INVESTIGATION OF A MAGNETRON ASSISTED PECVD PROCESS FOR DEPOSITION OF a-Si:H AND µc-Si:H FROM A SILANE-HYDROGEN-ARGON GAS MIXTURE

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INTRODUCTION

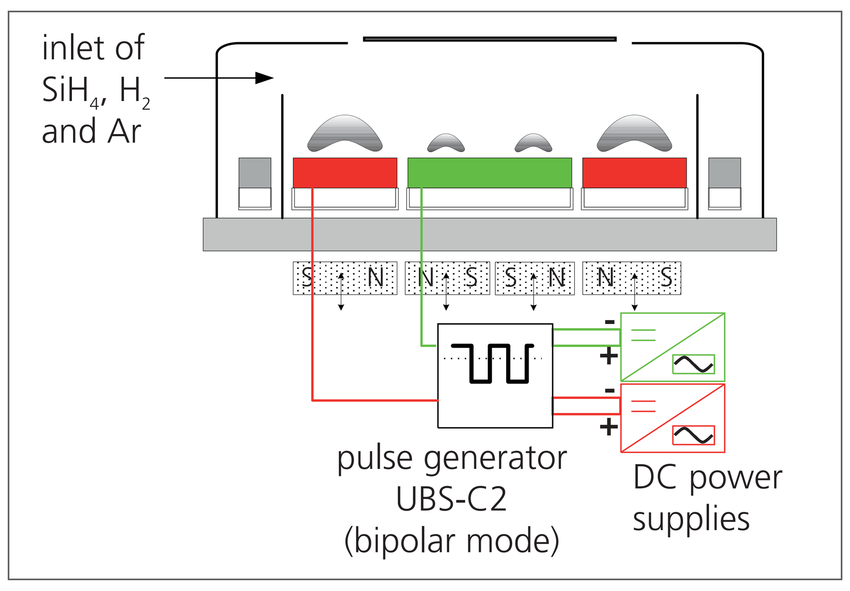
Our work investigated a magnetron assisted PECVD process for the deposition of amorphous and microcrystalline silicon. The utilised plasma source was a double ring magnetron sputter source for middle frequency (50 kHz) pulse magnetron sputtering, with two concentric silicon targets. Power was delivered between each target and the anode (unipolar pulse mode) or alternating between the two targets (bipolar pulse mode). The precursors were silane and hydrogen. The additional inlet of argon was used to stabilise the discharge and ensure long-time process stability. This offered also the possibility for parallel sputter deposition from highly doped targets to deposit doped layers through parallel PECVD and sputter deposition. The process pressure ranged from 0.5 ... 5 Pa.

MOTIVATION

- alternative scalable PECVD process for deposition of solar cell silicon
- potential for high deposition rates of amorphous silicon
- potential for deposition of microcrystalline silicon
- potential for reducing costs by avoiding complex microwave and RF technologies
- reduction of PECVD process pressure: easier combination of PVD and PECVD in in-line equipment, thereby reducing of handling costs
- contribution to film growth both from the precursor and from the target

