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# Polarization Effects in Radiation-Induced Conductivity

Harold P. Hjalmarson

*Sandia Labs, Albuquerque, NM 87185*

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## Abstract

Calculations of polarization effects to be expected in a radiation-induced conductivity (RIC) are described.

## I. INTRODUCTION

This document describes calculations of radiation-induced conductivity (RIC) using REOS. These calculations illustrate the effects of charge polarization caused by defects for a particular fused silica sample for which RIC data has been obtained.

## II. EXPERIMENT

The RIC data was collected for several insulating samples including fused silica, sapphire, alumina, Teflon, Kapton and Pyralux.

The experiments were performed on samples mounted in a holder that minimizes enhanced dose effects. In this holder, the currents from two samples are collected at the same time. The samples are press-fitted into this sample holder.

The thickness of each sample is approximately 250 microns (0.01 inch) and the irradiated area is 1.8 $cm^2$. The focus of this report is on the fused silica sample.

## III. THEORY

The theoretical foundation of the calculations is described. A specific simple model is described in which the kinetics of the electrons and holes are controlled by defects present in large concentrations. These defects tend to trap carriers. As the density of defects with trapped carriers grows, these defects act as recombination centers. For example, the neutral defects that trap electrons begin to trap holes. This process recombines the electrons and holes.

Specific traps for electrons and holes are assumed to exist in the oxide. The electron trap is assumed to have two states, a neutral $T_n^0$ and a negative $T_n^-$ charge state. The corresponding reactions are the following:

$$T_n^0 + n \rightarrow T_n^- \tag{1}$$

$$T_n^- + p \rightarrow T_n^0. \tag{2}$$

The hole trap is assumed to have two states, a neutral $T_p^0$ and a positive $T_p^+$ charge state. The corresponding reactions are the following:

$$T_p^0 + p \rightarrow T_p^+ \tag{3}$$

$$T_p^+ + n \rightarrow T_p^0. \tag{4}$$

The kinetic equations for the electrons and holes then become:

$$\frac{dn}{dt} = \frac{1}{q}\nabla \mathbf{J}_n + g - k_{n1f}[T_n^0]n + k_{n1r}[T_n^-] - k_{p2f}[T_p^+]n + k_{p2r}[T_p^0] \tag{5}$$

$$\frac{dp}{dt} = -\frac{1}{q}\nabla \mathbf{J}_p + g - k_{p2f}[T_p^0]p + k_{p1r}[T_p^+] - k_{n2f}[T_n^-]p + k_{n2r}[T_n^0] \tag{6}$$

in which $g$ is the generation rate for electrons and holes. The following are the drift-diffusion equations for the electron and hole currents:

$$\mathbf{J}_n = qn\mu_n E + qD_n \nabla n \tag{7}$$

$$\mathbf{J}_p = qp\mu_p E - qD_p \nabla p \tag{8}$$

A noteworthy point is that these trap levels are so deep that carrier emission can be ignored. This follows because all the materials are wide bandgap insulators. One consequence of this assumption is that equilibrium is not assumed for these charge states. Thus one must assume that their occupancy must be set as an initial condition. In the calculations to be described, the traps are initially neutral.

## IV. REOS CALCULATIONS AND DISCUSSION

In this section, REOS calculations of photocurrent for $SiO_2$ are described. The sample consists of a 250 $\mu m$-thick $SiO_2$ layer sandwiched between two 1 $\mu m$-thick Si layers. The right-hand side Si-layer has $10^{17}$ cm$^{-3}$ n-doping; the left-hand side Si-layer has $10^{17}$ cm$^{-3}$ n-doping. The electron diffusion coefficient is take to be 0.5 cm$^2 s^{-1}$ and the hole diffusion coefficient is taken to be $10^{-5}$ cm$^2 s^{-1}$. The $SiO_2$ layer has two types of midgap recombination centers with densities $[T_n^0] = 10^{19}$ cm$^{-3}$ and $[T_p^0] = 10^{19}$ cm$^{-3}$. The cross-sections for neutral capture are $\sigma_0 = 10^{-15}$ cm$^2$ and for Coulomb capture they are $\sigma_c = 10^{-13}$ cm$^2$. This sample is inserted in a simple circuit consisting of voltage source and resistance $R = 10^{-2}$ Ohm.

