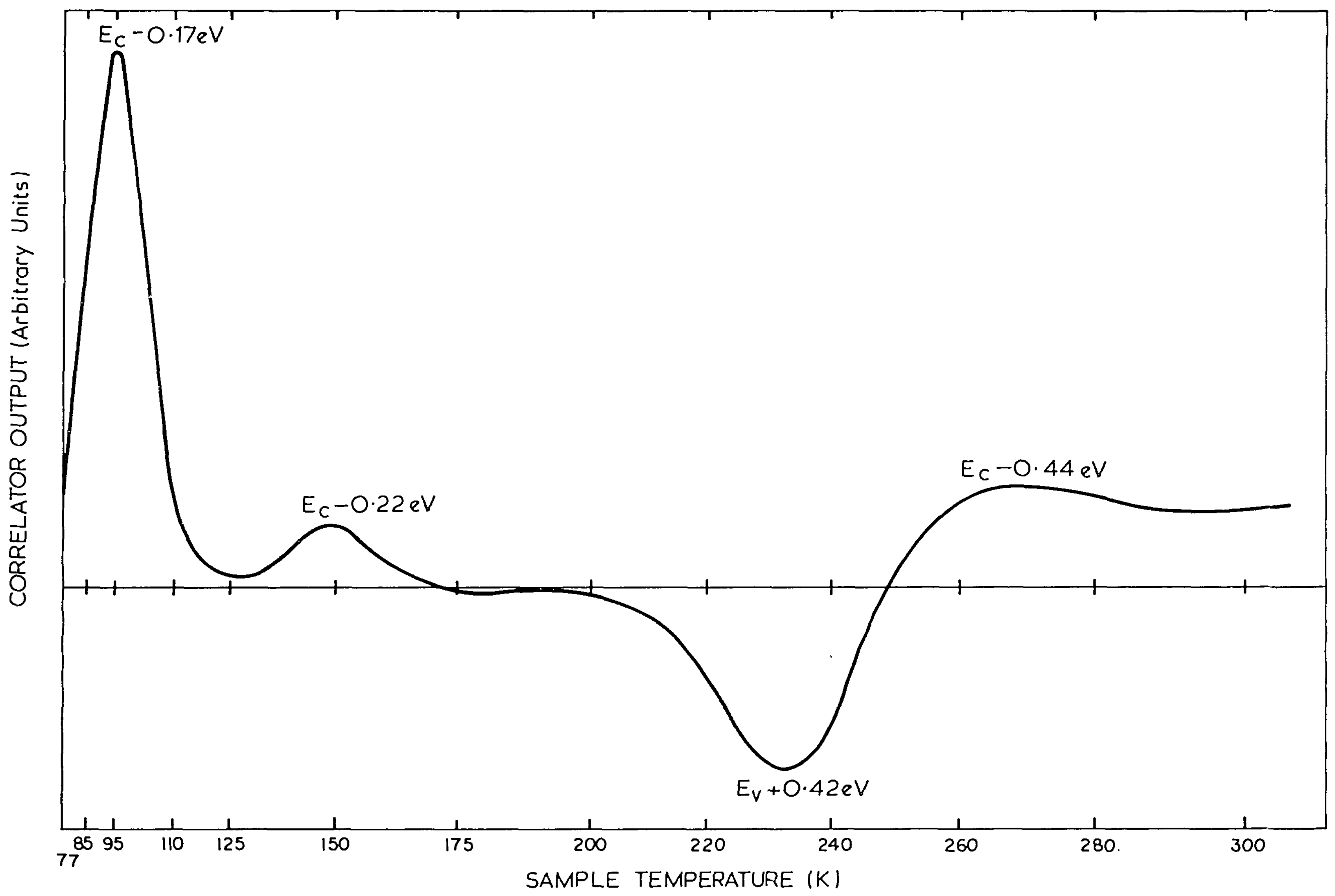

FIGURE 1(a) DLT CONDUCTANCE SPECTRUM FOR DOSE OF 5 MGy (500 Mrad), GATE FORWARD BIASED TO DISPLAY MINORITY DEFECTS

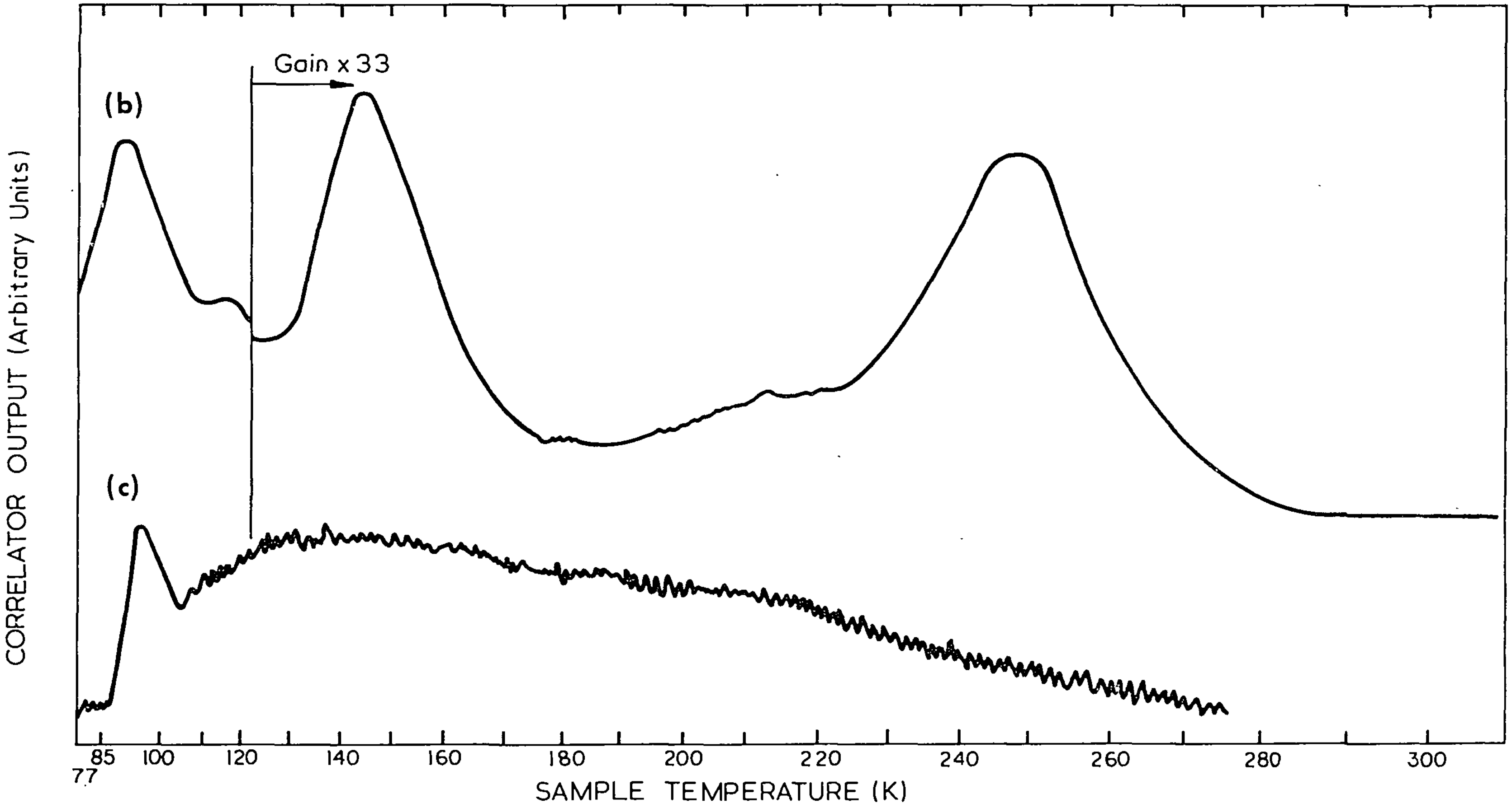

FIGURE 1 (b) TRANSIENT CONDUCTANCE MAJORITY DEFECT SPECTRUM FROM A γ-IRRADIATED 2N4416 FIELD EFFECT TRANSISTOR FOR DOSE OF 5 MGy (500 Mrad)

(c) DLT CONDUCTANCE SPECTRUM FOR DOSE OF 50 kGy (5 Mrad)

