Influence of Plasma Power on the Si Solar Cell Passivation Properties of Al_2O_3 Thin Films deposited by Plasma Enhanced Atomic Layer Deposition

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AVS 64th International Symposium & Exhibition


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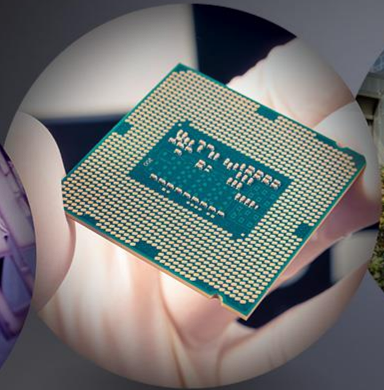

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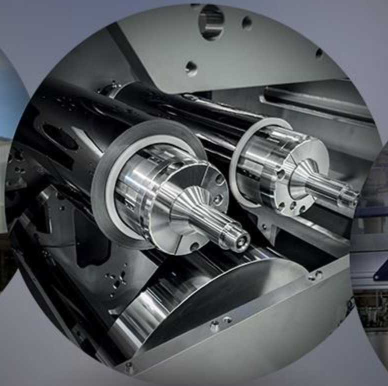

Industrial Equipment

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Outline

- Background
- Beneq TFS-200 with the plasma option
- Results
  - Growth characteristics
  - General properties
  - Si solar cell passivation
- Conclusions

Background

- (PE)ALD Al_2O_3 increasingly used to minimize the surface recombination of Si solar cells
  – Chemical and field effect passivation

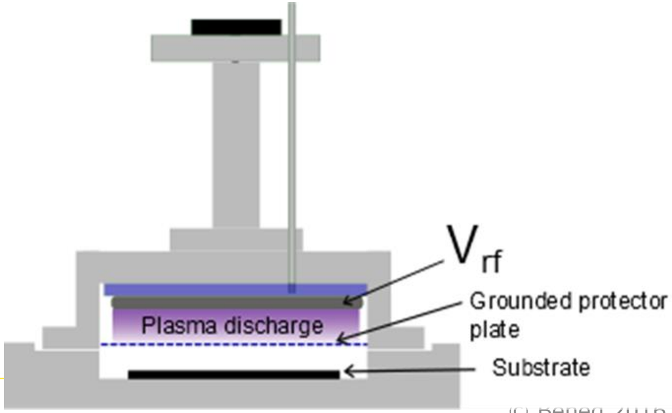
Deposition parameters		Post-deposition treatments	Best $S_{eff,max}$ (cm/s)		Ref.
T_{dep} (°C)	d (nm)		as-deposited	annealed	
200	7-30	30 min anneal at 425°C	1875	13; 2	B. Hoex et al.; *Appl. Phys. Lett.* **89** (2006) 042112
25-400	30	10 min at 400 °C	400	3	G. Dingemans et al.; *Electrochem. Solid-State Lett.* **13** (2010) H76
200	2-30	10 min anneal at 300-500 °C	$2000^{(p\text{-}type)}$; $1500^{(n\text{-}type)}$	$5^{(p\text{-}type)}$; $0.8^{(n\text{-}type)}$	G. Dingemans et al.; *Phys. Status Solidi RRL* **4** (2010) 10
200	3.6-30	5-25 min anneal at 425°C	5000	11	J. Schmidt et al.; *Phys. Status Solidi RRL* **3** (2009) 287
200	30	10 min at 400-450 °C; Plasma exposure	3000	2.8	G. Dingemans et al.; *Electrochem. Solid-State Lett.* **14** (2011) H1

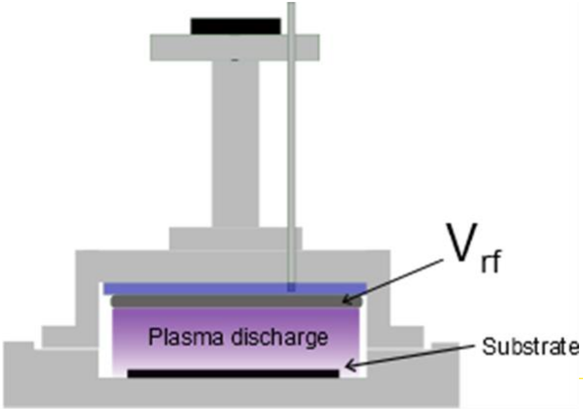
Beneq TFS-200 with the plasma option

- Capacitively coupled plasma (CCP)
- Both remote and direct plasma modes are always included in Beneq PEALD
- Switching between the remote and direct mode is easy
  - ➢ Just remove the grounded protector plate

