Amorphous Silicon

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Abstract

Amorphous Silicon(a-Si) is noncrystalline and lacks long range order but has local order on atomic scale which is directly resposible for the observable properties of a-Si. The discovery of the ability to control the optical bandgap by alloying Si with other materials has given a-Si an edge. These alloys have tailormade optical and dielectric properties and have applications in solar cells, electrophotographic printers, image scanners and liquid crystal flat panel displays. Possible future applications are in image pickup tubes, x-ray and charge particle detectors, optical waveguides and memories.

Some of the physical properties of a-Si:H which account for its various uses are reviewed.

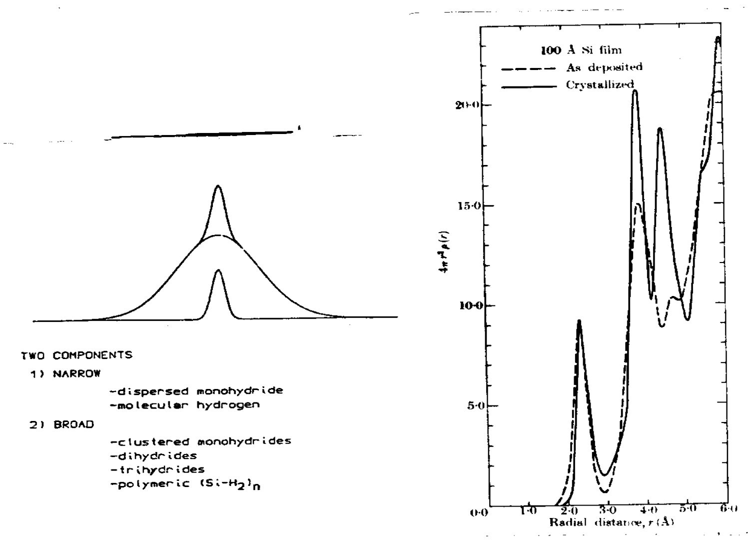

Figure 1: Radial distribution function (RDF) of a-Si and crystalline Si as determined from electron diffraction data and NMR lineshape of a-Si:H

Introduction

When prepared with conventional techniques like evaporation or sputtering, a-Si contains a large density of defects and microvoids. Using plasma enhanced chemical vapour deposition (PECVD) significantly reduces the defect densities due to band saturation by incorporated Hydrogen. Similar film properties are observed by other hydrogenation techniques like reactive sputtering in Hydrogen and Argon mixture or post hydrogenation of evaporated or sputtered films by CVD using SiH_4 . It is known that the best quality films are deposited from pure SiH_4 at substrate temperatures of $200 - 260^o$C with R.F power and have 15 at. percent H_2.

Structural properties

Electron diffraction data indicate short range order in a-Si (Fig. 1) [1].

Scanning Tunneling Microscopy of a-Si:H over length scales of less than 1 nm indicate heterogeneity and local ordering[2]. Vibrational spectroscopy in mid Infrared region identifies Hydrogen distributed among four different environments in a-Si:H. It is generally agreed that device quality a-Si:H contains only monohydride bonding configuration [3]. As per NMR studies a component lineshape is ubiquitous and is observed for all films produced from all laboratories (Fig. 1).

NMR studies also indicate compositional disorder in amorphous a-Si:H in the distribution of H_2 [4].

Because of its short range order and low temperature deposition a-Si:H films can be easily fabricated, are adaptable to any geometry and area, and have low cost of manufacturing.

Optical properties

As a-Si is disordered there is no requirement for momentum conservation and the fine structure of crystalline Si dissappears (Fig. 2).

The imaginary part of the dielectric function $\epsilon_2(\omega)$ which depicts absorption process

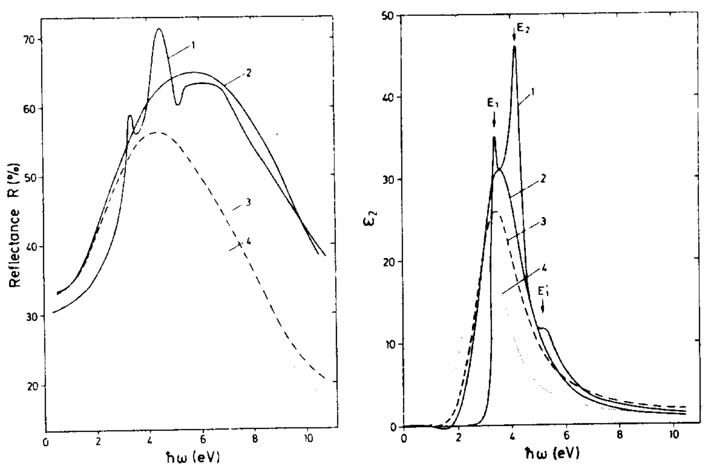

Figure 2: Reflectance and $\epsilon(\omega)$ of crystalline(1) and a-Si prepared by(2)glow discharge($T_s = 400^oC$),(3)slow evaporation ,and (4) fast evporation.

