

Expanding cascaded arc plasma beam deposition of a-Si:H for photovoltaic cells

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EXPANDING CASCADED ARC PLASMA BEAM DEPOSITION OF a-Si:H FOR PHOTOVOLTAIC CELLS

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Introduction

Undoped amorphous hydrogenated silicon is used as the intrinsic layer in amorphous silicon solar cells. In order to gain a better understanding of the deposition mechanism, new techniques differing from conventional PECVD are being tried out. A technique based on an expanding thermal arc in an argon hydrogen mixture seeded with SiH₄ has lead to high growth rates: typ. >100 Å/s. To determine suitability for photovoltaic applications, a number of properties have to be examined, such as the refractive index, the optical bandgap, the dominant bonding type (SiH, SiH₂), the oxygen impurity content, the photoresponse and the photoconductivity.

Experimental

The plasma source is an argon/hydrogen-fed cascaded arc (typ. 50 A, 100 V), as described in [1]. The plasma, which is dominated by hydrogen ions, expands into the low pressure vessel (0.2 mbar), and silane is injected into the plasma beam immediately after the nozzle, in a flow mixture of Ar:H₂:SiH₄=55:10:6 scc/s. The substrate holder is clamped on a yoke perpendicularly to the flow direction of the plasma beam. As the electron temperature in the expanding beam is low, typically 1 eV, radicalization of the injected silane is achieved by a sequence of (dissociative) charge exchange with atomic hydrogen ions emanating from the arc, and consecutive dissociative recombination. Main differences with conventional PECVD are thus:

PECVD	PBD
ionizing	recombining
transport by diffusion	directed flow
substrate self-bias	low self-bias

Table 1. Differences between conventional PECVD and PBD.

For *in-situ* monitoring of the refractive index, He-Ne ellipsometry is employed. As the film increases in thickness, the optical path increases, but so does the absorption. The result is a converging spiral in the ellipsometric plane, with the convergence point representing the refractive index of the deposited film; typical values are 3.8 ± 0.2 . From the spiral time constant the growth rate can be calculated, and thus an estimate for layer thickness.

The optical bandgap is determined ex-situ with a spectroscopic transmission measurement. The absorption coefficient near the absorption edge depends on photon energy according to Tauc's approximation: $\alpha \approx (h\nu - E_{gap})^2/h\nu$. A fit typically yields a value of 1.80 eV for the bandgap.

Bond concentrations are measured using Fourier-Transformed InfraRed transmission measurements (FTIR). Absorption at 640 cm^{-1} is specific to Si-H_x vibrations (x=1,2,3), 890 cm^{-1} to Si-H₂, 1050 to Si-O, 2000 to Si-H and 2100 to Si-H₂ and Si-H on internal voids. After background deconvolution, bond concentrations are calculated from the surface area of these absorption peaks (fig. 1). The 640 cm^{-1} bond concentration yields the hydrogen concentra-

tion in the film (typically 10-30%). The parameter $R^* = I_{2100}/(I_{2000} + I_{2100})$ (typically 0.3-0.6) represents the hydrogen fraction bonded differently than in SiH, and is called the amount of microstructure [2].

Layer conductivities, as measured by Utrecht University, are obtained by measuring the photocurrent (under 100 mW/cm² AM1.5 illumination) and dark current (extrapolation in cooling down curve) when applying 100 V to previously deposited silver electrodes of 2cm length, 0.6mm apart. From a test batch of four samples, the highest photoconductivity was 10⁻⁶ Ω⁻¹cm⁻¹, and the highest light-to-dark conductivity ratio (photoresponse) 10⁶.

Results and Discussion

A comparison between device quality a-Si:H and the tested batch is given in table 2.

	demand	PBD samples
n_{IR}	3.53	3.1
n_{HeNe}	4.3	3.8
$E_{gap, Tauc}$	1.8	1.8
H-conc.	≤10%	15%
R^*	≈0	> 0.2
σ_{ph}/σ_d	>10 ⁵	10 ⁶
σ_{ph}	>10 ⁻⁵	10 ⁻⁶

Table 2. Comparison of PBD a-Si:H to device quality material.

It was found that the bandgap for the specimen under study remained almost constant, whereas the hydrogen concentration ranges typically between 15 and 25%, and the R^* parameter is larger than 0.2. According to [2], this indicates that the material contains voids, where the mass density can decrease to 85% of device quality material. This yields, when using an Effective Medium Approximation, a refractive index of 3.8 at HeNe wavelength, and 3.1 in the infrared.

The fact that the photoresponse is OK, but the photoconductivity too low, might be associated with a low free carrier mobility: the diffusion length is known to depend sensitively on contaminant concentration (such as oxygen) [3] or microstructural defects such as voids. However, more tests are necessary to substantiate.

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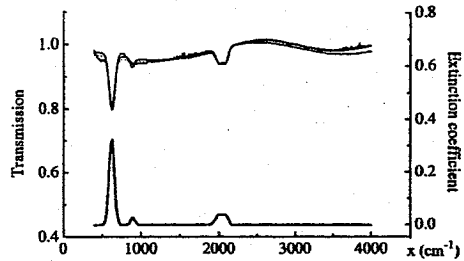


Figure 1. FTIR measurement and deconvoluted absorption peaks for PBD a-Si:H