DEPOSITION OF PURE SILICON PV-ABSORBER THIN FILMS BY HIGH-RATE ELECTRON BEAM EVAPORATION

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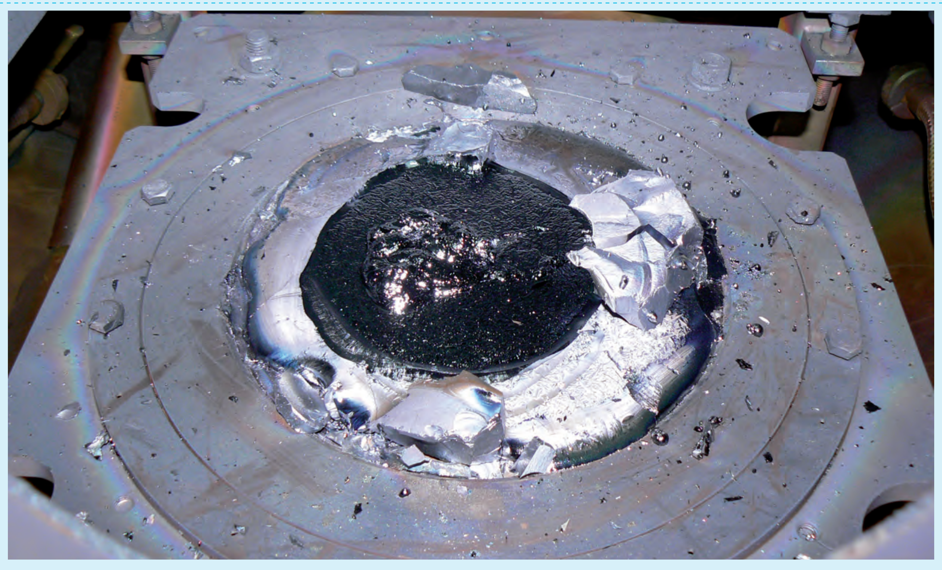
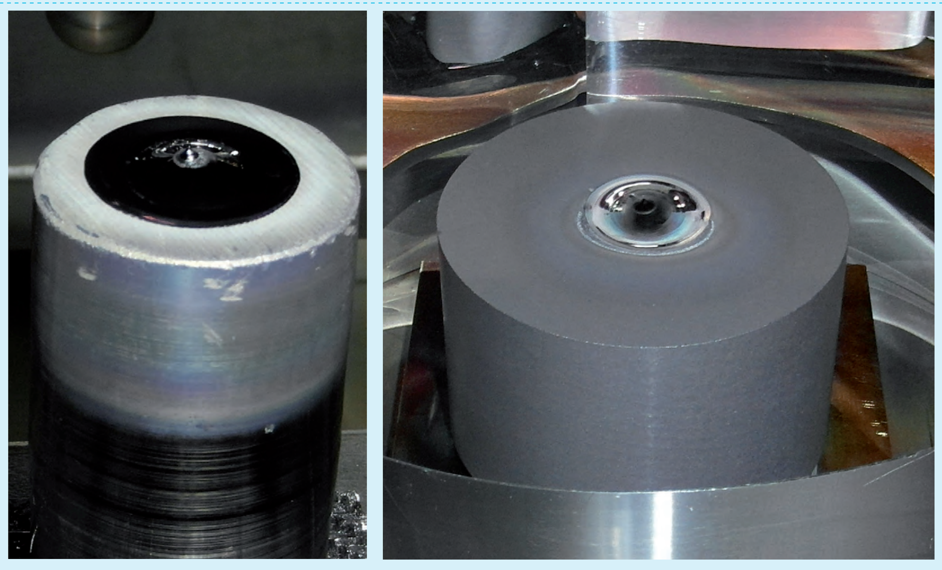
PURPOSE

The production of silicon thin film solar cells needs low-cost deposition of the PV absorber layer including following conditions:

- high throughputs
- high purity layer without any metallic contamination
- low process temperature to minimize external entry of contamination impact
- dense and amorphous layer for subsequent crystallization

Electron beam physical vapor deposition (EB-PVD) is a promising candidate to fulfill these requirements. Under high vacuum conditions large evaporation rates can be achieved. Additionally EB-PVD can be combined in-situ with subsequent manufacturing processes, such as crystallization [1, 2], metallization [3] and contact formation [4]. Because Si purity is the key for PV thin film application, two EB-PVD processes from water-cooled crucible and a crucible-free evaporation from an electronic-grade purity Si single crystal are experimentally compared.

