

# Thermally stimulated detrapping in porous silicon

C. Anastasiadis \*, D. Triantis

*Electronics Department, Technological Education Institute, Egaleo, 122 10 Athens, Greece*

## Abstract

A thermally stimulated current (TSC) methodology has been used to reveal the mechanisms of detrapping in porous Si (C. Bucci, R. Fieschi, G. Guidi, Phys. Rev. 148 (1966) 816). This thermally stimulated method consists of electrically polarizing a sample at temperature,  $T_0$ , which is depolarized consequently during heating, giving rise to a depolarization or trap-discharge displacement current which can be recorded. When double layer dielectric-semiconductor materials such as porous silicon on a heavily doped silicon substrate are subjected to an electret formation cycle, charge trapping may easily occur. This is explained by the fact that the heterogeneity at the interface between Si and PSi is the source of numerous discontinuities and imperfections in the Si crystal in addition to those existing in the porous layer, all of which are capable of capturing electric carriers because the transition region near the interface may also produce new allowed electron states in the bandgap. The electrical behaviour of the whole material is affected by such an internal structure which is mostly similar to an extended semiconductor surface due to its pores (R.C. Anderson, R.S. Muller, C.W. Tobias, J. Electrochem. Soc. 138 (1991) 3406). Thus, one may state that the electrical properties of PSi are close to those of a surface dominated semiconductor. In the present work an attempt has been made to calculate the activation energy of hole traps within porous Si. © 2000 Elsevier Science S.A. All rights reserved.

*Keywords:* Porous silicon; Thermally stimulated discharge currents; Traps

## 1. Introduction

Porous silicon (PSi) is believed to exhibit an electrical behaviour similar to that of electrets. Charge trapping and detrapping may easily occur due to the numerous imperfections in its lattice. In the present work the method of thermally stimulated discharge currents (TSDC) was applied for the calculation of the activation energy of hole traps within PSi. We used a circular, 15 mm in diameter and 20  $\mu\text{m}$  thick PSi sample with 46% porosity which had been prepared on a heavily doped p-type Si  $\langle 100 \rangle$  substrate with a specific resistance  $\rho = 0.01 \Omega \text{ cm}$  whose thickness was 380  $\mu\text{m}$  [1]. The specific resistance of the porous layer was  $\rho = 4.7 \times 10^{10} \Omega \text{ cm}$ . Due to the extremely large quantity of imperfections and discontinuities in the porous layer lattice, there are many carrier traps in it, most of which are already occupied at room temperature and in this case they are adequate to produce TSDC. For this reason, no irradiation was used for the excitation of the material and the subsequent filling of all empty traps by carriers generated in this way.

## 2. Experimental

The sample was subjected to a  $5 \text{ kV cm}^{-1}$  electric field polarization for 30 min at room temperature. The applied field was perpendicular to the porous layer and the positive terminal of the source was connected to the porous surface via a platinum plated copper electrode whilst the negative terminal was connected to the surface of the solid silicon substrate. The polarization results in an initial ‘sweeping’ of those carriers that have not been trapped, driving them to the respective electrodes. Following this, with the field still on, the sample was cooled to 180 K. Then, the electric field was removed, the sample was shorted through a sensitive electrometer and heated to 300 K at a linear rate  $b = 0.065 \text{ K s}^{-1}$ . As the temperature increased, detrapping of carriers started. It was indicated by a weak hole current as seen in Fig. 1. The assumption that the detrapped carriers are holes, is based on the fact that the sample is very heavily doped with boron atoms. Boron is a substitutional impurity from group III of the periodic table and requires an extra electron to complete the valence bonding, and therefore, at all except the very low temperatures, the B-atom takes an electron from a neighbouring host atom and creates a hole.

\* Corresponding author.

E-mail address: cimon@ee.teiath.gr (C. Anastasiadis)

