Effect of rf power on the electrical properties of glow-discharge a-Si:H

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Abstract

Hydrogenated amorphous silicon films were prepared in an rf glow-discharge system by decomposing undiluted silane at various rf power densities. Dark conductivity and photoconductivity of the films have been measured in the temperature range 420K-100K at four different photon fluxes. It was observed that both dark conductivity and photoconductivity increase with increasing rf power density.

Key Words: A. Dark conductivity; B. Photoconductivity; Rf power density; D. Activation energy; E.Hydrogenated amorphous silicon.

1. Introduction

Amorphous tetrahedral semiconductors have been known for a long time, but interest in this class of materials has increased rapidly since the discovery by Spear and Lecomber in 1975 that amorphous hydrogenated silicon (a-Si:H) can be doped [1]. The connection between fundamental research and technological applications has stimulated the world-wide studies to understand the properties of amorphous hydrogenated silicon and its alloys. Glow-discharge deposition has become the technique for production of high-quality amorphous silicon films. The electronic and optical properties of a-Si:H films are strongly dependent on the preparation conditions such as rf power density, subsrate temperature, gas flow rate and chamber pressure etc.

In this study, dark conductivity σ_d and photoconductivity σ_{ph} of a set of a-Si:H films, which were prepared by glow-discharge deposition of silane SiH_4 gas in a capacitively-coupled rf plasma reactor, have been investigated as a function of rf power density. The effect of rf power density on the dark conductivity activation energy E_a, deposition rate dr and photoconductivity have been studied.

2. Experimental Details

Films of a-Si:H used in this study were prepared at Hacettepe University by glow-discharge decomposition of SiH_4 gas in a capacitively coupled rf plasma system [2]. The films were deposited on Corning 7059 glass substrates kept at $\approx 280^0$C. The thickness of the films were determined from the optical transmission measurements using the method described by Swanepoel [3,4]. The gas pressure was kept constant at 200 mTorr. For the electrical conductivity measurements, evaporated gap-type aluminium electrodes were used. The separation between the electrodes was 100 μm. The current in all experiments was measured with a Keithley 619 electrometer under the electric field 10^3 V/cm in the temperature range of 420 K-100 K. A bundle of λ=630 nm light-emitting diodes (LED) was used as a light source. The LED current was varied to obtain constant photon fluxes between F=2.5x10^{14} and 1.0x10^{17} photons/cm^{2}s.

The glow-discharge plasma apparatus has 55 mm diameter parallel plate electrodes with 30 mm distance between the two parallel plates. A radio frequency oscillator (11 Mhz and max. output 20 W) were used as the rf power supply. The dissipated rf power in the reactor cannot be measured directly. However this value can be approximately calculated from the measured rf voltage value between the plates and the geometric factors of the chamber [5]. Calculated rf power densities are also shown in Table 1

3. Experimental Results and Discussion

For all the samples; applied rf voltage V_{rf}, calculated rf power density P_{rf}, film thickness d, deposition time dt, deposition rate dr, activation energy E_a, room temperature dark conductivity $[\sigma_d(RT)]$ and the photoconductivity power-law exponent γ are given Table 1. As seen in the table, the samples can be classified into two groups. The first group is composed of Sample 1 and Sample 2 which are deposited at lower rf power density (30 mW/cm^2 and 40 mW/cm^2, respectively). The second group is composed of Sample 3 and Sample 4 which are deposited at relatively higher rf power density (70 mW/cm^2 and 120 mW/cm^2, respectively).

The deposition rate of the films increase with increasing rf power density as shown in Table 1. A similar result was also reported for a-Si N_x:H[6], a-Si$_{1-x}$C$_x$:H[7] alloys and a-Si:H[8] films. Temperature dependence of the dark conductivity of the samples deposited at various values of P_{rf} is shown in Figure 1. The dark conductivity σ_d showed an activated behaviour and is well expressed by the expression

$$\sigma = \sigma_0 \exp(-E_a/kT).$$

The variation of the activation energy E_a and the room temperature dark conductivity σ_d (RT) are shown in Table 1. With increasing P_{rf}, the activation energy slightly increases. The room temperature dark conductivity of the films deposited at high rf power density are nearly one order of magnitude higher than the films deposited at low rf power density.

Table 1. Deposition parameters and some measured physical properties of the samples: applied rf voltage V_{rf}, calculated rf power density P_{rf}, film thickness d, deposition time dt, deposition rate dr, activation energy E_a, room temperature dark conductivity $\sigma_d(RT)$ and photoconductivity power-law exponent γ.

| Sample	$V_{rf}(V_{pp})$	(mW/cm^2) P_{rf}	d (μm)	dt(h)	dr (Å/s)	E_a (eV)	$(\Omega.cm)^{-1}$ σ_d(RT)	γ
1	1.0	30	1.0	4	0.7	0.50	3.2x10^{-8}	0.40
2	1.2	40	1.0	4	0.7	0.53	1.0x10^{-8}	0.37
3	1.6	70	1.5	4	1.0	0.60	3.1x10^{-7}	0.60
4	2.0	120	1.1	3	1.0	0.57	0.9x10^{-7}	0.50