EXPERIMENTAL

evaporation method	(A) close crucible wall EB-PVD	(B) far crucible wall EB-PVD	(C) crucible-free EB-PVD
	 *Fig. 1a: Si-pieces were completely EB molten up in a water-cooled crucible*	 *Fig. 1b: Si fragments in a larger water-cooled crucible without melting up completely*	 *Fig. 1c: single crystal Si rods (Ø ≈4..10 cm) after evaporation experiments*
maximum EB power	15 – 30 kW	4 – 8 kW	0.3 – 2.5 kW
equipment	load-lock system with cryogenic pump		batch machine with a turbo pump system
base pressure	2 × 10^{-6} mbar	2 × 10^{-7} mbar	3 × 10^{-7} mbar
substrate temperature	80 ... 400°C		

RESULTS

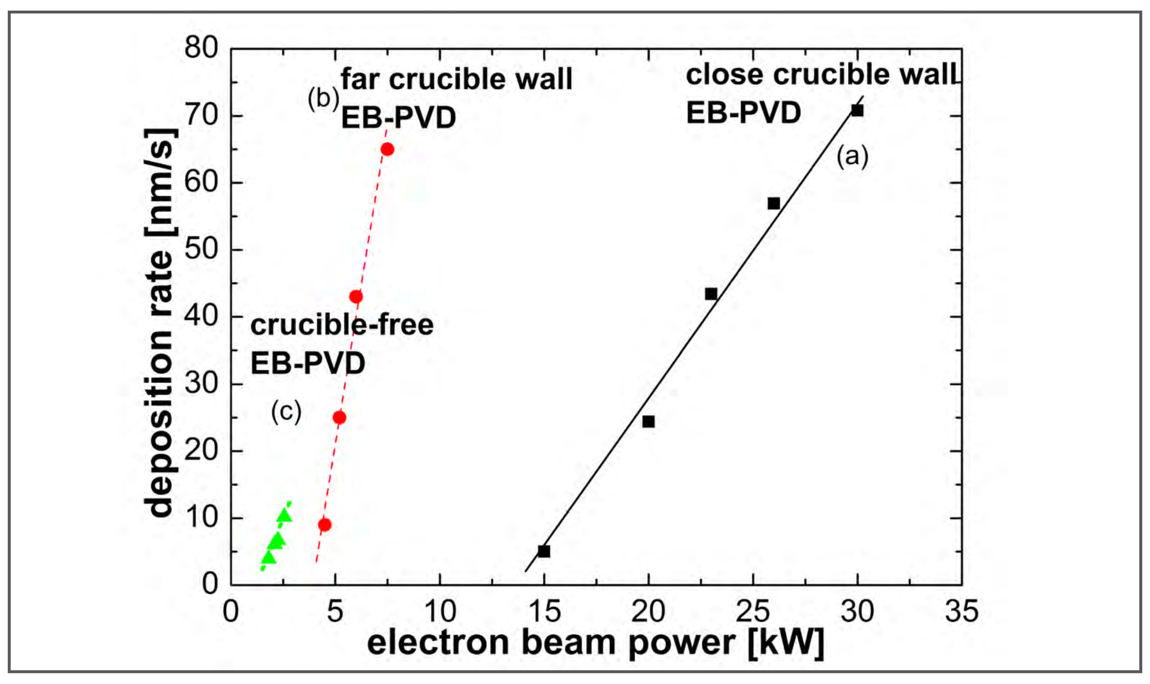


Fig. 2a: Achieved deposition rates vs. required electron beam power for the three evaporation methods (A, B, C).