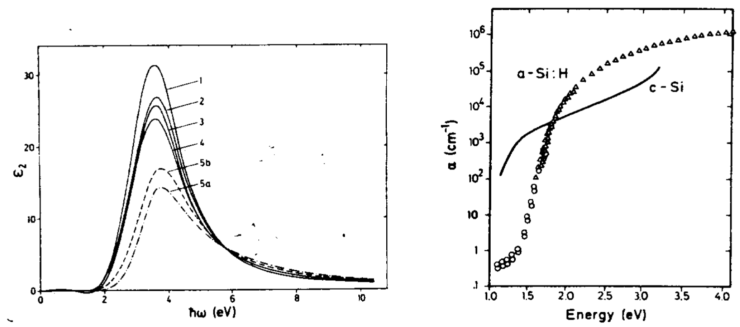

Figure 3: Spectra of $\epsilon(\omega)$ of a-Si:H deposited at various temperatures T_s in ^oC (1) 400 (2) 260 (3) 140 (4) 65 (5a) 27 (5b) 27, and annealed at 260 , and (α) of a-Si:H derived from optical transmission (Δ) and photoconductivity (O)

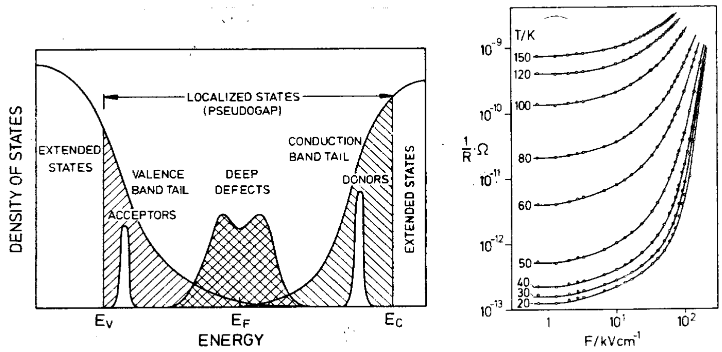

Figure 4: Density of states distribution in a-Si:H and photoconductance(1/R) vs Field Strength (F) of a-Si:H

.	Drift Mobility($\frac{cm^2}{Vs}$)	Act. Energy (eV)	Band Mobility($\frac{cm^2}{Vs}$)	Bandtail Slope (eV)
Elect.	<0.8	0.13	10	0.027
Holes	10^{-3}	0.32	0.67	0.043

Table 1: Transport Parameters of a-Si:H

peaks at lower energy in a-Si. The peak height is also decreased and depends on the details of film preparation (Fig. 3) [5]. The $\epsilon_2(\omega)$ is the highest for plasma deposited a-Si:H. Thr deposition temperature has little effect on the peak position but considerable effect on the peak height (Fig. 3)

Various experimental methods have been used to determine absorption constant (α) in a-Si:H [6]. The higher α in amorphous Si compared to crystalline Si is due to loss of momentum conservation in the disordered structure. In the visible range the α is larger by an order of magnitude in a-Si compared to that of crystalline Si (Fig. 3).

This means that most of the sunlight can be absorbed in a film of about 1μm thickness. *This is the basis of application of this material in photovoltaics.* The optical gap (E_g) is defined as either $E_0.3$ or $E_0.4$ depending on whether α is 10^3cm^-1 or 10^4cm^-1 respectively. The value of E_g appears to be a unique function of the Hydrogen concentration (c_H) in the film [7]. It amounts to 1.2-1.5 eV in evaporated or sputtered material and varies linearly with c_H in a-Si:H films (1.6-2.0 eV). Doping with both phosphorous and boron causes change of the E_g [8].

Electronic properties Electronic properties depend sensitively on density and energy distribution N(E) of the localized gap states. In particular these states determine the doping effficiency, transport and recombination as well as the width and potential profile of the space charge layer in devices (Fig. 4) [5]. Trnsport properties of a-Si:H [9]by using multiple trapping analysis and assuming varying bandtail are given in the table (Tab. 1).

In a-Si, density of gap states is low and therefore the transport is considered to occur cheifly at mobility edges. If transport is by electrons conductivity ($\sigma(T)$) and thermoelectric power S(T) are given by

$\sigma = \sigma_0$ Exp$(\frac{-E_c - E_f}{kT})$
S = $\frac{E_c - E_f}{eT} + \frac{k}{e}$ A(T)

Here k is Boltzman's constant and A is an arbitrary constant. The extensive work on luminescence and spin dependant properties of a-Si:H has provided evidence that dangling bonds are the most important defects involved in deep trapping and recombination. Regarding photoconductivity at temperatures $< 60^o K$ the observations are 1) $\sigma_p h$ depends linearly on light intensity. 2) $\frac{\sigma_p h}{eG} = 10^- 11 \frac{cm^2}{V}$ depending very little on the preparation condition and defect densities. 3) The decay of photocurrent seems to be fast and occurs in a time scale shorter than average radiation lifetime. This has been confirmed that this is due to hopping of carriers in localized bandtail state [10]. In the case of photoconductivity at temperatures $> 60^o K$ (Fig. 4) thermal excitation of carriers to mobility edges becomes important and this depends strongly on the position of the Fermi level [11].

Shifting the Fermi level of conduction band causes tremendous enhancement in photoconductivity.

As a-Si:H has low density of states, the Fermi level can be easily moved by doping, illumination, or external bias to a space charge layer, thus givig us a material whose properties we can vary.

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