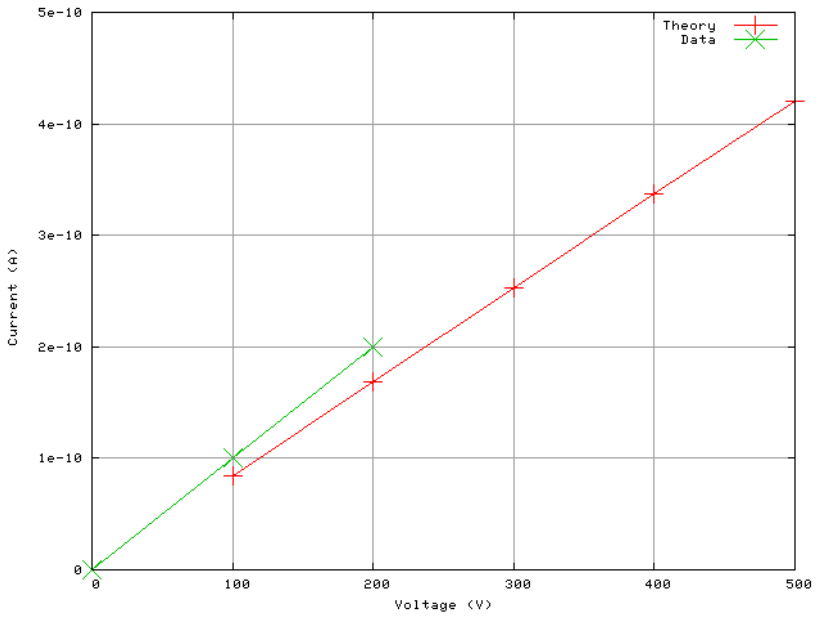


FIG. 1: Compares the experimental and theoretical current as a function of voltage.

Fig. 1 compares the experimental and theoretical currents as a function of applied voltage. The magnitude of the current is governed by the electron collection length. This quantitity

$$L_{cn} = \mu_n \tau_n F \tag{9}$$

depends on the electric field $F$, the mobility and the carrier lifetime. In this particular case the electron lifetime serves as an empirical parameter that is used to fit the data. In particular

$$\frac{1}{\tau_n} = v_{th} \sigma_{n0} [T_n^0] \tag{10}$$

depends mostly on the electron trap density $[T_n^0]$ because the other quantities are known. A density

$$[T_n^0] = 10^{18} \text{ cm}^{-3} \tag{11}$$

is used to fit the data [1].

Fig. 2 shows two transient currents. The top curve shows transient current as a function of time for a bias voltage 300 V and a radiation pulse of duration $10^{-6}$ s. The saturated value of this current corresponds to the current at 300 V in Fig. 1. The lower curve shows

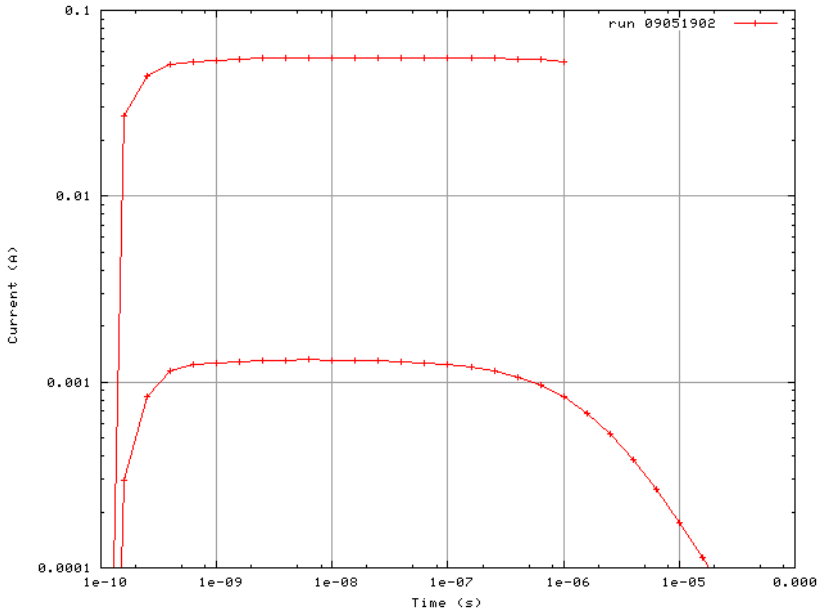


FIG. 2: The top curve shows transient current as a function of time for a bias voltage 300 V. The radiation pulse duration is $10^{-6}$ s. The lower curve shows the depolarization current during subsequent irradiation with no bias. This current flows until the sample is depolarized.

the depolarization current during a subsequent irradiation with no bias. This current rises to a saturated value determined by the circuit. It flows until the sample is depolarized.

## V. DISCUSSION

The depolarization current shown in Fig. 2 is driven by the polarization of the sample caused by the first irradiation of a sample with no trapped charge. This polarization is caused by defect reactions that depend on the positions of the traps in the insulating region. In the first irradiation, the holes are driven to the RHS and the electrons to the LHS. Thus more holes are trapped on the RHS and fewer electrons recombine with these trapped holes. Similar reasoning applies to the effects on the LHS of the sample.

The polarization current has been eliminated by the second irradiation. However, the sample has not been restored to its initial condition prior to the first irradiation because it remains charged. In other words, the second irradiation has simply made the charge distribution uniform. Another method, such as heating to release the trapped charge, would be necessary to restore the sample to its initial condition.

The polarization current discussed in this report represents one way that previous irradiation history can be seen in subsequent experiments. This effect can be affected by additional radiation. In this particular example, the polarization effect can be removed by irradiation but the sample remains charged because the irradiation produces equal concentrations of electrons and holes.

## VI. SUMMARY

The polarization current discussed in this report represents one way that previous irradiation history can be seen in subsequent experiments. A measurement of this current has the potential to give new information about the defects in the insulating material. Such information may be very useful because the densities and properties of these defects are usually not well-known but these defects have a dominant role in controlling the electrical effects of these materials.

## VII. ACKNOWLEDGMENT

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[1] H. P. Hjalmarson and E. F. Hartman, "Calculations of radiation-induced conductivity compared with data," 2009.