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LIGHT INDUCED DEGRADATION OF HYDROGENATED AMORPHOUS SILICON – GERMANIUM ALLOY (a-SiGe:H) THIN FILMS

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Hydrogenated amorphous silicon germanium alloy thin films prepared by Plasma Enhanced Chemical Vapor Deposition (PECVD) with varying Germanium concentrations have been investigated in both the annealed and the light soaked state. Samples were characterized using steady state photoconductivity and dual beam photoconductivity (DBP). The Staebler-Wronski effect has been investigated by monitoring the changes in the photoconductivity, σ_{ph}, and the increase in the sub-bandgap absorption coefficient, α. The kinetics of defect creation for different germanium contents has also been compared with those for unalloyed hydrogenated amorphous silicon films. It is found that for the films with low Ge fraction, both a decrease in the photoconductivity and an increase in α (1.0eV) show similar time dependences to those observed in a-Si:H films. However, as the Ge content increases, σ_{ph} degrades faster and the same time dependence is not seen in the increase of α(1.0eV).

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1. Introduction

Hydrogenated amorphous silicon-germanium (a-SiGe:H) alloy thin films are potential candidates to replace the lower bandgap absorber layer in multi junction solar cells [1]. Increasing the Ge concentration from pure amorphous silicon (0%Ge) decreases the bandgap and increases the Ge-related defect states in the alloy. Both silicon- and germanium-related defects are detected by electron spin resonance (ESR) [2]. However, sub-bandgap absorption measurements carried out using the constant photocurrent method (CPM) and photothermal deflection spectroscopy (PDS) do not show a distinction between Si and Ge related defects [3]. It is known that illumination with intense light leads to the creation of additional metastable states in the mobility gap of a-Si:H, i.e. the Staebler-Wronski effect [4]. This effect is also observed in hydrogenated amorphous silicon germanium alloy thin films [5]. In early studies carried out during the 1980s, a negligible SWE was reported in those lower quality alloy films [6,7]. More detailed investigations [8-11] have since been carried out after the material quality improved, and the issue of light induced degradation in these alloys has become a truly significant concern [12-15]. One of the major investigations of the SWE in a-SiGe:H alloys was reported in 1992, where the degradation in photoconductivity exhibits roughly a cube root dependence on the exposure time, which is similar to the degradation kinetics of a-Si:H films [16]. In addition, the degradation kinetics investigated using the sub-bandgap absorption resulted in no qualitative difference between a-SiGe:H alloys and pure a-Si:H films [17]. Another detailed investigation of deep defect creation in the alloys was carried out by using the drive–level capacitance profiling method [18]. It was found that as the Ge concentration increases, less deep defects are created.

In this study, the Staebler-Wronski effect for intrinsic a-SiGe:H alloy thin films with different Ge concentrations was investigated using the steady-state photoconductivity and dual beam

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photoconductivity (DBP) techniques, to understand the effect of rhe Ge content on the kinetics of defect creation, using 15-sun white light illumination.

2. Experimental procedure

Intrinsic hydrogenated amorphous silicon-germanium alloy thin films with different germanium concentrations were deposited by Plasma Enhanced Chemical Vapor Deposition (PECVD) [5], on glass substrates. The thicknesses of the samples, obtained from transmission measurements, were between 0.42 and 1 μm. All samples were annealed in vacuum at 180 °C for 2½ hours, before annealed state characterization. Steady state photoconductivity, σ_{ph}, measurements in the annealed and light soaked states were made using a 690 nm interference filter and a RG - 610 filter, together with a calibrated ENH type white light source. The intensity of the light was reduced using neutral density filters. The applied dc bias was in the ohmic region of the contacts. The light soaking procedure was carried out by illuminating the film at an intensity of 15 Suns, for determined time intervals. The temperature was kept constant at about 45 °C, using fans. Measurements were carried out after each light soaking period, and then the samples were re-annealed before beginning the next light soaking step. The sub-bandgap absorption spectrum, $\alpha(h\nu)$, was obtained from the dual beam photoconductivity (DBP) measurements (see [19] for a detailed description). In this study, the DBP yield spectrum, Y_{DBP}, measured at high and low bias light intensities, and the simultaneously measured transmission signal from the substrate side of the sample were used to calculate the absolute $\alpha(h\nu)$ spectrum, using a procedure [20] based on the Ritter-Weiser formula [21]. The Staebler-Wronski effect was characterized by monitoring the changes in the steady-state photoconductivity and sub-bandgap absorption coefficient.

