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THE EFFECTS OF COMPENSATION ON LIGHT-INDUCED METASTABLE DEFECTS IN a-Si:H

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The effects of compensation on light-induced defects in a-Si:H have been investigated using photothermal deflection spectroscopy. We show that fully compensated material exhibits the smallest increase in defects after illumination. Departure from full compensation leads to a significant rise in the defect density. The results indicate that the observed change in the density of defects is due to new Si dangling bonds and not to Fermi level shifts. The implication of these findings for solar cell technology is discussed.

1. INTRODUCTION

Little attention has been given to the effects of compensation (doping with both p and n types) on the light-induced metastable defects in a-Si:H[1] (Staebler-Wronski effect). By varying the degree of compensation, it is possible to isolate effects due to Fermi level motion from those due to the incorporation of dopants. Also, since gap-state optical absorption studies have shown that compensation removes Si dangling bond defects[2], it is of interest to investigate the effects of compensation on the magnitude of the Staebler-Wronski effect. Using photothermal deflection spectroscopy[3] to measure the optical absorption of the defect, we show that fully compensated films (equal doping concentrations of phosphorus and boron) exhibit the smallest increase ($\sim 10^{15}$ dangling bond defects/cm^3) after illumination. Departure from full compensation, towards either phosphorus- or boron-rich material, results in a corresponding increase in the density of the light-induced defects.

2. RESULTS AND DISCUSSION

The samples were deposited by rf glow discharge and contained a constant phosphorus concentration of 10^{-3} and a variable boron concentration ranging from 0 to 4×10^{-3}. The illumination-anneal cycle consisted of exposing the

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a-Si:H films to ~1.0 W/cm^2 of unfiltered light from a quartz tungsten halogen lamp for 1.5 hours. Annealing was done by heating the films to ~150°C for 1.5 hours under vacuum and in the dark.

In Fig. (1) we show that illumination enhances the gap-state absorption, while annealing restores it to the original value. This result is consistently reproducible when the illumination-anneal cycle is repeated several times. No detectable change is seen in the exponential (Urbach) edge.

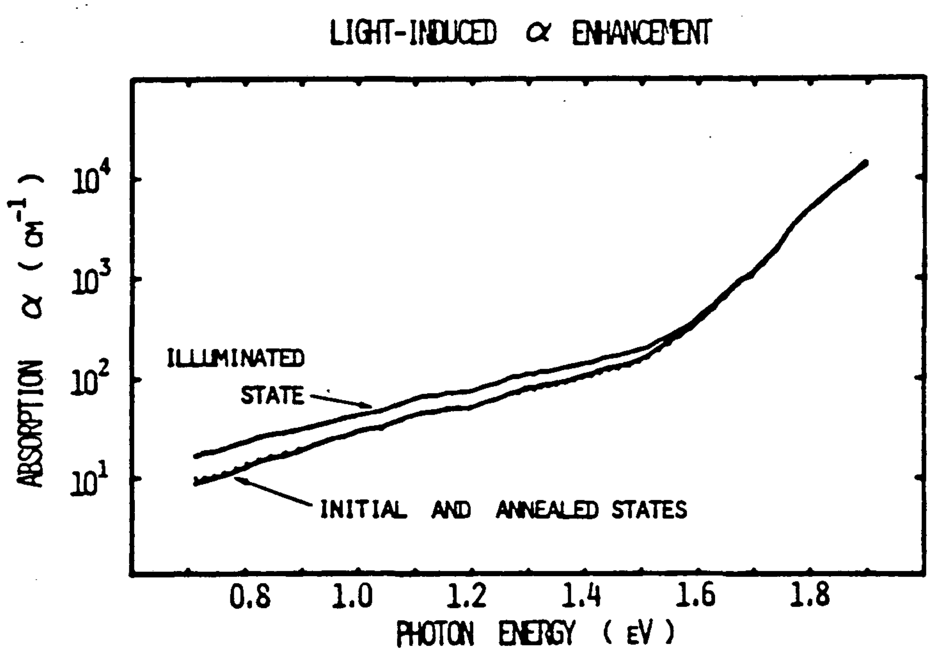

FIGURE 1
The effect of illumination on gap-state absorption in compensated a-Si:H (P:10^{-3} and B:$5x10^{-5}$). Dotted spectrum is for second anneal.

Previous work[2] has demonstrated that the magnitude of gap-state absorption in a-Si:H provides a direct measure of the density (N_s) and energy of the silicon dangling bond defect. Using the same procedure for the light-induced change in the optical absorption, we measured the difference in defect density between the annealed and illuminated states (ΔN_s). Fig. (2) shows the dependence of ΔN_s on the degree of compensation.

