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# RELATION BETWEEN THE PROPERTIES OF a-Si:H THIN FILMS AND THE GROWTH RATE

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**Abstract.** The results following an extensive characterization study involving dark- and photoconductivity measurements as a function of temperature, and the optical and structural properties of hydrogenated amorphous silicon (a-Si:H) thin films prepared at varying deposition rates were analyzed. The thin films were deposited by homogeneous chemical vapour deposition at low pressure. The growth rates were varied by changing the gas pressure and gas temperature. We found that the activation energy, the conductivity pre-exponential factor, the photo-sensitivity, the refractive index and the inhomogeneity parameter exhibit a maximum in the dependence on the deposition rate. The optical band gap and the optical coefficient $B$, including information on the band tail states, do not change significantly with the increase of the deposition rate.

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## 1. Introduction

The hydrogenated amorphous silicon (a-Si:H) has attracted as a promising material for low-cost solar cells and other applications. For many of the applications, for example nuclear radiation detectors, thicker films are needed. The increase of the deposition rate, however, is connected with the deterioration of film quality. In plasma CVD (glow discharge) the properties are governed by a competition between the rate of the film growth and the rate of thermally activated surface reactions at the filmgrowing surface [1]. Reducing the film deposition rate results in high quality films. The relationship of the film quality of the deposition rate is so-called negative. Many different approaches have been attempted [2-6] to increase the deposition rate of a-Si:H. Owing the complexity of the plasma, it is difficult to investigate the relation between the film quality and the deposition rate taking into account all plasma processes. During growth, the a-Si:H surface is exposed to neutral particles, ions, electrons and photons. All these may affect the surface chemistry and the resulting film properties.

In this work we investigate the relation between the deposition rate and film properties of a-Si:H deposited by a homogeneous chemical vapour deposition (HOMOCVD). In HOMOCVD, the silane decomposition occurs by pyrolysis, as in normal CVD.

 

However, the substrate is cooled such that enough hydrogen can be incorporated into the film to saturate the dangling bonds. Compared to the glow discharge, an energetic electron and ion bombardment is absent. The average particle energy is less than 0.1 eV. The deposition rate does not depend on substrate temperature up to 350 °C and it can be varied by changing the gas pressure or gas temperature. The deposition conditions were chosen to prevent powder formation in the reactor [7].

## 2. Experimental

Undoped a-Si:H films were deposited by HOMOCVD in reactor, described elsewhere [7, 8]. Pure nondiluted electronic grade silane was used in all experiments. The films were grown on Corning 7059 glass, fused quartz and crystalline silicon substrates. The deposition time was the same for all samples and equaled 180 min, the thickness variations resulted from the different deposition rates.

Optical properties were evaluated from film transmittance, using a Perkin-Elmer 330 spectrophotometer. The absorption coefficient and refractive index were calculated using the method proposed by R. Swanepoel [9] for inhomogenous amorphous silicon films. The optical gap was determined from the Tauc plot. The square of the Tauc plot slope was used to obtain the constant $B$, which described the shape of the band edge and related with the range of disorder in amorphous materials [10]. The stylus method performed by Talystep was used to determine the thickness and, therefore, the deposition rate. The Swanepoel method permitted to calculate film thickness from the transmittance data. The difference between the computed optical film thickness and the measured by Talystep was lower than 5–7 %.

The electrical properties of the a-Si:H films were measured by a standard conductivity measurement setup. For these measurements the coplanar samples were used with aluminum strip electrodes and a gap of 0.3 mm between them. The samples were annealed in a vacuum at 180 °C for 30 min and cooled down at $\approx 1.5$ K/min before measurement. The temperature dependence of the conductivity was investigated from 20 to 200 °C. The measurements were carried out in a vacuum at $10^{-3}$ Torr, using a high impedance input electrometer. The illumination of a tungsten halogen lamp was used for the photoconductivity investigation.

## 3. Results and Discussion

The results demonstrated in this work were obtained varying the deposition rate by changing gas temperature in the interval 650–710 °C. The rest of parameters were kept constant — gas pressure in the reactor 100 Pa, gas flow rate 60 sccm and substrate temperature 250 °C.

In Fig. 1 the dependence of the optical band gap (circles) and constant $B$ (triangles) on the deposition rate is shown. The optical band gap increases from 1.62 eV to 1.85 eV with increasing of the growth rate in the investigation range. The optical band gap has a strong correlation with the film deposition rate [1] which is explained by the growth rate dependence of the hydrogen content. With increasing of deposition rate the incorporation of radicals ($SiH_2$, $SiH_3$, $SiH_4$) in the film growth becomes possible, which

augments the hydrogen concentration and band-gap, respectively, at fixed substrate temperature.

The constant $B$ slowly decreases with the deposition rate increase (Fig. 1), suggesting a decrease of the short range order. The slow deposition rate causes the lattice to be more relaxed. Only the atoms (not particles) on the surface are mobile and slow deposition will render them more possibilities for searching low-energy sites.

