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TEMPERATURE MODULATED-SCLC, USED FOR THE STUDY OF THE LIGHT INDUCED, METASTABLE DENSITY OF STATES OF a-Si:H

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The density of states has been measured for undoped a-Si:H by means of a temperature modulated space-charge-limited currents (TM-SCLC) method in an annealed state A and after prolonged illumination - state B. With increasing illumination time the peak in the DOS at $E-E_C \doteq 0.61$ eV grows and we attribute this to the D^- Si dangling bond level. From the difference in the position of this D^- level and the stable Fermi level in state B ($E_F - E_C \doteq 0.79$ eV) we deduce the effective correlation energy of Si dangling bond in undoped a-Si:H to be $U_{eff} = +0.36 \pm 0.03$ eV.

1. INTRODUCTION

Staebler and Wronski[1] discovered in 1977 a decrease of dark conductivity and photoconductivity of a-Si:H after intense illumination, an effect reversible by annealing at 150 - 200°C. Light induced, reversible changes, known as Staebler-Wronski (S-W) effect, of many other properties of a-Si:H have since been observed.

ESR results[2], TOF studies[3] and recent results by Stutzmann et al.[4] have shown that new, predominantly Si dangling-bond (DB) states are created. DB is characterised by its position (controversial at present) and by its effective correlation energy U_{eff}. $U_{eff} \approx 0.3 - 0.4$ eV of DB has been estimated on the basis of ESR[5] or PDS[6] results on differently doped a-Si:H. Because the DB in doped samples can create complexes, the estimate of U_{eff} based purely on undoped a-Si:H would be valuable.

One of the true bulk methods for finding the density of gap states (DOS) is that of space-charge-limited currents (SCLC). No systematic study of S-W effect by SCLC has been published. We present such results and moreover we use the improved, so-called TM (temperature modulated)-SCLC[7] method.

The principal difference between standard and TM-SCLC is that one measures not only the voltage dependence of the current but also the voltage dependence of the current activation energy E_a, which is deduced from the current response to temperature modulation around the preselected temperature, RT in our case. This provides the complementary experimental information, which allows more re-

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liable determination of the energy dependence of the DOS.

2. EXPERIMENTAL DETAILS

The measurements of TM-SCLC were made at 300 K on a-Si:H n^+-i-n^+ structure, deposited on a Cr-coated 7059 Corning glass. For details of the glow-discharge preparation of a-Si:H see ref. 8. The thickness of the n^+-a-Si:H layer was 40 nm and that of the undoped a-Si:H layer 1.35 μm.

Annealing (1 hour at 170° C) and also illumination (heat filtered halogen lamp $\approx$ 50 mW cm^{-2}) of the a-Si:H, together with the measurements of TM-SCLC, were all done in an evacuated cryostat.

3. RESULTS AND DISCUSSION

The TM-SCLC experimental results on an a-Si:H n^+-i-n^+ structure are shown in fig. 1. With increasing illumination (B1→ B6) the I-V resp. E_a-V curves shift to lower currents resp. higher voltages.

In fig. 2 there are the curves of the DOS, deduced from the I-V and E_a-V curves of fig. 1. The first important observation is that the Fermi level moves quickly from state A (0.70 eV) to B1 (0.79 eV) and thereafter (B1-B6) is

