LBL--27532

DE90 000168

MATERIAL PARAMETERS IN THICK HYDROGENATED AMORPHOUS SILICON RADIATION DETECTORS

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Transient photoconductivity measurements of basic material parameters: carrier mobility, mobility-lifetime product and the ionized dangling bond den ty of thick hydrogenated amorphous silicon detectors are presented. We found that only a fraction (~ 30 - 35%) of the total defect density as measured by ESR is ionized when the detector is biased into deep depletion. The measurements on annealed samples done to relate the ionized dangling bond density and the ESR spin density also showed that this fraction i. about 0.3. The time dependence of defect relaxation was found to be a stretched exponential.

1. INTRODUCTION

Charge collection in hydrogenated amorphous silicon (a-Si:H) p-i-n detectors depends on various material parameters namely carrier mobility, mobility-lifetime product and the ionized dangling bond density[1]. The ionized dangling bond density determines how rapidly the electric field falls off in the active i region of the detector and, therefore, determines the thickness that can be depleted at reasonable bias without causing excessive reverse current and noise[2]. In this paper we present measurements of these material parameters in 27 μm and thicker samples. The transient photoconductivity measurements were done using a 510 nm pulsed laser system with 3 ns pulse width.

2. MEASUREMENT OF MATERIAL PARAMETERS

Table 1 shows the measured parameters of interest - μ_e, μ_h, $\mu_e\tau_e$, $\mu_h\tau_h$ - and the ionized dangling bond density N_d^* of various samples from time of flight experiments[3]. Also shown are the ESR spin densities on some samples.

It is seen that the ionized dangling bond density values are a small fraction of the total spin density. This observation is corroborated by the fits to the integrated hole signal using measured values of μ_h and $\mu_h\tau_h$. Values of N_d^* obtained thus are in good agreement with the values obtained from transient photoconductivity experiments.[1]

The dangling bond density of a 27 μm p-i-n (GSI) sample with tin oxide film on the substrate was obtained from the $\mu_e\tau_e N_d$ product which follows from the basic expressions relating the capture process with the trap limited transport in amorphous semiconductors[4]. An average value of $\mu_e\tau_e N_d \approx 2.5 \times 10^8$ was adopted for this purpose.

To eliminate possible effects of

*This work was supported by the Director, Office of energy Research, Office of High Energy and Nuclear Physics, Division of High Energy Physics of the U.S. Department of Energy under contract No. DE-AC03-76SF00098.

Thickness (μm)	27	28	48	27**
Type	n-i-p	n-i-p	n-i-p	n-i-n
μ_e(cm^2/vs)	1	1.4	0.56	1.2
$\mu_e\tau_e$(cm^2/v)	8×10^{-8}	1.1×10^{-7}	9×10^{-8}	1.2×10^{-7}
μ_h(cm^2/vs)	0.003	0.003	<0.003	0.004
$\mu_h\tau_h$(cm^2/v)	1×10^{-8}	2.7×10^{-8}	$<3.8\times10^{-8}$	1.2×10^{-8}
N_d*(cm^{-3})	8×10^{14}	6×10^{14}	7×10^{14}	7×10^{14}
N_d(cm^{-3})	2.6×10^{15}	2×10^{15}	2.3×10^{15}	2.1×10^{15}
N_d*/N_d	31%	30%	29%	33%***
$\mu_e\tau_eN_d$(1/cmv)	2×10^8	2.2×10^8	2.1×10^8	2.5×10^8

TABLE 1

Measured parameters of different samples. **GSI Sample, ***Estimated from $\mu_e T_e N_d$

impurity variations in the various samples in relating ionized dangling bond densities and the spin densities, measurements were done on samples whose defect density was increased by heating. The initial spin density of a 27 μm n-i-p sample before heat treatment was 2.6 x 10^{15} cm^{-3} (ESR) and the ionized dangling bond density 8 x 10^{14} cm^{-3} (TOF). A spin density of 6.5 x 10^{15} cm^{-3} was measured (ESR) after heating at 300°c; the ionized defect density was measured to be 2 x 10^{15} cm^{-3}. The fraction of defects ionized (~ 30%) before and after heat treatment remained unchanged. Similar results were obtained from a sample whose defect density was increased by heat treatment to ~ 1 x 10^{16} cm^{-3}.

