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# Study of high rate a-Si:H growth using in-situ ellipsometry

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An increase in the a-Si:H growth rate can stimulate its application in thin film solar cells as a more competitive position in the energy market can be obtained. At the Eindhoven University a-Si:H layer are deposited at high growth rates (10 nm/s) by means of a remote expanding thermal plasma (ETP) created in a cascaded arc [1]. This high growth rate and the larger freedom and range in ETP parameters can give new insights in the a-Si:H growth mechanism.
In this paper the optical parameters of the layer are studied using single wave length (HeNe 632.8 nm) rotating compensator ellipsometry. Ellipsometry measurements are based upon the measurement of polarization change, expressed in the ellipsometric parameters Ψ and Δ, due to a reflection on the thin film [2]. In figure 1 a typically measured ellipsometric trajectory is presented. The starting value of Ψ and Δ are corresponding to reflection on c-Si substrate with on top a $SiO_2$ layer. Depositon starts with a jump in the Ψ-Δ plot corresponding to the initial growth of a inferior film (3 to 6 nm), caused by either nucleation or diffusion of the oxygen in to the film. Due to an increasing bulk a-Si:H film thickness the Ψ-Δ curve makes a clockwise inward spiral movement, towards the covergence point corresponding with the bulk $n_{bulk}$ and $k_{bulk}$ having a certain surface roughness.

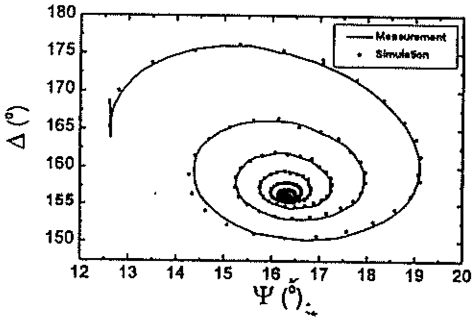

***Figure 1** Ellipsometry measurement (line) and simulation (squares). $T_{sub}$ = 400 °C, $Ar/H_2/SiH_4$ 55/5/10 sccs*

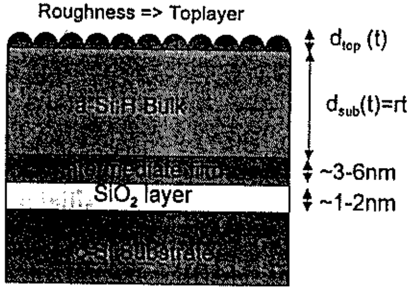

***Figure 2** Optical growth model*

The ellipsometry trajectory can not be simulated using a two optical layer model [3] but only by using a multi layer model presented in figure 2. The c-Si substrate refractive index $n_{sub}$ and extinction coefficient $k_{sub}$ at substrate temperature $T_{sub}$ used in the model is an empirical one [4]. $SiO_2$ layer of 1 to 2 nm having $n_{SiO2}$=1.462 at 632.8 nm. To explain the jump at the start and to obtain a higher accuracy in determination of $n_{bulk}$ and $k_{bulk}$ an intermediate layer is included. The bulk growth is assumed to be homogenous which is consistent with the simulation results; the fluctuation in refractive index $\Delta n_{bulk}/n_{bulk} < 0.02$. A top layer, simulating the roughness evolution, had to be included to explain the continuous shift in the Δ-direction in time, cf. Figure 1. The roughness is simulated by a top layer with an effective refractive index using the Bruggeman's effective medium approximation [5]. The void fraction of the toplayer is assumed to be 50%.

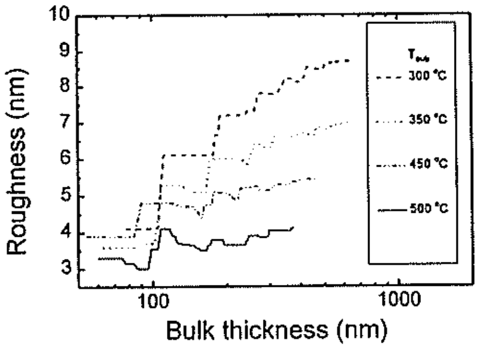

***Figure 3** Roughness versus bulk thickness at different $T_{sub}$, $Ar/H_2/SiH_4$ 55/10/10 sccs, arc current 45 A, p = 20 Pa.*

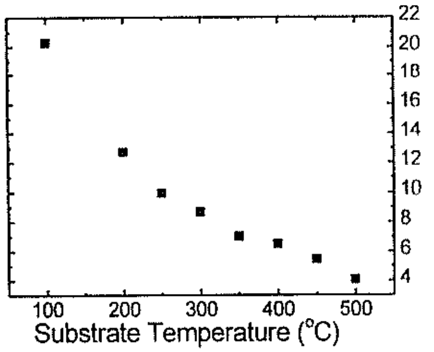

***Figure 4** Roughness versus substrate temperature at bulk thickness 500 nm. $Ar/H_2/SiH_4$ 55/10/10 sccs, arc current 45 A, p = 20 Pa.*

The model used, enables us to monitor the roughness evolution in time. In figure 3 the roughness evolution for four different substrate temperatures are plotted. The roughness is increasing in time and the absolute roughness decreases with increasing substrate temperature (figure 6). The substrate temperatures at which the best material is deposited [6] leads to films with the smallest top layer roughness.

In the most simple model the surface roughness $d_{top}$ evolves as $d_{top} \propto t^{\alpha}$, whit $\alpha=½$ corresponding with no surface diffusion during growth. For $\alpha<½$ processes before sticking are important. In figure 5 this $\alpha$ is plotted versus the substrate temperature. At substrate temperature of 300 $^0$C a maximum value for

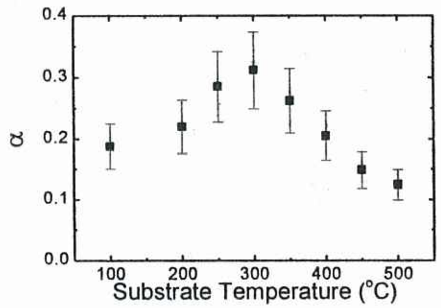

***Figure 5** Exponent α versus substrate temperature $Ar/H_2/SiH_4$ 55/10/10 sccs, arc current 45 A, p = 20 Pa.*

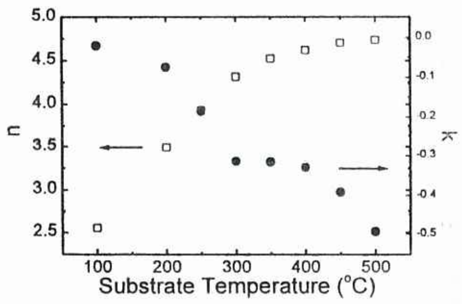

***Figure 6** n and k versus substrate temperature $Ar/H_2/SiH_4$ 55/10/10 sccs, arc current 45 A, p = 20 Pa.*

$\alpha$, meaning the smallest diffusion length, is observed. From this it can be concluded that at least two competitive growth mechanism play an important role in the structural smoothing at the surface.
In figure 6 it is shown that $n_{bulk}$ and the absolute $k_{bulk}$ value determined from the ellipsometry measurements increases with increasing temperature. This is caused by a lower hydrogen content at higher substrate temperatures, making the material more dense.

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