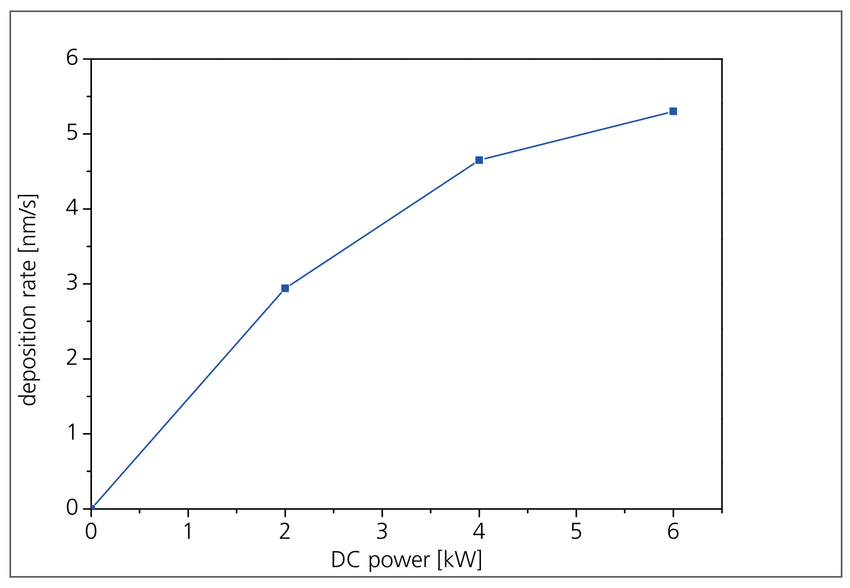
BASIC PROCESS CHARACTERISATION

- plasma source: double ring magnetron DRM 400 for middle frequency (50 kHz) pulse magnetron sputtering
- tests were carried out with silane inlet directed towards target in bipolar pulse mode
- lowest level of contamination and a plateau in hydrogen gradient due to the combined inlet of $SiH_4 + H_2 + Ar$
- additional argon kept the racetrack of the target free of deposition products → stable long-time operating was possible



Magnetron sputter source DRM 400 powered in bipolar pulse mode

- for characterisation layers were deposited on corning glass 1737 and silicon wafers

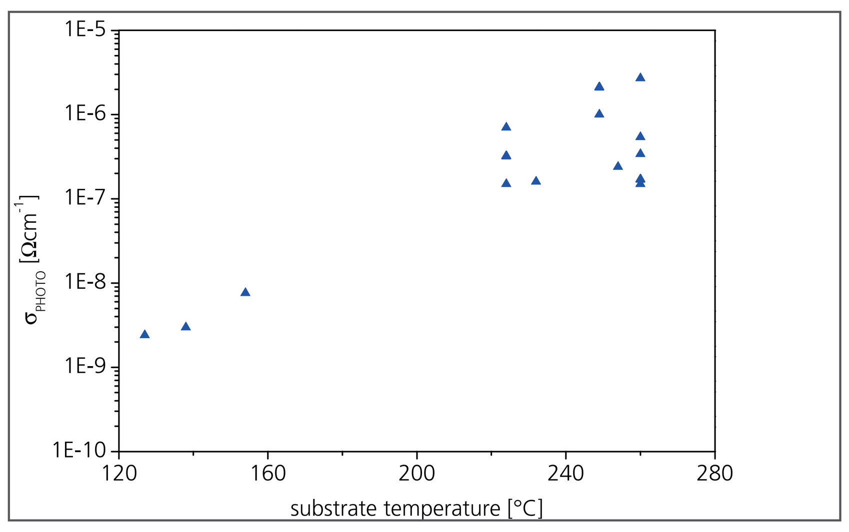


Stationary deposition rate for a-Si:H in dependence of DC power

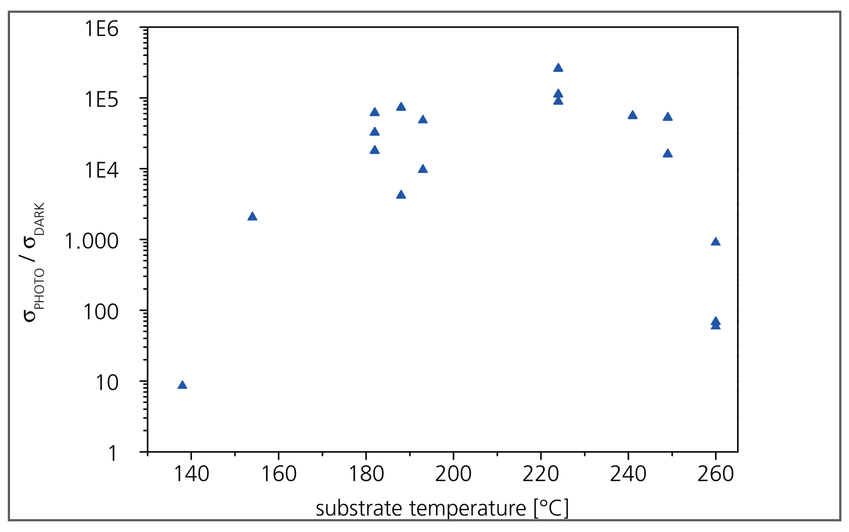
- the following measurements were carried out: conductivity measurements, GDOES, FTIR, UVVis spectroscopy, Raman spectroscopy, profilometry

