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THE CONTRIBUTION OF THE STAEBLER-WRONSKI EFFECT TO GAP-STATE ABSORPTION IN HYDROGENATED AMORPHOUS SILICON

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The contribution of light-induced conductivity and luminescence changes to gap-state absorption in a-Si:H was directly measured by photothermal deflection spectroscopy. We show that sample illumination enhances gap-state absorption while annealing restores its magnitude to the original level. Furthermore, we find that doping further enhances this absorption while compensation results in the smallest observed effect. We determine the energy position of the affected states to be 1.2-1.3 eV below the conduction band and tentatively attribute the enhancement to Si dangling bonds created by breaking the Si-Si bonds.

1. INTRODUCTION

Reversible photo-induced changes in hydrogenated amorphous silicon (a-Si:H) have attracted attention recently [1-8]. The exact mechanism responsible for such an effect remains to be fully elucidated. However, it is generally accepted that illumination creates metastable defects which are annealed away by heating. An interesting question to raise is how do these photo-induced changes affect the optical absorption spectrum of the gap-states in this material. The answer provides information on the number of the states affected, and more importantly, gives the energy level at which these states reside in the gap. We have employed the technique of photothermal deflection spectroscopy [9] to investigate the contribution of these photo-induced defects to gap-state absorption.

2. EXPERIMENTAL CONSIDERATIONS

The photothermal deflection spectroscopy technique has been described elsewhere [9]. The samples used in this investigation were undoped, singly doped, and compensated films deposited by glow discharge. The illumination-annealing cycle consisted of exposing the a-Si:H films to 0.5W/cm² of unfiltered light from a Quartz Tungsten-Halogen lamp. Exposure time was typically 1.5 hours. Annealing was achieved by heating the films at 175°C for 1.5 hours in vacuum and in total darkness.

3. RESULTS AND DISCUSSION

Fig. (1) shows the effect of illumination upon the optical absorption of the undoped material. It can be readily seen that exposure to light enhances gap-state absorption. Furthermore, annealing at 175°C restores the magnitude of this absorption to its original value. Little or no change is seen in the Urbach tail absorption.

Fig. (1). The effect of Illumination on the Absorption Spectrum of Undoped a-Si:H.

We have shown earlier that the magnitude of gap-state absorption in a-Si:H correlate directly to the number of spins as determined by ESR and that these states are due to silicon dangling bonds [10]. Since illumination yields a qualitatively similar absorption spectrum, with the only difference being the increase in the absorption of gap-states, then one can employ the procedure described in Ref. [10] to calculate the number of photo-induced spins, ΔN_s , in the various samples we investigated. In Fig. (2) we plot the optically-deduced ΔN_s as a function of doping level for singly doped and compensated materials as a function of dopant concentration. As can be seen, for singly doped material, the photo-induced spins increase in density with increasing dopant concentration. The compensated material exhibited a light-induced enhancement comparable to that measured in the undoped films.

Fig. (2). Photo-Induced Change in Spin Density as a Function of Doping. $\square$: Boron; $\circ$: Phosphorus; $\blacktriangle$: Compensated (10^{-3} P, 10^{-3} B in Vapor Phase); $\bullet$: Undoped.

From our results, we deduce that illumination appears to increase the density of those states residing ~ 1.2 - 1.3 eV below the conduction band. This conclusion holds for all of our samples, implying that the photo-induced metastable defect is probably the same for the doped and the undoped materials.

Given our earlier finding that the maximum in the density of state 1.2 - 1.3 eV below the conduction band is due to Si dangling bond, we are led to tentatively conclude that the observed photo-induced enhancement in gap-state

absorption is caused by an increase in the number of Si dangling bonds. This conclusion is further supported by ESR and field effect data [3,7]. The model for the dangling bond generation being that illumination breaks the "weak" Si-Si bonds which is followed by the relaxation of the surrounding network.

We would like to point out, however, that the photo-induced increase in the density of states near mid-gap does not uniquely imply the creation of additional dangling bond defects. A shift in the Fermi level, without any increase in the number of gap-states, will also result in apparent increase in the number of these states. Clearly more work is needed in order to understand the origin of the photo-induced metastable gap-state.

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