- **Remote plasma**
  - Most common PEALD type
  - No ion bombardment on substrate

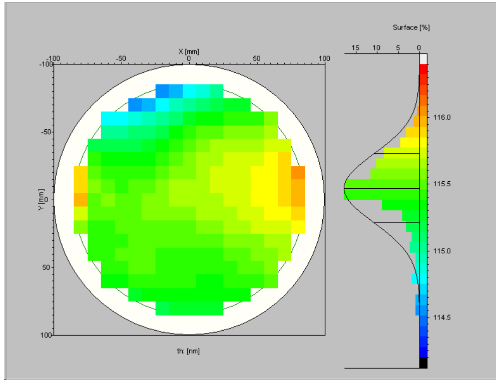
- **Direct plasma**
  - Possible to tune film properties *e.g.* film stress
  - Adhesion pre-treatments etc... possibilities





Experimental

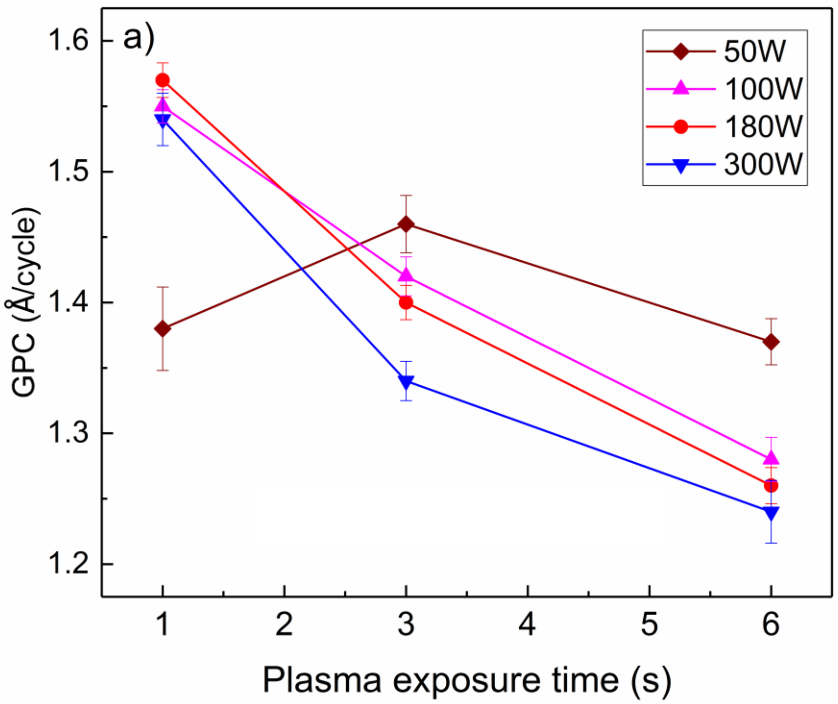
- Film growth
  - TMA + O_2 plasma @ 90 °C
  - Pulsing sequence
    - 0.2 s TMA – 3 s purge – 1-6 s O_2 plasma pulse – 2 s purge
  - Plasma power 50–300 W
- Si solar cell passivation
  - Cz n-type (5.5–7 Ωcm) substrate
  - 25 nm PEALD Al_2O_3
  - O_2 plasma expusure time 1 s
  - Annealing at 400 °C in N_2 for 30 min



RESULTS

Growth characteristics

- GPC decreases with increasing
  - Plasma power
  - Plasma exposure time
  - Except for a short 1 s plasma pulse with 50 W power