3. Results and discussion

In Fig. 1a, the steady state photoconductivity, σ_{ph}, results are shown in the annealed state for a-SiGe:H samples with Ge contents of 0, 15 and 25%, respectively. Higher photoconductivity values were obtained as the Ge content in the silicon network increases. The exponent γ of the photoconductivity was less than unity, and changed between 0.70 and 0.90. The degradation of samples began from these annealed state values as they were exposed to 15 Suns of white light illumination, filtered with a water filter to eliminate heating during the light soaking procedure. The degradation of σ_{ph} as a function of time is shown in Fig. 1b, for the same a-SiGe:H samples. It is clearly seen that σ_{ph} degrades as a power law function of the exposure time. Pure a-Si:H (0%Ge) and a a-SiGe:H alloy thin film with 15% Ge content exhibit similar degradation kinetics and show a characteristic $t^{-1/3}$ rule. However, a-SiGe:H alloy thin film with 25% Ge content degrades faster and shows a slope of approximately -2/3.

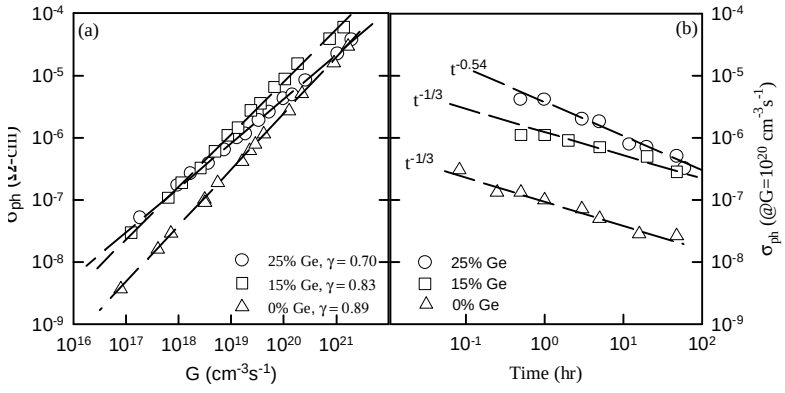

Fig.1. (a) Photoconductivity vs generation rate for a-SiGe alloys in the annealed state, (b) Degradation of the photoconductivity measured at $G = 10^{20}$ $cm^{-3}s^{-1}$, as a function of the illumination time.

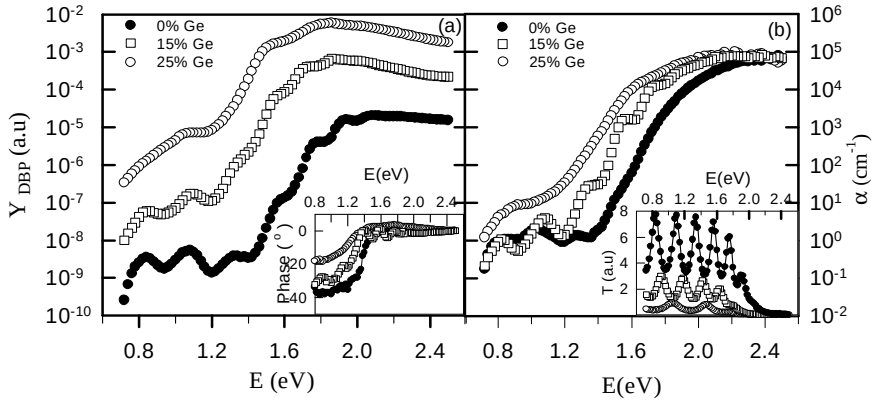

Fig. 2. (a) Raw Y_{DBP} spectra of a-SiGe:H alloy thin films with different Ge contents. The inset shows the phases of the corresponding DBP signal. (b) Absolute α (hν) spectra of samples, calculated from the Y_{DBP} spectrum and simultaneously measured transmission signals. The inset shows the transmission spectra.