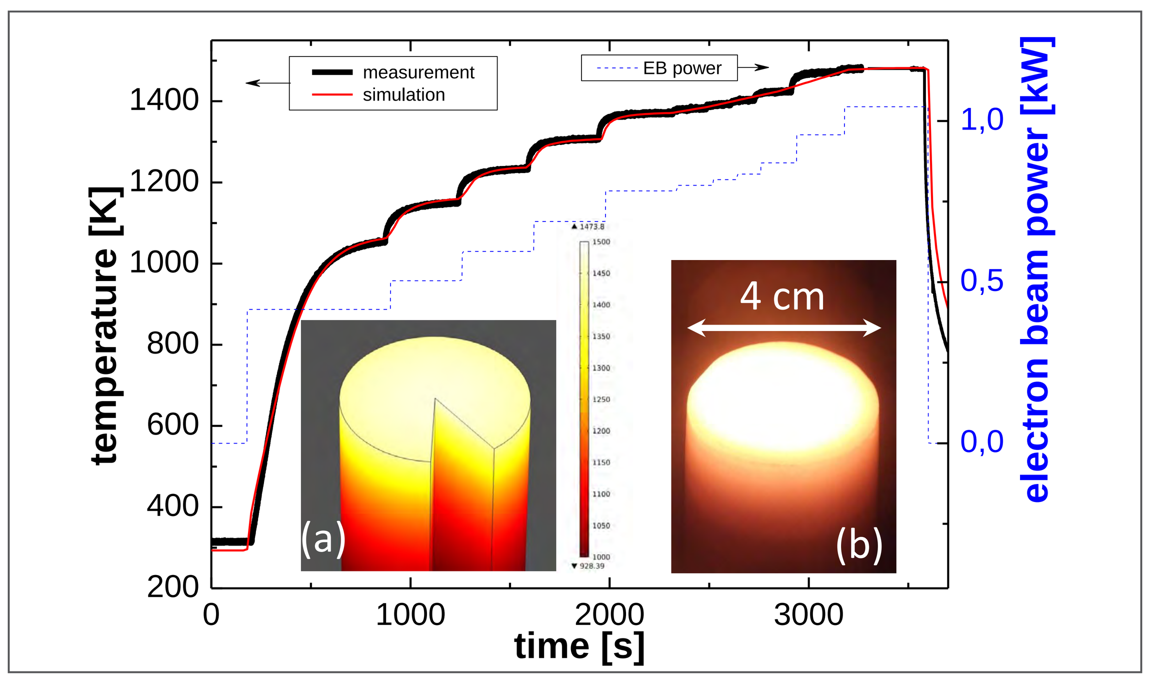


Fig. 2b: Measured (black bold line) and FEM-simulated (thin red line) temperature of Si rod top face vs. time during heat up process. The EB power was gradually increased (blue dashed line). Inset: (a) FEM-simulated temperature field of the Si rod, respectively (b) photograph of the glowing Si rod (EB power ≈1 kW).