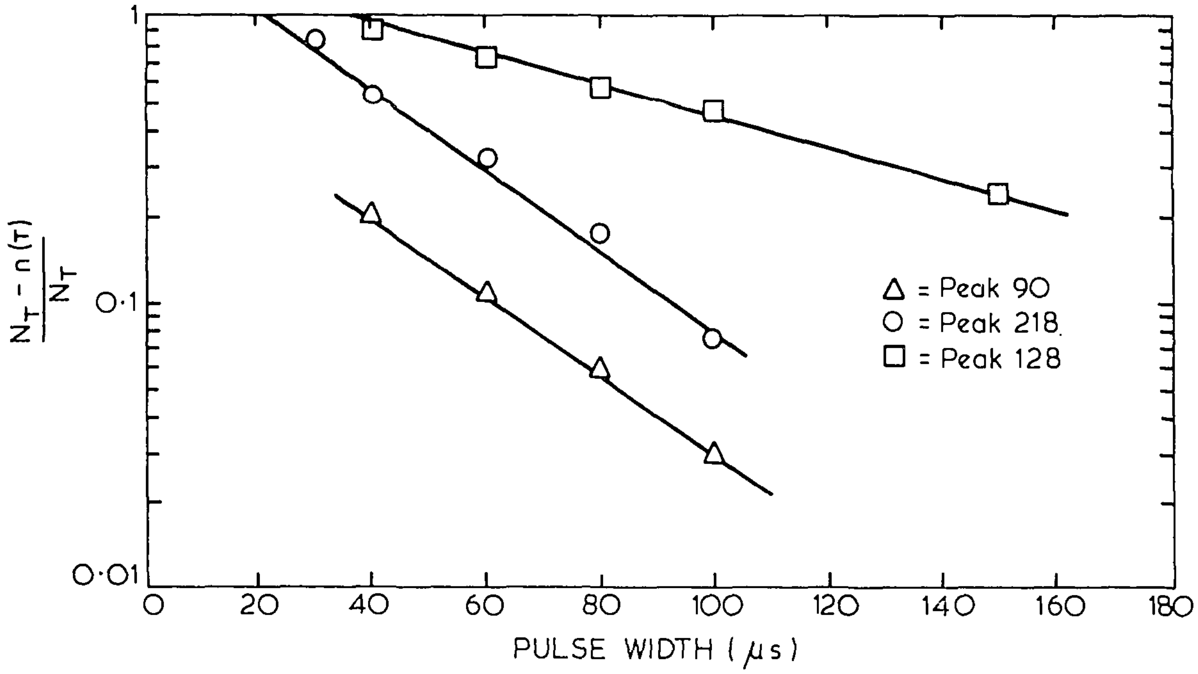

FIGURE 2 (a) RELATIVE CORRELATOR SIGNAL OUTPUT v. PULSE WIDTH FOR THREE DOMINANT MAJORITY LEVELS

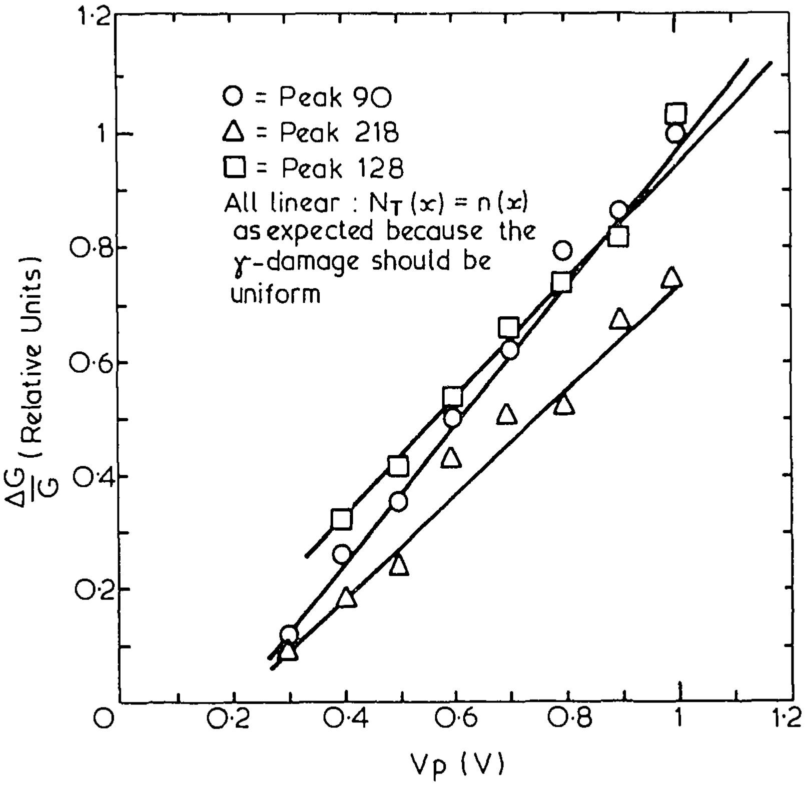