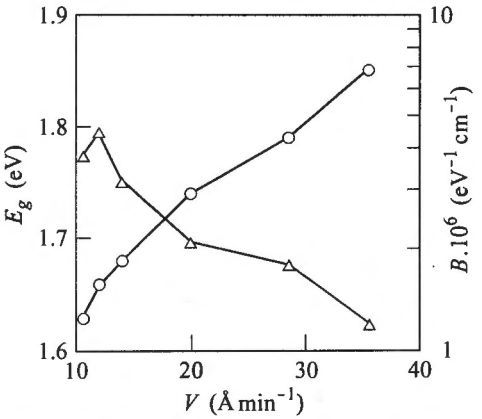


**Fig. 1.** Deposition rate dependence of the optical band gap $E_g$ (circles) and constant $B$ (triangles). $T_s = 250\,°C$

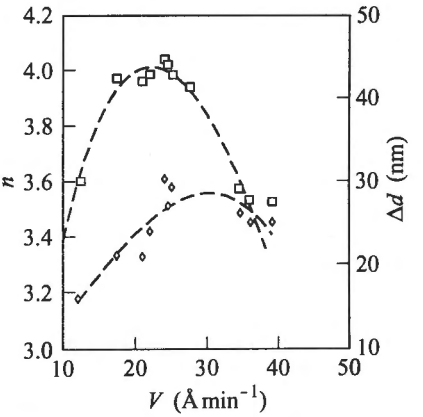


**Fig. 2.** Dependence of the refractive index $n$ (squares) and inhomogeneity parameter $\Delta d$ (diamonds) on the deposition rate

Figure 2 demonstrates the variation of the refractive index $n$ values at 2000 nm (squares) and of the optical inhomogeneity parameter $\Delta d$ (diamonds) with deposition rate. The latter is estimated by R. Swanepoel's method of calculation [9] and reflects the variations in film thickness and refractive index. As it can be seen in Fig. 2, the refractive index does not change monotonously, showing a maximum of about 25 Å/min. The decrease of the refractive index at higher deposition rates is probably related with the mobile particles on the growing surface which makes the film less dense. Such a suggestion is confirmed by the microstructure data, demonstrated in Fig. 3. The microstructure parameter $R$ is defined as $R = 2080(2000+2080)$ [11], where the brackets denote the absorption strengths of the IR modes at the respective wave numbers. As it can be seen in Fig. 3 the microstructure parameter increases with the increase of the deposition rate, which denotes the increase of the micropore density, and the long-range inhomogeneities. In the full range of considered deposition rates, however, the microstructure parameter remains below 0.5, which can be regarded as an indication of a high a-Si:H quality. The variation of photoconductivity (at room temperature) for a-Si:H films deposited at different deposition rates is shown in Fig. 4. The illumination intensity is 10 mW/cm$^2$.

Photoconductivity decreases with increasing the deposition rate, as established by many authors [3-6]. It may be related to the increased disorder and compares very well with the behaviour of constant $B$ (Fig. 1), optical inhomogeneity parameter $\Delta d$ (Fig. 2) and microstructure parameter $R$ (Fig. 3). While the photoconductivity decreases

with increase of deposition rate, the activation energy $E_a$ (Fig. 5) does not change monotonously. At the deposition rate 30–35 Å/min a pronounced maximum is observed. The activation energy was determined from the single-straight line in the dark conductivity temperature dependence. The decrease of the value of the activation energy for higher deposition rates may denote that the position of Fermi level seems to move towards the conduction band. This again goes to indicate the creation of additional defects in the a-Si:H films with increasing the deposition rate.

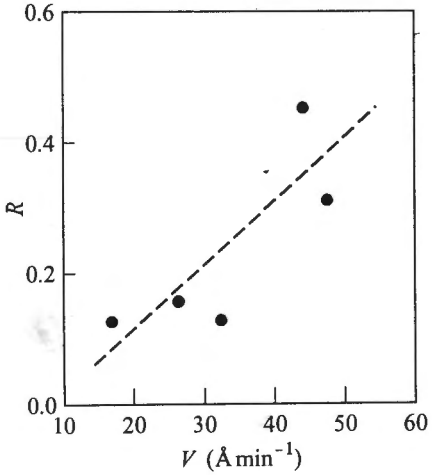


Fig. 3. Dependence of the parameter of microstructure on the deposition rate

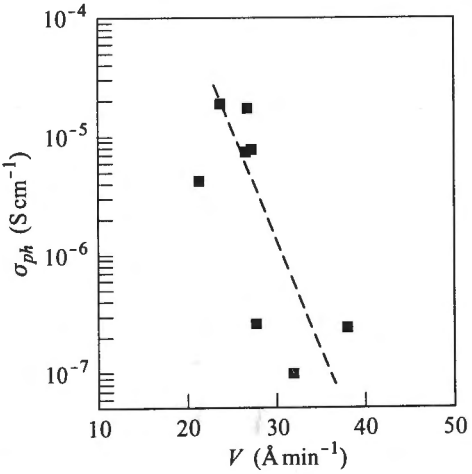


Fig. 4. Deposition rate dependence of the photoconductivity

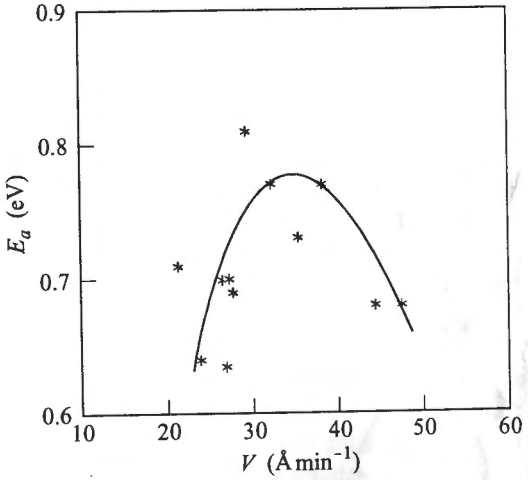


Fig. 5. Deposition rate dependence of the activation energy

## 4. Conclusions

The hydrogenated amorphous silicon thin films grown by HOMOCVD were studied. Deposition conditions were chosen, where the power formation in the gas space of the reactor was excluded. The deposition rate was varied gas pressure and gas temperature varying. In the investigated range of the deposition rates deterioration of structure parameters and photoconductivity were established. They remained, however, in the range of device quality parameters. This allowed to suggest the possibility to rise the deposition rate for HOMOCVD method using gas-phase conditions, permitting the formation of powder in the gas space of the reactor.

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