Preparation and Characterization of Reactively-Sputtered Amorphous Si:H Films

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Introduction

What is the essential difference in properties between glow-discharge amorphous Si:H films (GD-a-Si) and reactively-sputtered ones (SP-a-Si)? Presumably no one gives a clear answer because SP-a-Si has not yet been well characterized compared with GD-a-Si.

The purpose of this report is to present the first systematic map of the structural and electronic properties of SP-a-Si film for various deposition conditions and to point out the strong correlation between both properties in connection with those of GD-a-Si films.

Experimental

SP-a-Si films were prepared in diode-type sputtering system (NEVA FP-46) by varying deposition parameters. Used parameters are listed in Table 1, among which H₂ concentration (x vol. %) in Ar-H₂ sputtering gas, substrate temperature (Tₛ), RF power and gas pressure (Pₒ) are important. Emission spectra of RF plasma were monitored during deposition, giving information on deposition kinetics. For all the samples prepared, film density, ir vibrational spectra (600-3000 cm⁻¹), optical transmission spectra (0.4-2.6 μm), dark- (σₐ) and photoconductivity (Δσₚ) were measured.

Bonded H and Ar in films

From the experimental data on film density and ir spectra we determined the content (at.%) of bonded hydrogen and the medium wave number (νₓ) of stretching mode absorption for Si-H complexes. The medium νₓ gives a measure of the absorption ratio of SiH₂ to SiH modes. Both quantities are shown in Fig.1(a) and (b) as a function of Tₛ for different H₂ concentrations (x), which shows that the amount of bonded H as well as its environment can be widely controlled. EPMA traces have shown that more than 5 at.% of Ar atoms are involved in SP films depending on preparation parameters.

Optical gap and photoconductivity

Figure 2 shows optical gap Eₒ vs. Tₛ for samples prepared for different H₂ concentrations (x). Eₒ was graphically determined using the empirical relation

\[
\sqrt{\alpha \nu} = (hν - Eₒ) \]

Figure 3 shows Eₒ as a function of bonded H content in the films, which is replotted from the data of Figs.1(a) and 2. Eₒ increases drastically from 1.1 to 2.0 eV with an increase in bonded H content. Thermal effect is another factor shifting Eₒ to higher energies.

Figures 4 and 5 show σₐ and Δσₚ vs. Tₛ for the samples used in the above experiments. σₐ keeps decreasing with increasing x up to 40%, while Δσₚ takes a maximum value at x=20%. Figure 6 shows spectral response of nₑᵣ, that is, Δσₚ normalized to the absorbed photon flux, where n is quantum efficiency, e electron mobility and τ electron life time. The data suggest that surface recombination prevails in photoconduction process.

Connecting the above results with other annealing studies, conclusions are summarized into following items: (1) The amount of bonded H and its environments can be controlled by varying H₂ concentration in Ar-H₂ sputtering gas, Tₛ, RF power and Pₒ. (2) Eₒ is mainly determined by the amount of bonded H, and to a lesser degree by thermal stabilization. (3) Photoconductivity is strongly correlated with the absorption ratio of SiH₂ to SiH modes as well as bonded H content. (4) Ar
atoms involved in SP films play the role of steric hindrance against H diffusion, so SP films are more stable than GD films at high temperatures. These results are discussed in comparison with those of GD-a-Si:H.

References
(1) T.E.Moustakas et al.: Solid State Commun. 23 (1977) 155
(3) W.E.Spear: Adv. in Phys. 26 (1977) 811

Table 1 Deposition Conditions

<table>
<thead>
<tr>
<th>Gas</th>
<th>Target</th>
<th>Substrate</th>
<th>T_s (°C)</th>
<th>RF Power</th>
<th>P_G (W)</th>
<th>P_base (torr)</th>
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<tbody>
<tr>
<td>Ar+x%H_2</td>
<td>c-Si</td>
<td>C#7059</td>
<td>RT-300</td>
<td>100-300W</td>
<td>7-50torr</td>
<td>3x10^-7 torr</td>
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<tr>
<td>0 ≤ x ≤ 40</td>
<td>(5-150-cm)</td>
<td>c-Si(ir)</td>
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<td></td>
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Fig. 1

Fig. 2

Fig. 3

Fig. 4

Fig. 5

Fig. 6

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