3. DEFECT RELAXATION ON ANNEALING

The heat treated samples were annealed at 175°c and 225°c and the ionized defect density measured as a function of annealing time as shown in Fig. 1. Also shown are the defect density values derived from the measured values of $\mu_e\tau_e$ and $\mu_e\tau_eN_d$ = 2 x 10^8 in good agreement with the average value. The relaxation time dependence is a stretched exponential of the form[5]

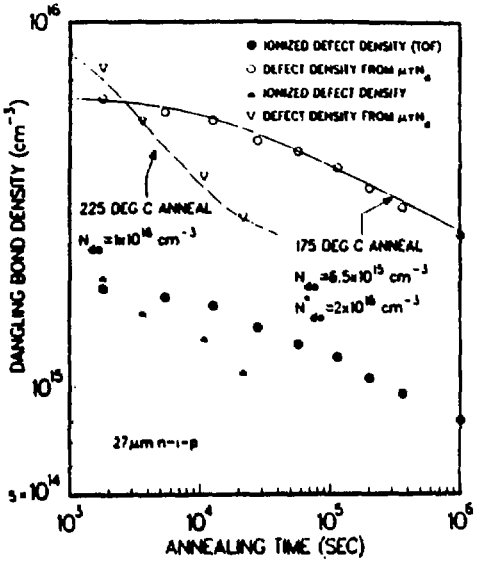

FIGURE 1

Ionized defect density N_d* (TOF) vs. annealing time. Also shown is defect density N_d from $\mu_e\tau_eN_d$= 2 x 10^8 $v^{-1}cm^{-1}$).

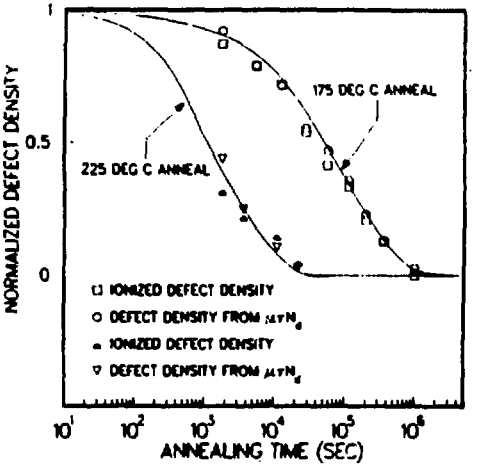

FIGURE 2

Relaxation data at 175°c and 225°c.

$$N_d - N_{deq} = N_{do} - N_{deq} \exp\left[-(t/\tau_s)^{\beta}\right]$$

where N_{do} and N_{deq} are the initial and equilibrium defect densities. β is a dispersion parameter and τ_s the time required for structural relaxation. Fig. 1 also shows relaxation curves done at 175°c and 225°c. The curves show good agreement with the derived values of N_d. The normalized defect density as a function of annealing time is shown in Fig. 2. From Figs. 1 and 2 it is seen that the ionized defect density as a function of annealing time also has the dependence of stretched exponential but reduced by about a factor of 3 implying that we are looking at the same effect.

4. IONIZED DEFECT DENSITY AND FERMI ENERGY

Fig. 3 shows the calculated fraction of ionized defects as a function of the shift of the Fermi energy. The observed ionization fraction corresponds to a shift of the Fermi level of 0.05 - 0.1 eV.

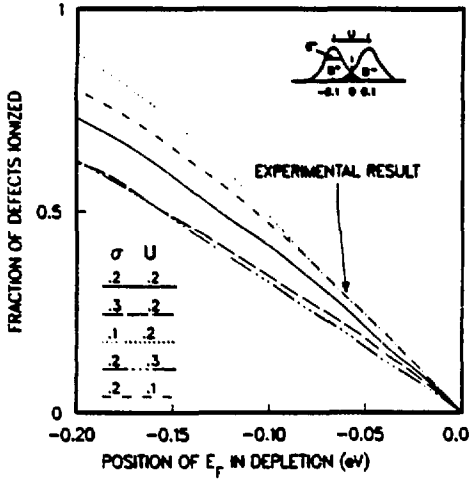

FIGURE 3
Fraction of defects ionized vs. shift in Fermi energy on depletion.

5. SUMMARY

Transient photoconductivity and ESR measurements made on relatively thick samples of a-Si:H show that ~30% of the defects are ionized in deep depletion. This observation is further corroborated by measurement on samples whose spin density was initially increased by heat treatment and reduced by subsequent annealing. It is also seen that the defect relaxation follows a stretched exponential behavior and is the same for the ionized and the total defect density. Analysis of a simple density of states model shows that the experimentally observed ionization fraction may correspond to a shift of the Fermi energy of 0.05 - 0.1 eV.

ACKNOWLEDGEMENT

We would like to thank C.C. Tsai of Xerox Parc and P. Bhat of Glasstech-Solar (Wheat Ridge, CO) for making the samples for this work.

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