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Deposition of photosensitive hydrogenated amorphous silicon–germanium films with a tantalum hot wire

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Abstract

We study the optical, electrical and structural properties of a-SiGe:H thin films deposited by hot-wire chemical vapor deposition (HWCVD). The best films are deposited with a Ta filament heated to 1750 °C and the substrate temperature held at 200 °C. For the same precursor gas ratio of GeH_4 to SiH_4, a lower filament temperature produces films with higher Ge incorporation than with a higher filament temperature. For Tauc band gaps between 1.22 and 1.30 eV, the photoconductivity and photosensitivity are significantly higher than for plasma-enhanced CVD a-SiGe:H films exhibiting the same band gap. The filament lifetime is much longer for a Ta filament than for a W filament at these operating temperatures.

Keywords: Amorphous silicon-germanium alloy; Optical bandgap; Tauc bandgap; Photo-to-dark conductivity ratio; Photosensitivity, and photon absorption coefficient

1. Introduction

When low HWCVD filament temperatures ($T_f \leq 1850$ °C) are used for Si thin film deposition, a tantalum (Ta) filament may be superior to a tungsten (W) filament because the Ta filaments last about 5 times longer before breaking [1,2]. W filaments have long lifetimes at elevated temperatures ($T_f \sim 2000$ °C), but tungsten silicide forms rapidly at lower T_f [3], causing problems with film reproducibility and filament lifetime. In this study, we used a Ta filament to deposit hydrogenated amorphous silicon germanium (a-$Si_{1-x}Ge_x$:H) alloys from SiH_4, GeH_4, and H_2 precursor gases. Earlier studies with a W filament indicated that high quality low-band gap a-SiGe:H films are obtained at $T_f < 1850$ °C at growth rates of 2 to 4 Å/s [4], but filament lifetime and film reproducibility problems were evident.

Band gap profiling of the a-$Si_{1-x}Ge_x$:H material is needed to make efficient solar cells, requiring high quality alloys with a range of Ge contents (x) and Tauc band gaps (E_g) [5]. In this study, we report the properties of a series of a-$Si_{1-x}Ge_x$:H alloy films which were deposited with a Ta filament held at low T_f, but with different values of x and E_g. The film composition is varied by adjusting the ratio of GeH_4 to SiH_4 in the gas flow, while holding the hydrogen dilution constant. We found that we could grow up to 11 μm of a-SiGe:H without changing filaments, a dramatic improvement over the W filament used at the same low T_f.

2. Experiment

We grew a-SiGe:H by HWCVD with a 0.5-mm-diameter Ta filament located 5 cm from the substrate holder, in a tube reactor described elsewhere [6]. The main film series was deposited with a hydrogen dilution of unity (i.e., the total flow of GeH_4 and SiH_4 was equal to that of the H_2) at a total pressure of 12.5 mT. Table 1 shows the percentage of GeH_4 in the non-hydrogen gases [$GeH_4/(GeH_4+SiH_4)$] for each of these films. The filament current for this series was 10.5 A, resulting in an estimated [7] $T_f \sim 1850$ °C. Films were deposited at other Ta filament and substrate temperatures, and these changes are indicated when discussed.

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Table 1
$GeH_4/(SiH_4+SiH_4)$ gas flow ratio, film thickness, film deposition rate, and Ge content of films grown at T_f = 1850 °C

Sample	%GeH_4 to (SiH_4+SiH_4)	Thickness (Å)	Deposition rate (Å/s)	%Ge in film
L1182	0	2800	2.33	0
L1129	2.5	2833	3.15	10.2
L1130	5	3003	3.34	14.9
L1131	10	3386	3.76	24.6
L1132	20	3126	4.34	39.9
L1195	20	2481	3.45	41.6
L1133	25	2446	4.53	47.2
L1198	25	2275	3.70	47.7
L1127	35	2367	5.64	63.2
L1183	35	2369	3.95	62.8
L1266	50	1462	4.87	81.5
L1134	100	995	6.63	100

We deposited the films simultaneously on 1737F Corning glass and c-Si wafer substrates. We evaporated two coplanar Cr contacts onto the films deposited on the glass substrates for conductivity measurements and used the films on the c-Si substrate for Fourier transform infrared spectroscopy (FTIR) and secondary ion mass spectrometry (SIMS) measurements. The photoconductivity is measured under an ELH lamp having an optical spectrum close to the AM 1.5 standard. The thickness and band gap of the films on glass were determined from transmission–reflection spectra using an n&k 1280 Analyzer. The Tauc band gap is taken from the fitting of E vs. $(\alpha h\upsilon)^{1/2}$, in which the method of interference-free determination of optical absorption coefficient on the raw transmission (T) and reflectance (R) data [8] is used to calculate α.