RESULTS a-Si:H

INFLUENCE OF SUBSTRATE TEMPERATURE



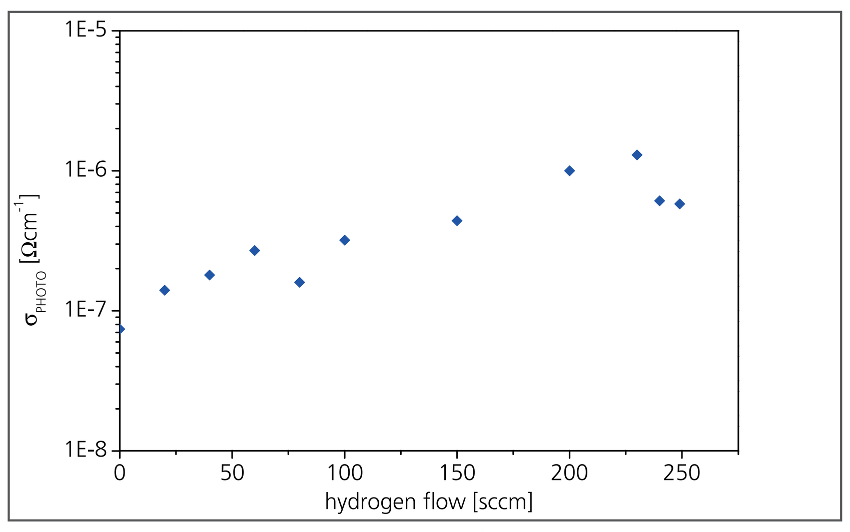
Photoconductivity in dependence of substrate temperature



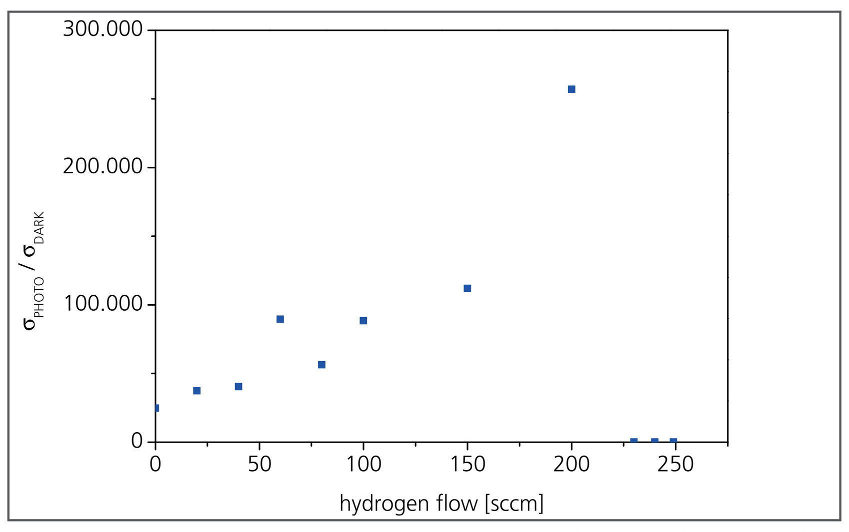
Ratio of photoconductivity and dark conductivity in dependence of substrate temperature

The maximum ratio of photoconductivity and dark conductivity was achieved with a substrate temperature of approx. 225°C. At temperatures higher than 260°C, both the hydrogen content and photoconductivity concur with values from the literature (10 at.% and $>10^{-5}$ Ωcm^{-1}). Here, the dark conductivity also is seen to increased and thereby the value of $\sigma_{photo}/\sigma_{dark}$ was close to zero. All samples were pre-heated, however the main contribution to substrate temperature rise occurs from the process itself.