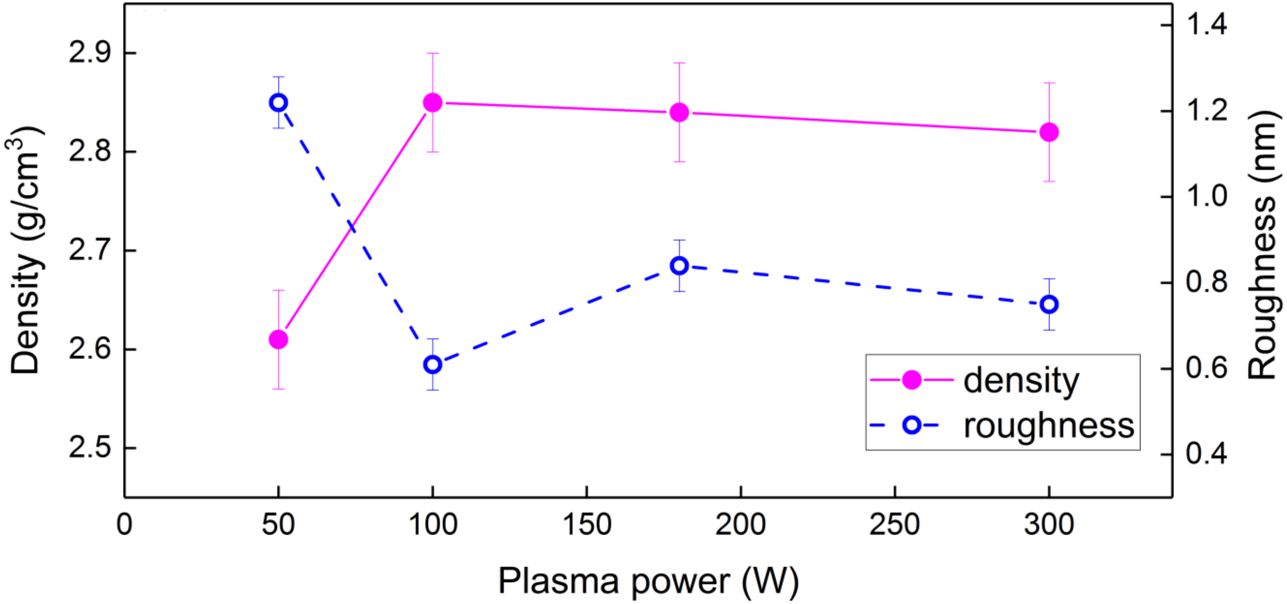


RESULTS

General properties

- Density is stabilized for plasma powers ≥100 W
- Some variation seen in the film roughness

1s O_2 plasma exposure

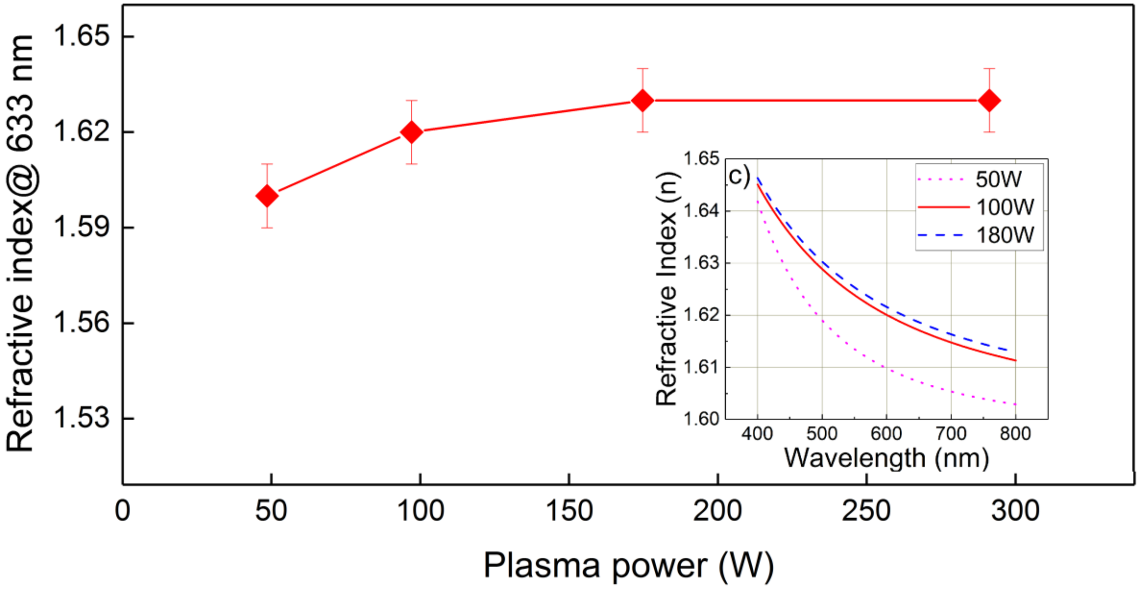


RESULTS

General properties

- Refractive index stabilixed for plasma powers ≥180 W
  - Correlation to density