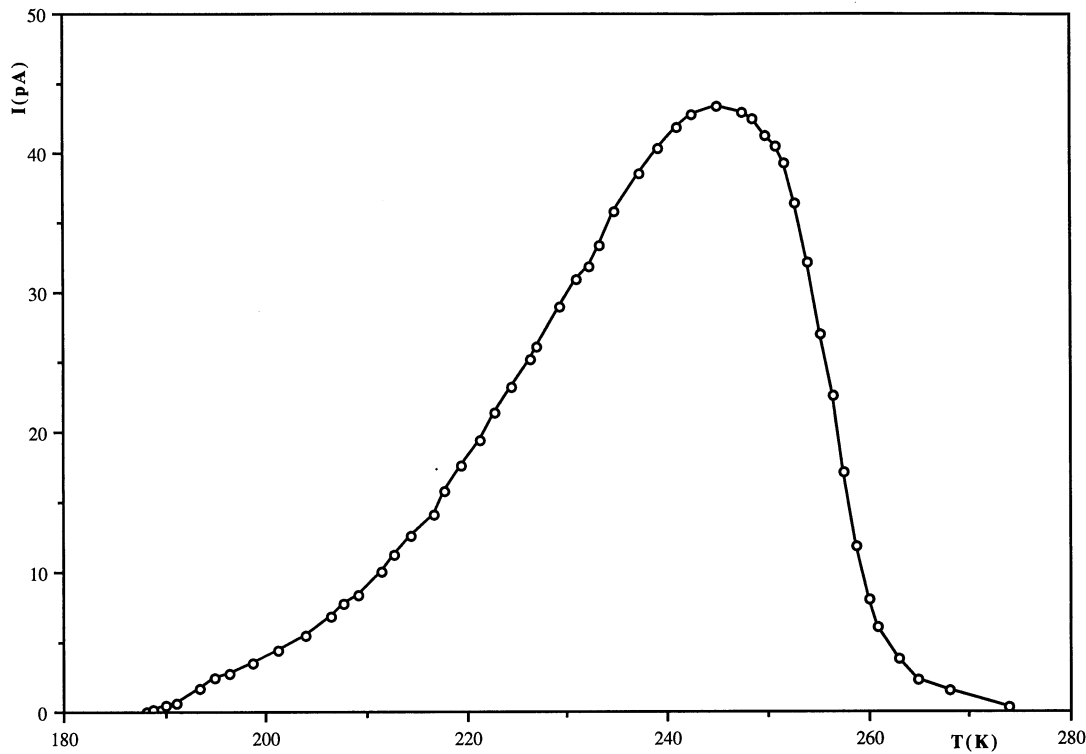


Fig. 1. Trap discharge current vs. temperature.

The hole concentration corresponding to the resistivity of the sample in the temperature range of this experiment is approximately  $10^{20} \text{ cm}^{-3}$  [2]. The trap density in the porous part of the sample is approximately  $10^{19} \text{ cm}^{-3}$  [3]. We suppose that the temperature is sufficiently low in relation to the relative boron ionization energy (0.045 eV), so that the concentration of thermal carriers may be neglected [4]. For simplicity we also assume that the recombination coefficient is the same for electron-hole recombination as for electron-trap capture. Under these conditions, it is statistically impossible for a detrapped electron to contribute to a thermally stimulated current (TSC) instead of recombining with a hole. Hence, the measured TSC is due to detrapped holes. The plot of current  $I$  versus absolute temperature  $T$  is a typical TSDC curve.

After this result an attempt was made to calculate the activation energy  $E$  of the traps engaged in the TSDC procedure. Two methods for evaluating  $E$  were used. First, we used the Bucci–Fieschi–Guidi (BFG) method [5] to calculate the relaxation time of holes by taking advantage of the whole TSDC curve:

$$\tau(T) = \frac{\frac{1}{b} \int_t^{\infty} I(t) dt}{I(t)} \quad (1)$$

where  $\tau$  is the relaxation time of the holes,  $b$  is the heating rate and  $I$  is the measured discharge current.

By integrating of the TSDC curve using Eq. (1) and considering the Arrhenius relation:

$$\tau = \tau_0 \exp(E/kT) \quad (2)$$

where  $E$  is the activation energy, and  $k$  is Boltzmann's constant, it was calculated from the slope of  $\ln \tau$  against  $1/T$  that  $E = 0.32 \text{ eV}$ .

The method of selected temperatures was also used to determine  $E$  [6]:

$$E = \frac{3.94 k T_L \cdot T_M}{T_M - T_L} \quad (3)$$

where  $T_L$  is the temperature corresponding to  $0.05 I_{\max}$  of the TSC curve,  $T_M$  is the temperature corresponding to  $I_{\max}$ . This method gave a slightly smaller activation energy  $E = 0.31 \text{ eV}$ .

### 3. Conclusions

PSi was found to obey the rules of the TSDC methodology. Our sample exhibits a clear monoenergetic temperature induced current peak which is attributed to the discharging of existing occupied carrier traps within the imperfect lattice. The activation energy that was calculated indicates that for the characteristics of the sample examined and for the method used there

is a single dominant detrapping mechanism. No conclusions can be drawn about the influence of different values of porosity and polarization field.

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### **References**

- [1] G. Polisski, H. Heckler, D. Kovalev, M. Schwartzkopff, F. Koch, *Appl. Phys. Lett.* 73 (1998) 1107.
- [2] W. Shockley, *Electrons and Holes in Semiconductors*, Van Nostrand Reinhold, New York, 1950.
- [3] R. Schwarz, F. Wang, M. Ben-Chorin, S. Grebner, A. Nikolov, F. Koch, *Thin Solid Films* 255 (1995) 23.
- [4] A.G. Milnes, *Deep Impurities in Semiconductors*, Wiley, New York, 1973.
- [5] C. Bucci, R. Fieschi, G. Guidi, *Phys. Rev.* 148 (1966) 816.
- [6] D. Triantis, C. Anastasiadis, S. Orfanakos, *Phys. Stat. Sol.* 114A (1989) 491.