INFLUENCE OF ADDITIONAL HYDROGEN



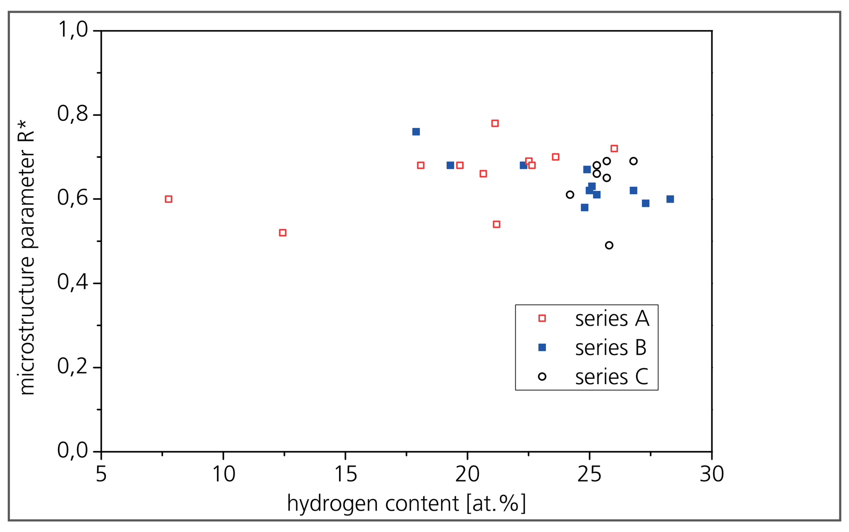
Photoconductivity as a function of hydrogen flow



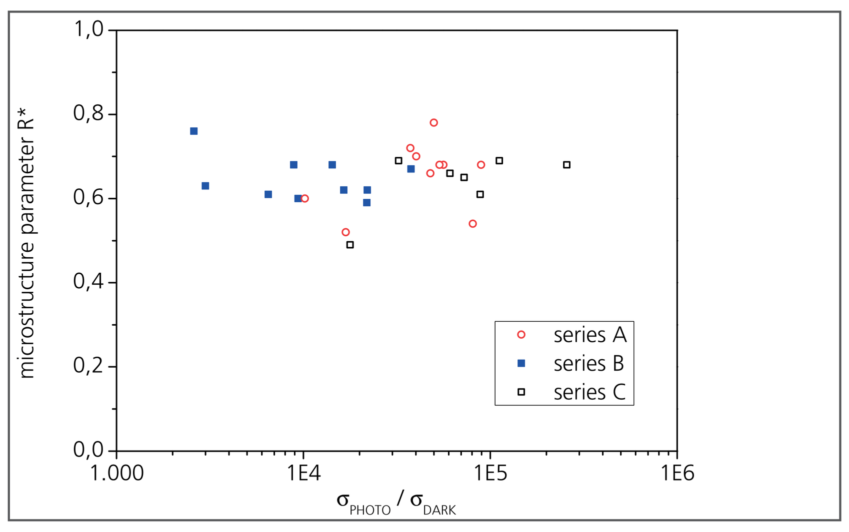
Ratio of photoconductivity and dark conductivity as a function of hydrogen flow

Additional hydrogen increases the photoconductivity and thereby the ratio of photoconductivity and dark conductivity up to a hydrogen flow of 200 sccm to values of about 2×10^5. At a greater flow of 200 sccm, the ratio reduces to almost zero due to the strong increase in dark conductivity. The achieved photoconductivity of $1.3 \times 10^{-6}\Omega cm^{-1}$ was still one order of magnitude too low compared to those in the literature.