FIGURE 2 (b) TRANSIENT CONDUCTANCE CHANGE v. PULSE AMPLITUDE FOR THREE DOMINANT MAJORITY LEVELS

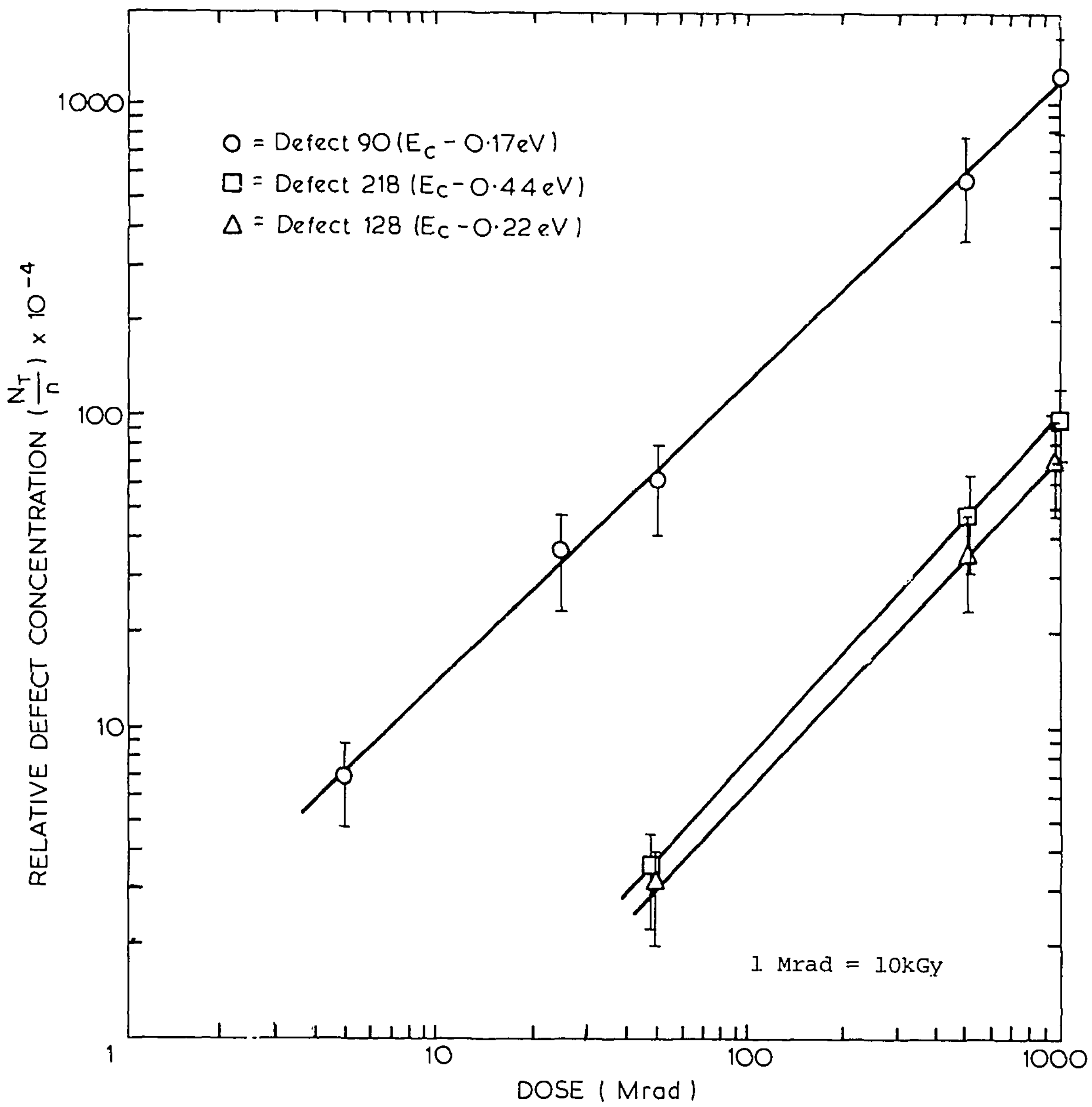

FIGURE 3. DOSE DEPENDENCE OF RELATIVE DEFECT CONCENTRATION