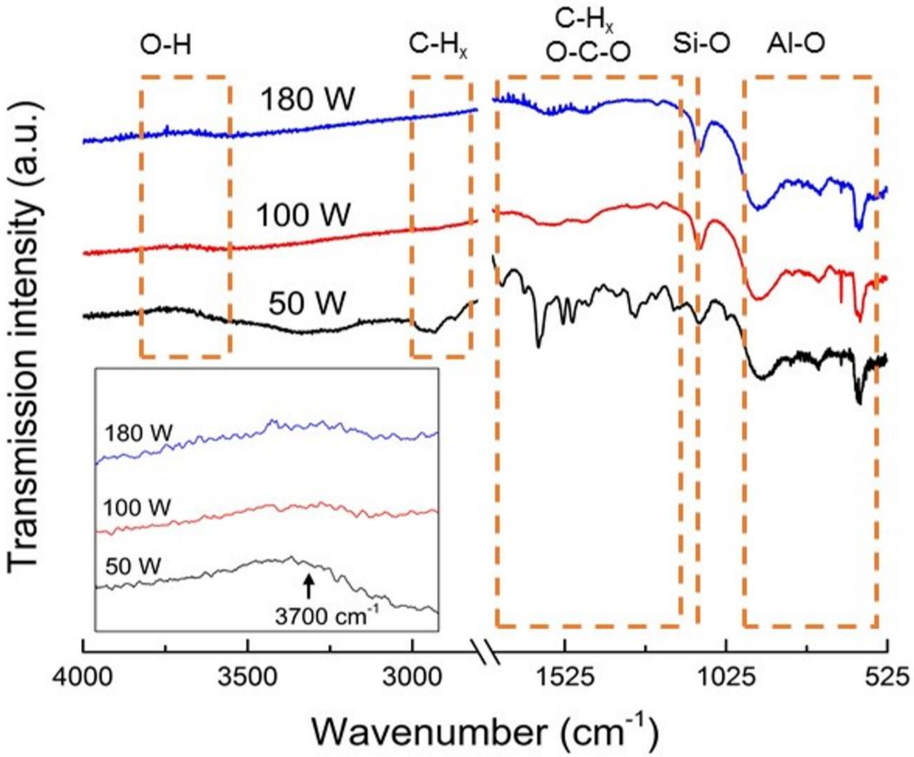
1s O_2 plasma exposure



RESULTS

General properties

- Significant decrease of impurities observed for plasma powers ≥100 W
  - Carbonaceous
  - Hydroxyls