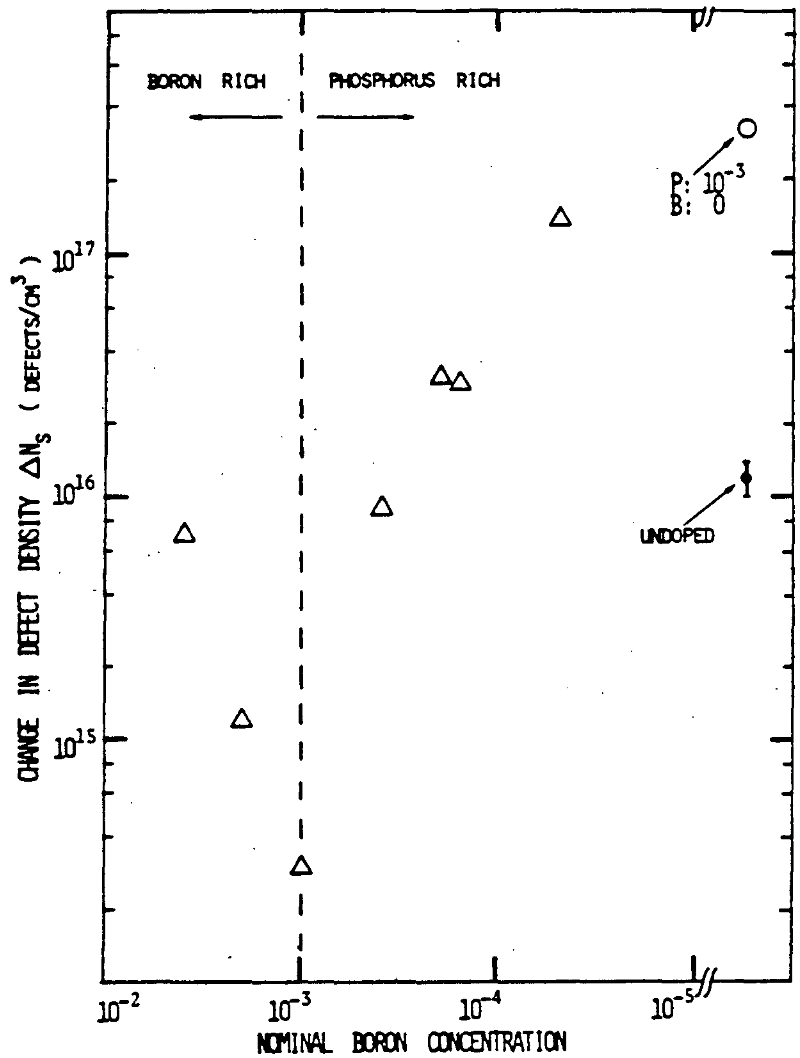

FIGURE 2
The dependence of ΔN_s on the degree of compensation.
ΔN_s for typical undoped (•) and singly-doped phosphorus
(o) materials are shown for comparison.

It is clear that full compensation minimizes the Staebler-Wronski effect. When compared with undoped material, ΔN_s for the fully compensated films is an order of magnitude lower. As the relative concentration of boron to phosphorus deviates from unity, ΔN_s rises sharply. We determine the energy of the light-induced defect to be ~1.25 eV below the conduction band, a value consistent with the defect being an Si dangling bond.

The results clearly show that the observed increase in dangling bond density is not simply due to Fermi level motion. If Fermi level shifts were the only mechanism, one would expect ΔN_s to increase as full compensation is reached and the Fermi level reaches the mid-gap region. Furthermore, in the case of boron-rich material, since fewer dangling bond states are occupied, ΔN_s would drop off. This is the opposite of what we observe experimentally.

The conclusion that Fermi level shifts do not account for the increase in ΔN_s is supported by an earlier study of the effects of single doping and defects on the Staebler-Wronski effect.[4,5] For singly-doped material, ΔN_s increases as the dopant concentration increases. Also, the ratio $\Delta N_s/N_s$ was found to be independent of the doping level, thus indicating that the light-induced defects are related to dopants or doping-induced defects instead of Fermi level shifts.

In addition, from the previous results on doping dependence one would expect that for fully compensated material ΔN_s would be large due to the high doping level of phosphorus and boron. Yet this material yields the smallest ΔN_s. Evidence from photoluminescence[6] and NMR[7] studies indicates that boron and phosphorus form complexes during deposition. It is possible that these complexes, because they are in their "desired" bonding configurations, no longer contribute to the defect creating mechanism.

Finally, the results presented here have implications for solar cell technology. Since the compensated material exhibits insensitivity to light-induced fatigue, it could then be used as the outer layer of solar cells in order to avoid the reported degradation in efficiency.[1,9]

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