HYDROGEN CONTENT AND MICROSTRUCTURE PARAMETER



Microstructure parameter as a function of hydrogen content



Correlation between microstructure parameter R and $\sigma_{photo}/\sigma_{dark}$*

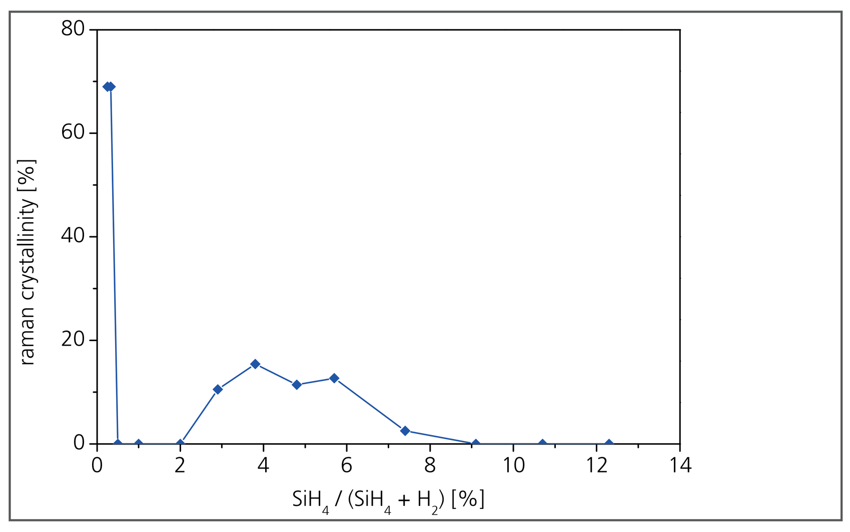
The microstructure parameter (R*) was seen to be relative independent upon the hydrogen content and achieved relative high values from 0.54 … 0.86. This means most of the hydrogen is bound as unwanted SiH_2 and SiH_3 instead of SiH. There was no impact of process parameters on R*, like DC-power, pre-heating power or argon flow observed. Despite the high values of R* a good value of $\sigma_{photo}/\sigma_{dark}$ was obtained.

RESULTS µc-Si:H

MICROCRYSTALLINE FRACTION

power [kW]	SiH_4 / ($SiH_4 + H_2$) [%]	Deposition rate [nm/s]
4.0	0.33	0.52
7.5	0.50	0.87
10.0	0.50	1.24

Deposition rate for µc-Si:H in dependence of DC power



Crystalline fraction in dependence of silane content

The main parameter to obtain microcrystalline silicon is the degree of dilution of silane in hydrogen SiH_4 / (SiH_4+H_2). The microcrystalline fraction increased through increased substrate temperature and increased hydrogen dilution. Between a silane content of 0.5 and 2.0 percent the microcrystalline fraction was unexpectedly zero.

SUMMARY

The amorphous layers deposited in the bipolar pulse mode at a static deposition rate of 2.7 nm/s exhibited low roughness and low particle levels which is attributed to the higher plasma density in the bipolar pulse mode. The best values of $\sigma_{photo}/\sigma_{dark}$ were achieved at substrate temperatures of approx. 225°C. Nevertheless, the absolute values of the photoconductivity of around 10^{-6} Ωcm^{-1} were still one order of magnitude lower than required. An explanation for this could lie in the relative high microstructure parameter, which suggests that hydrogen in the a-Si:H-layer is predominantly bonded as SiH_2 and SiH_3 instead of SiH. The initial experiments for depositing microcrystalline silicon were successful and a deposition rate of more than 1 nm/s was obtained. The estimated Raman crystallinity was around 70%. Resultantly the magnetron PECVD process showed potential for photovoltaic applications and is well-suited for the deposition of a-Si:H and µc-Si:H layers with high deposition rates. Further investigations and optimisation of the parameters are required.

property	Fraunhofer FEP sample	reference literature
dark conductivity	2.9×10^{-12} Ωcm^{-1}	$< 1 \times 10^{-10}$ Ωcm^{-1}
photoconductivity	1.0×10^{-6} Ωcm^{-1}	$> 1 \times 10^{-5}$ Ωcm^{-1}
photocond. / dark cond.	2.5×10^5	$> 10^5$
hydrogen content	21.2 at.%	9 … 11 at.%
microstructure parameter R*	0.6	< 0.1
band gap, Tauc	2.0 eV	1.8 eV

Summary of achieved a-Si:H layer properties compared to those from literature

CONTACT

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