3. Results and discussion

3.1. Film composition

Table 1 shows the film Ge content (x) for each sample. We found that the films deposited with the Ta wire at 1850 °C, resulting in deposition rates between 2 and 5 Å/s, have higher film Ge contents compared to those using a W filament operating at 2000 °C, and with much higher deposition rates (8 to 100 Å/s) [9]. We believe that the higher Ge fraction at low T_f is due to less efficient decomposition of SiH_4 on the cooler wire. Most likely the GeH_4 reaching the filament decomposes completely at both high and low T.

3.2. Optical absorption coefficient and band gap

Fig. 1 shows the Tauc band gap, taken from the fitting of E vs. $(\alpha h\upsilon)^{1/2}$. The calculated Tauc gaps decrease with increasing Ge content, in parallel with the E04 gap (see insert), defined as the photon energy at which α exceeds

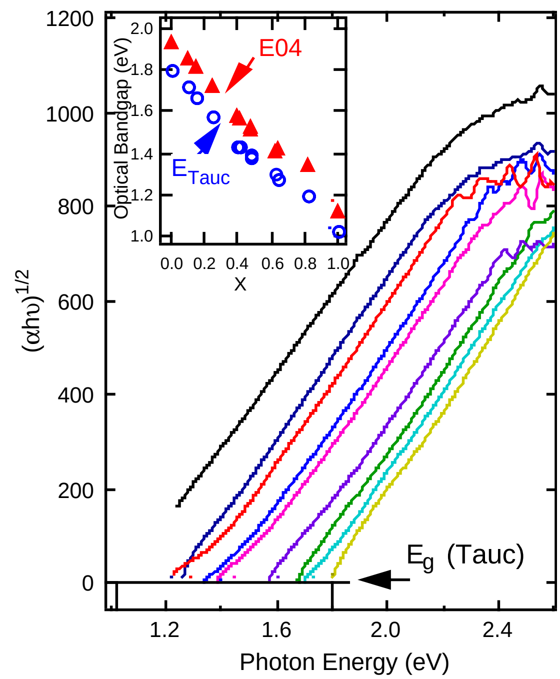

Fig. 1. Tauc plot of optical absorption, α, vs. photon energy. The insert shows calculated E_{Tauc} and E04 as a function of Ge content in the films.

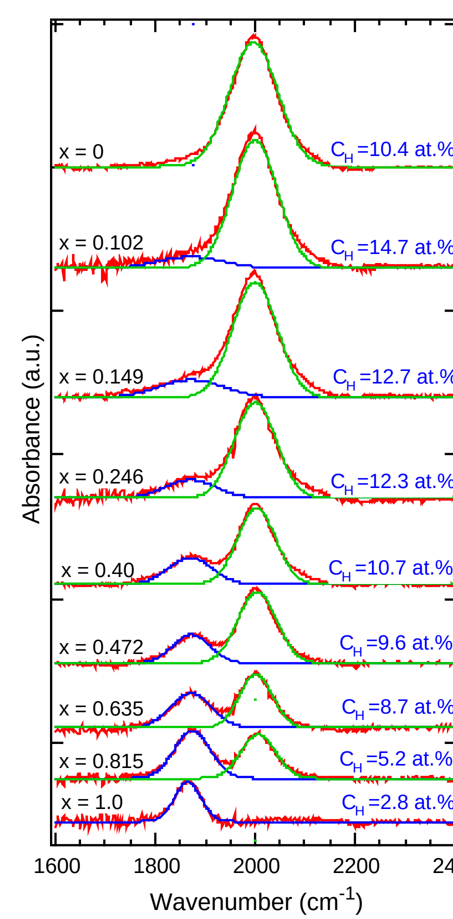

Fig. 2. IR absorption in the stretch mode region for films of varying Ge film content.