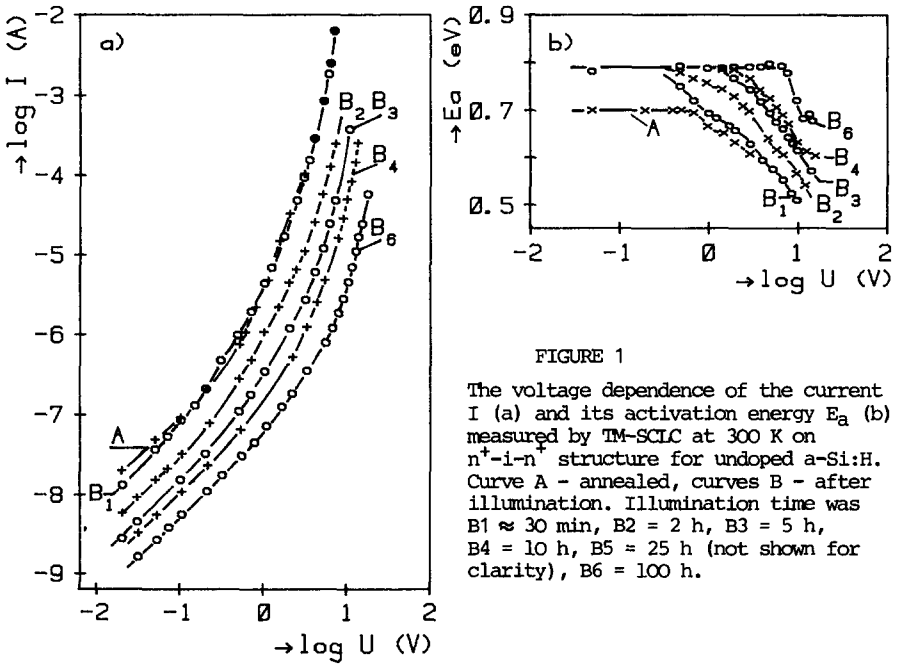

FIGURE 1

The voltage dependence of the current I (a) and its activation energy E_a (b) measured by TM-SCLC at 300 K on n^+-i-n^+ structure for undoped a-Si:H. Curve A - annealed, curves B - after illumination. Illumination time was B1 $\approx$ 30 min, B2 = 2 h, B3 = 5 h, B4 = 10 h, B5 = 25 h (not shown for clarity), B6 = 100 h.

practicaly constant ($\pm$ 0.03 eV). With increasing time of illumination, the peak (labelled I) in the DOS at about $E-E_c \doteq 0.61$ eV grows. There is an additional shoulder in the DOS at about 0.75 eV (labelled II) which quickly develops and then remains practicaly unchanged with increasing time of illumination. The quick movement and then a stable position of E_F is difficult to explain, if the growing peak in the DOS at ≈ 0.61 eV is associated with the states having $U_{eff} = 0$. This leads us to the conclusion that the peak in the DOS at ≈ 0.61 eV is related to the doubly occupied D^- silicon DB states, which are "created" from D^0 states by a shift of the Fermi level, related to the SCLC measurement itself.

We assume, along with Spear et al.[9] that the stable position of the Fermi level corresponds to the midpoint between the D^0 and D^-. If the above assumptions are correct then our results allow us, to deduce the value of the Si-DB effective correlation energy in undoped a-Si:H $U_{eff} = 2x\ (0.79-0.61) = +0.36 \pm 0.03$ eV.

The initial shift of the Fermi level (from the A to the B1 state) can be explained if we assume that some other states (O or P atoms?), not associated with DB, hold the Fermi level in the annealed state A. If the concentration of DB increases on illumination, they start to play the major role and the Fermi level quickly shifts to the stable position inbetween the D^0 and D^-. If the DB are the only deep states, then the Fermi level does not move at all, as has

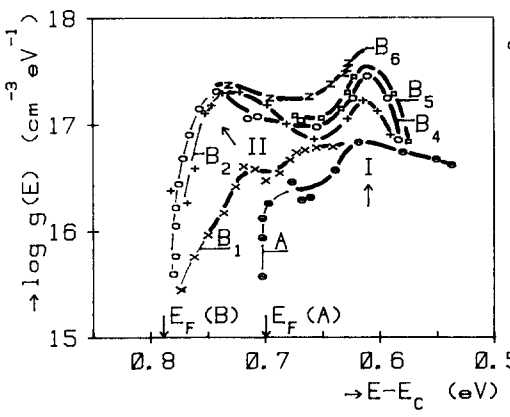

FIGURE 2

The density of states (DOS), deduced from the data of fig. 1. The data are reliable only $\approx$ kT above Fermi level (bold lines).

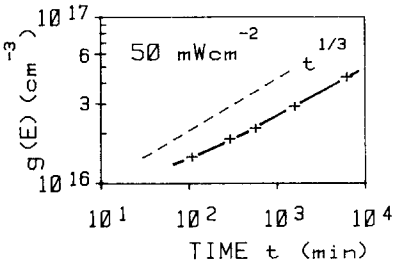

FIGURE 3

The illumination time dependence of the integrated light-induced metastable DOS in undoped a-Si:H (see Fig. 2).

been observed for undoped, electron-irradiated a-Si:H[2].

Concerning the origin of the shoulder in the DOS, labelled II, we speculate that these states may represent the broader "background" distribution of D^- states, which have different decay constants[4] and so may have correspondingly different dynamics for creation.

The illumination time dependence of the integrated density of light-induced metastable states from fig. 2 is displayed in fig. 3. These results agree with Stutzmann et al.[4], only the exponent is slightly less than 1/3.

For sample from the same run, in a state A, the DOS below the Fermi level, determined by deconvolution of the optical absorption coefficient (measured by CPM[10]) is equal to $2 \div 3 \times 10^{16}$ cm^{-3} eV^{-1}, which well corresponds to the SCLC data.

4. CONCLUSIONS

From above results, we make the following tentative conclusions:

a) With increasing illumination time, a peak in the DOS of undoped a-Si:H grows at $E-E_c \pm 0.61$ eV, which we attribute to the D^- silicon dangling bond state. The different position of the D^- level ($E-E_c \approx 0.85$ eV) on medium-PH_3-doped a-Si:H may be explained by a more complex nature for the D^- level in this case.

b) Assuming that the stable position of the Fermi level corresponds to the midpoint between D^0 and D^- states, we deduce that the Si dangling-bond effective correlation energy $U_{eff} = +0.36 \pm 0.03$ eV for undoped a-Si:H.

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