FOR THE THREE DOMINANT MAJORITY LEVELS

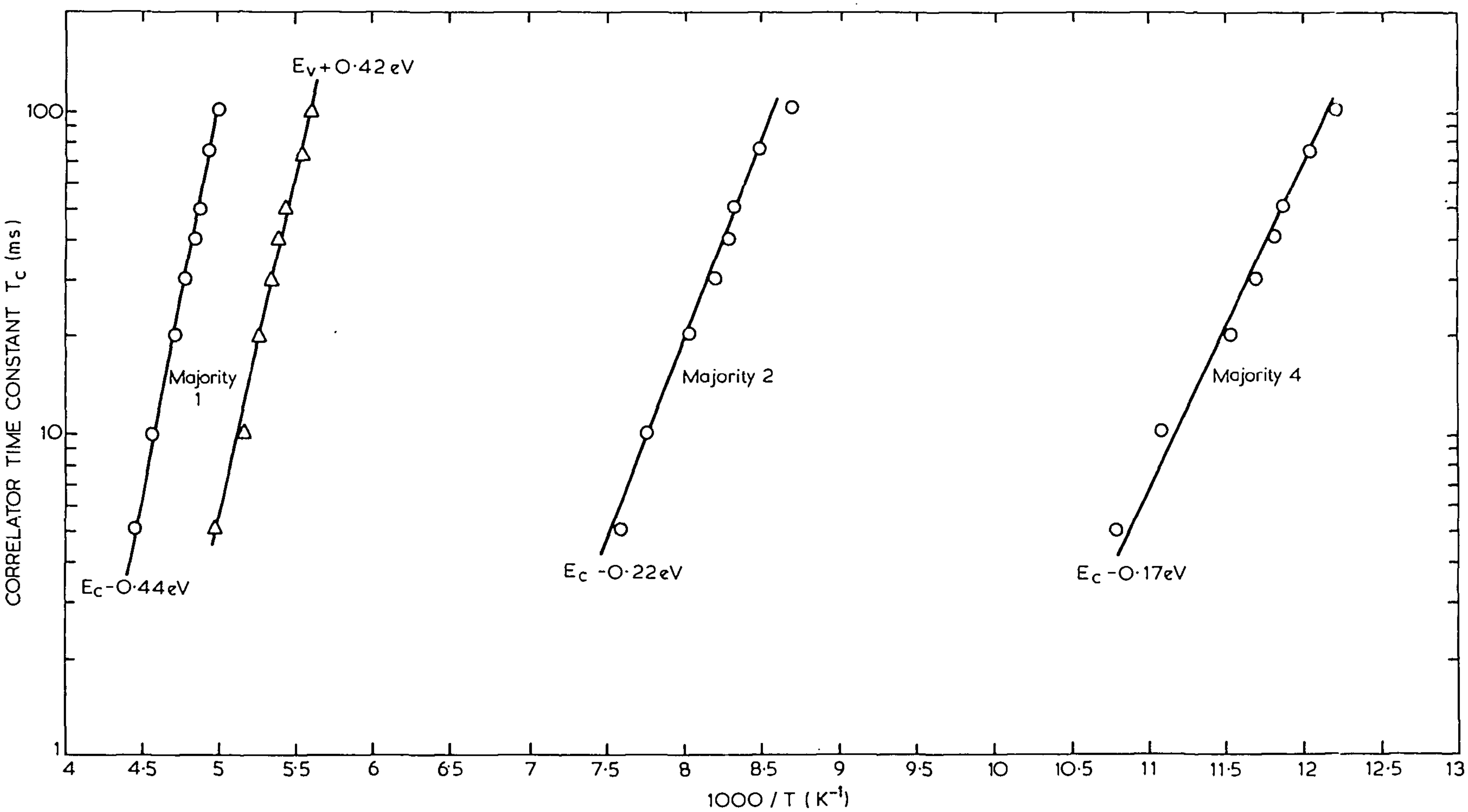

FIGURE 4. ARRHENIUS PLOTS OF THE FOUR MAIN DEFECT LEVELS

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