The degradation of a-SiGe alloys can also be also characterized using sub-bandgap absorption methods, since the absorption coefficient at such energies increases with light soaking time. The sub-bandgap absorption coefficient spectra of these samples were measured in the annealed and light soaked states, using the dual beam photoconductivity (DBP) method. In Fig. 2a, raw DBP yield spectra, Y_{DBP}, are shown for films with three different Ge contents, in the annealed state. The absolute absorption coefficient spectrum, α(hν), for each sample was calculated from Y_{DBP} and the corresponding transmission signals, as shown in the inset of Fig. 2b. It is clearly seen that as the Ge content increases from 0% (a-Si:H) to 25%, the bandgap at $\alpha(h\nu) = 10^4$ cm^{-1} shifts to lower energies, as is consistent with previous observations. In addition, there are also fringe patterns left on the spectrum after carrying out the fringe free calculation of the α(hν) spectrum for 0% and 15% Ge content films. This indicates that a defective inhomogeneous layer is present in these samples.

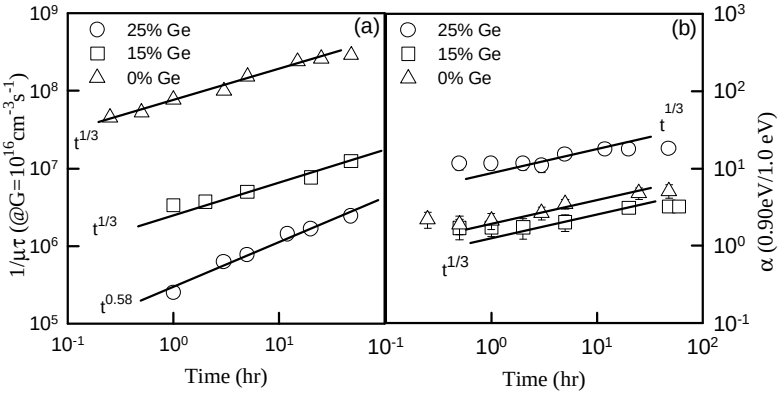

Fig. 3. (a) Degradation of $1/\mu\tau$ measured at G = 10^{16} cm^{-3}s^{-1} for three different Ge content films and (b) the increase of the sub-bandgap absorption coeffient at 1.0 eV for 0% and 15% Ge content samples and at 0.90 eV for a 25% Ge content sample. The error margins in (b) are comparable to the symbol sizes.

After each light soaking step, the calculated α(hν) spectrum showed that there is an increase only in the sub-bandgap region, and no change was detected in the exponential absorption part of the

spectrum. The values of $\alpha(h\nu)$ at 1.0 eV for 0% and 15% Ge content films, and at 0.90 eV for 25% Ge films were taken as a representation of the change in $\alpha(h\nu)$ after light induced degradation. The results of the degradation are summarized in Fig. 3 for both α(0.90 eV/1.0 eV) and $1/\mu\tau$ versus illumination time. For all samples, α (hν) shows no initial degradation up to a few hours, then obeys an approximately $t^{1/3}$ time dependence similar to that observed for intrinsic a-Si:H thin films [2]. Finally, it tends to reach a degraded steady state value after 30 hours of light soaking. In contrast, $1/\mu\tau$ shows a different time dependence, with a slope close to 1/3 for 0% and 15% Ge films and 0.58 for the 25% Ge content sample. Even though $\alpha(h\nu)$ tends to saturate, $1/\mu\tau$ still follows its time dependence. This difference between the time dependences of the sub-bandgap absorption and $1/\mu\tau$ was also observed in a-Si:H films, indicating that the increase of the $\alpha(h\nu)$ and degradation of the $\mu\tau$-product are not controlled by the same types of defect [22].

4. Conclusions

Preliminary results on the Staebler-Wronski effect for a-SiGe:H alloy thin films with different Ge contents were investigated using the steady-state photoconductivity and dual beam photoconductivity methods. It was found that for low Ge content films, the degradation of the photoconductivity and the increase in α(1.0eV) followed similar time dependences to those found for a-Si:H films [2]. As the Ge content increased, σ_{ph} degraded faster. However, this did not exhibit the same time dependence as that for the increase in α(0.90 eV). These results cannot identify the types of defect causing the degradation of both parameters in a-SiGe:H alloys. More detailed investigation is necessary to fully understand the degradation kinetics in the alloy thin films.

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