The temperature dependence of the photoconductivity of the samples measured at four different photon fluxes are shown in Figures 2-5. Temperature and light intersity-dependent photoconductivity curves show different behaviour depending on the selected temperature range and photon flux value. Dependence of photocurrent on light intensity is not linear in a-Si:H and in its alloys and usually is expressed by

$$\sigma_{ph} \approx F^{\gamma},$$

where γ is usually less than 1 and depends on preparation conditions [9]. It can be seen from Table 1 that the γ value is 0.4 for the samples prepared at low power densities, namely Sample 1 and 2. Light intensity dependence of photocurrent is somehow different for the samples prepared at higher power densities: The γ value is 0.6 for Sample 3 and 0.5 for Sample 4. Therefore, in a wide temperature range, a weak dependence of photoconductivity on light intensity is seen in Figure 2 and 3 for low light intensity (F_1 and F_2) for all the samples. However, at higher photon fluxes the difference on photoconductivity between the samples prepared at low and high rf power densities clearly show itself in Figure 4 and Figure 5 depending on the value of γ.
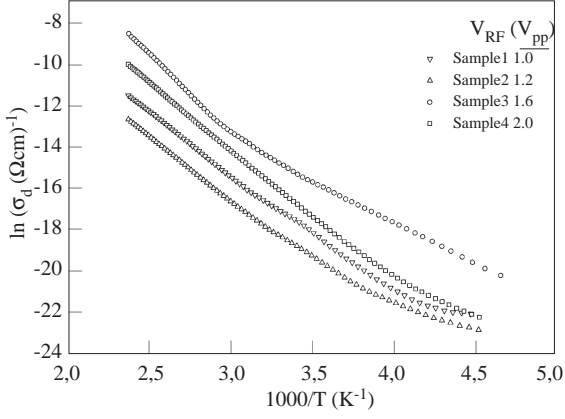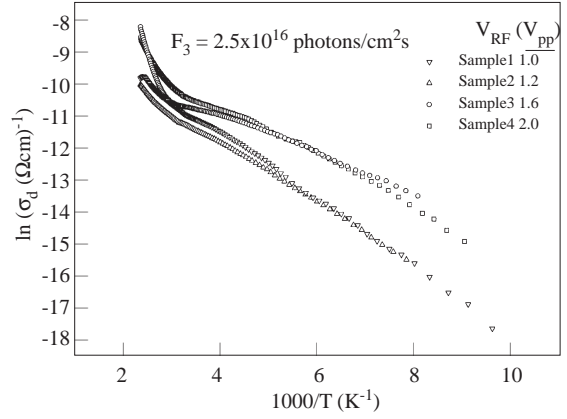
Figure 1. Temperature dependence of the dark conductivity as a function of applied rf voltage.
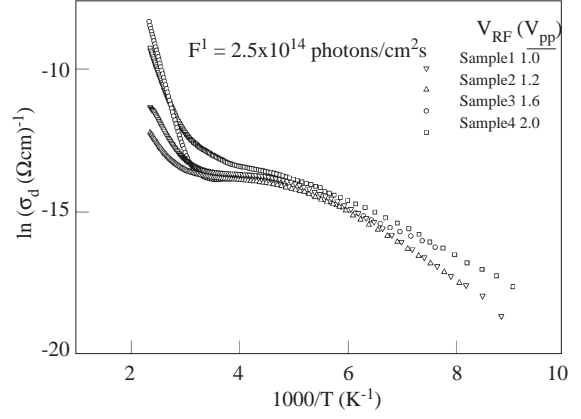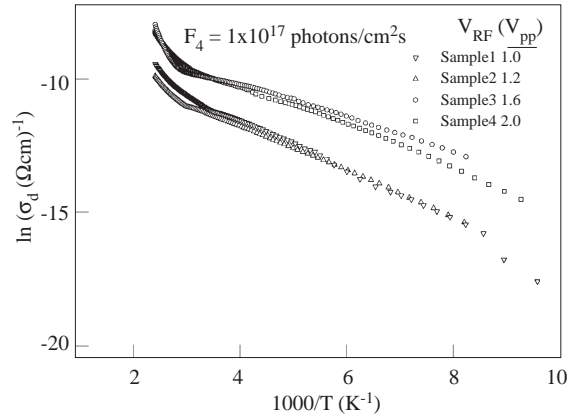
Figure 2. Temperature dependence of the the photoconductivity as a function of applied rf voltage. The photon flux is 2.5×10^{14} photons/cm^{2}s at 630 nm.
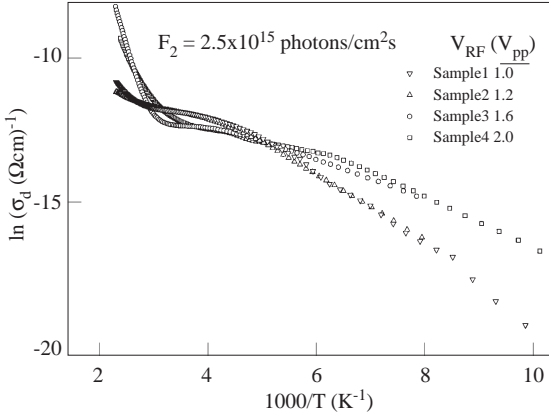
Figure 3. Temperature dependence of the photoconductivity as a function of applied rf voltage. The photon flux is 2.5×10^{15} photons/cm^{2}s at 630 nm.

Figure 4. Temperature dependence of the photoconductivity as a function of applied rf voltage. The photon flux is 2.5×10^{16} photons/cm^{2}s at 630 nm.

Figure 5. Temperature dependence of the photoconductivity as a function of applied rf voltage. The photon flux is 1.0×10^{17} photons/cm^{2}s at 630 nm.

Although the order of magnitude of the dark conductivity of the two samples prepared at high rf power density are same and higher than the dark conductivity of the samples 1 and 2 prepared at low rf power

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density, Sample 3 (rf power density is 70 mW/cm^2) has higher dark conductivity value than Sample 4 (rf power density is 120 mW/cm^2). Photoconductivity of the samples show similar behaviour.

In summary, I have reported in this study the effect of the variations in rf power density on the electrical properties of the a-Si:H films prepared by the glow-discharge decomposition of silane gas. It was observed that the deposition rate, the activation energy, the dark and photoconductivity increase with increasing rf power density.

Acknowledgements

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