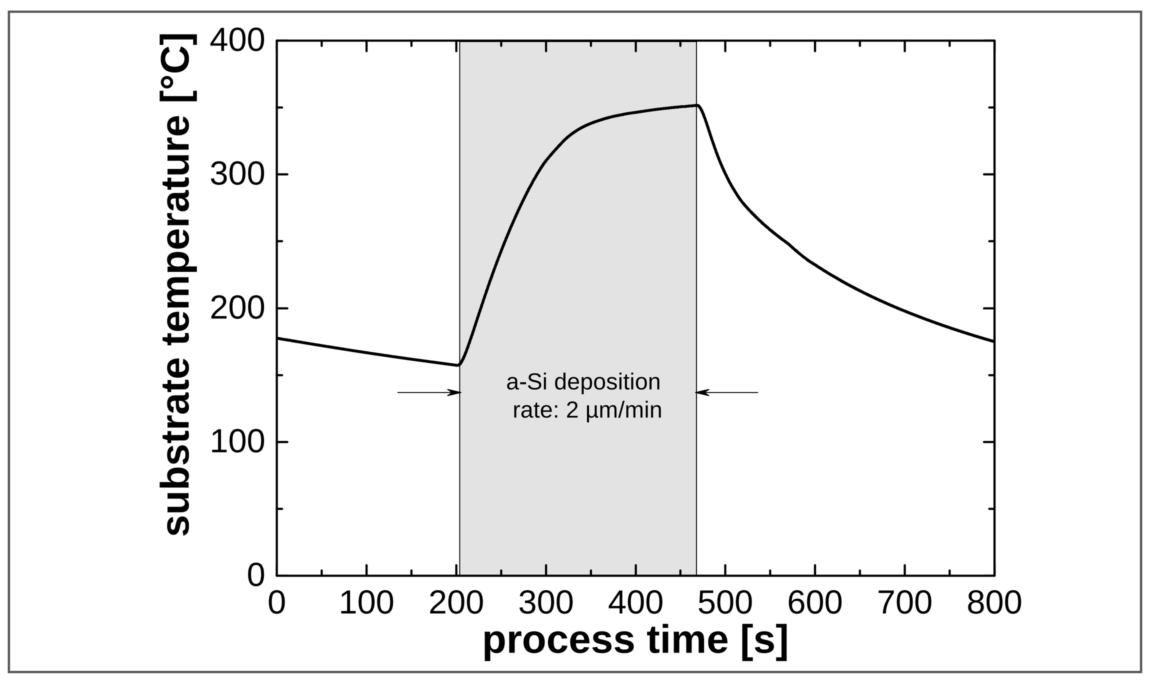


Fig. 2c: Rear side contact temperature of a 180 µm thick Si-substrate during deposition process. The initial temperature $T_{initial}$ could be controlled in the range of 20°C – 550°C. The final temperature T_{final} could be limited to 400°C by adjusting process parameters.

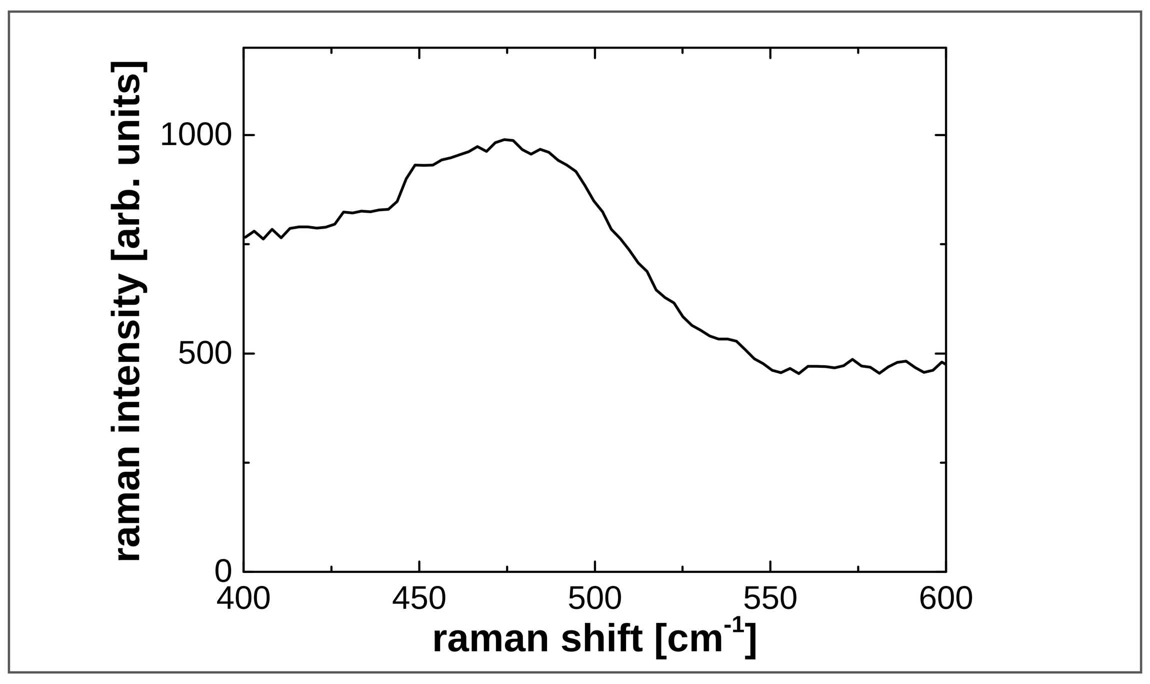


Fig. 2d: Raman-spectrum of an 8.6 µm thick Si-layer deposited by method (b) verifies amorphous morphology ($T_{initial}$ = 350°C, T_{final} = 380°C)

- high-rates up to 65 nm/s at moderate EB power can be achieved
- evaporation from a cooled crucible cannot completely avoid contamination
- evaporation from a high-purity silicon single crystal is feasible if an optimized heat up process is applied previously

CONCLUSION

For high-rate EB-PVD from a water-cooled cooper crucible contamination from the crucible material could not be avoided. The crucible-free EB-PVD from a Si single crystal is considered as a promising method for the high-rate deposition of high purity Si layers, if the dimensions of the evaporation material and the EB power input can be increased. The amorphous layer structure gives an excellent prerequisite to crystallize them in a following process. Further investigations are in progress.

REFERENCES

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