

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

**Citation for published version (APA):**

Severens, R. J., van de Sanden, M. C. M., Brussaard, G. J. H., Schaepkens, M., Meeusen, G. J., & Schram, D. C. (1994). Expanding cascaded arc plasma beam deposition of a-Si:H for photovoltaic cells. In M. C. M. van de Sanden (Ed.), *ESCAMPIG 94 : European Sectional Conference on Atomic and Molecular Physics of Ionized Gases, 12th, Noordwijkerhout, The Netherlands, August 23-26, 1994: Abstracts of invited lectures and contributed papers* (pp. 386-387). (Europhysics conference abstracts; Vol. 18E). European Physical Society (EPS).

**Document status and date:**

Published: 01/01/1994

**Document Version:**

Publisher's PDF, also known as Version of Record (includes final page, issue and volume numbers)

**Please check the document version of this publication:**

- A submitted manuscript is the version of the article upon submission and before peer-review. There can be important differences between the submitted version and the official published version of record. People interested in the research are advised to contact the author for the final version of the publication, or visit the DOI to the publisher's website.
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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 SiH<sub>4</sub> 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, SiH<sub>2</sub>), 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:H<sub>2</sub>:SiH<sub>4</sub>=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  $3.8 \pm 0.2$ . 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  $640 \text{ cm}^{-1}$  is specific to Si-H<sub>x</sub> vibrations (x=1,2,3),  $890 \text{ cm}^{-1}$  to Si-H<sub>2</sub>,  $1050$  to Si-O,  $2000$  to Si-H and  $2100$  to Si-H<sub>2</sub> and Si-H on internal voids. After background deconvolution, bond concentrations are calculated from the surface area of these absorption peaks (fig. 1). The  $640 \text{ cm}^{-1}$  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/cm<sup>2</sup> 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<sup>-6</sup> Ω<sup>-1</sup>cm<sup>-1</sup>, and the highest light-to-dark conductivity ratio (photoresponse) 10<sup>6</sup>.

## 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
$E_{gap}, T_{auc}$	1.8	1.8
H-conc.	≤10%	15%
$R^*$	≈0	> 0.2
$\sigma_{ph}/\sigma_d$	>10 <sup>5</sup>	10 <sup>6</sup>
$\sigma_{ph}$	>10 <sup>-5</sup>	10 <sup>-6</sup>

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.

## Acknowledgements

This work is supported by the Netherlands Agency for Energy and the Environment (NOVEM), the Foundation for Fundamental Research of Matter (FOM/STW) and the Netherlands Royal Academy of Sciences (KNAW). The help of E. Hamers (Utrecht University) is gratefully acknowledged.

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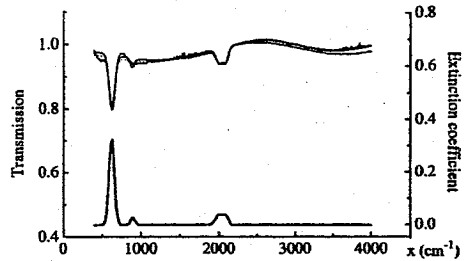


Figure 1. FTIR measurement and deconvoluted absorption peaks for PBD a-Si:H