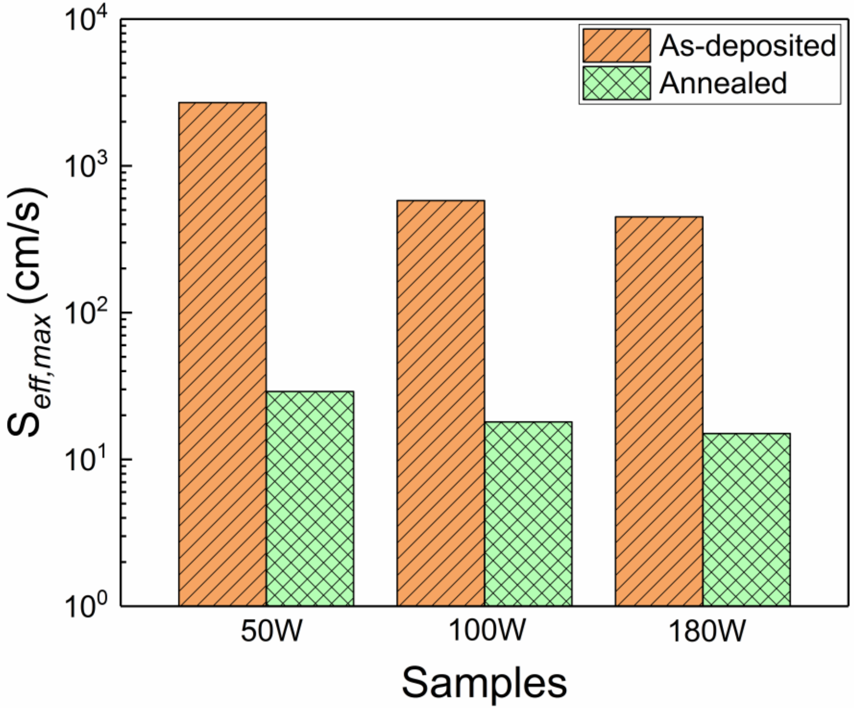


1s O_2 plasma exposure

RESULTS

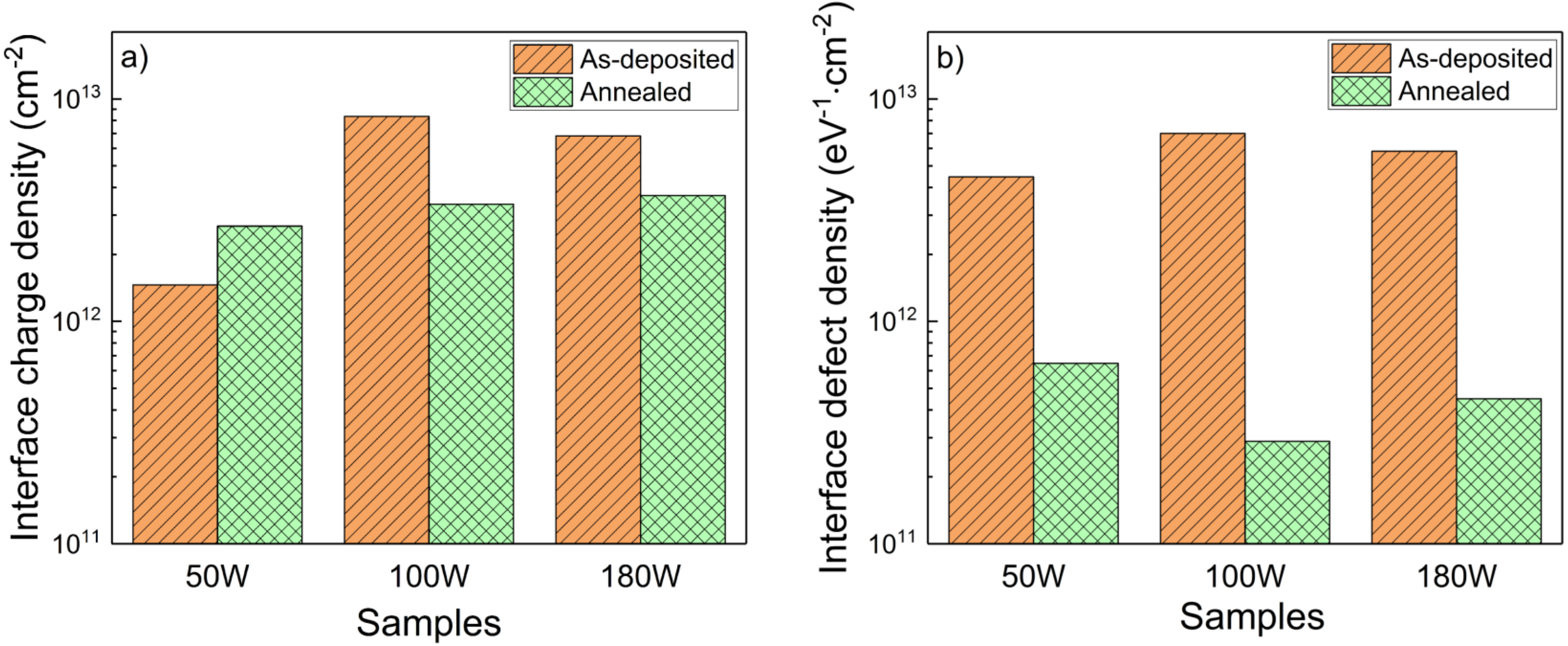
Si solar cell passivation

- Surface recombication velocity ($S_{eff,max}$)
  - Significantly decreased by annealing
  - Decrease with increasing plasma power



Si solar cell passivation

- Maximum interface charge density achieved with 180 W plasma power
- Minimum interface defect density achieved with 100 W plasma power



Conclusions

- Plasma parameters had a clear effect on PEALD Al_2O_3
  - Growth characteristics
  - General properties
- Surface passivation of Si solar cells with PEALD Al_2O_3 is plasma power dependent
  - Improved properties achieved with increasing plasma power
    - Lowest achieved $S_{eff,max}$ *was* 15 cm/s with 180 W plasma power

Thank you!

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RESULTS

Moisture barriers

- Barrier 4 nm Al_2O_3 PEALD film on PEN
- Barrier properties improved with
  - Increasing plasma power
  - O_2 plasma pulse time up to 3 s
    - Optimization
      - Nbr of reactive species
      - VUV radiation damage
    - Evident also for 50 and 180 W