Experimental and modelling comparison of a Siemens and a Fluidized bed reactor – does silicon price have to affect cell quality?

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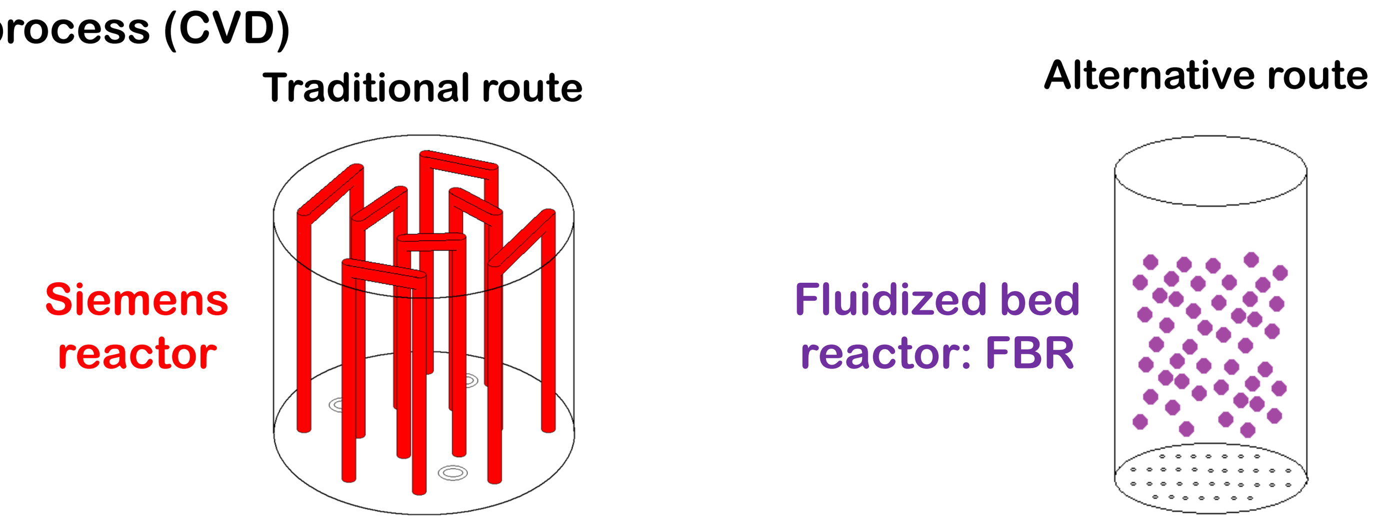
Motivation & objectives

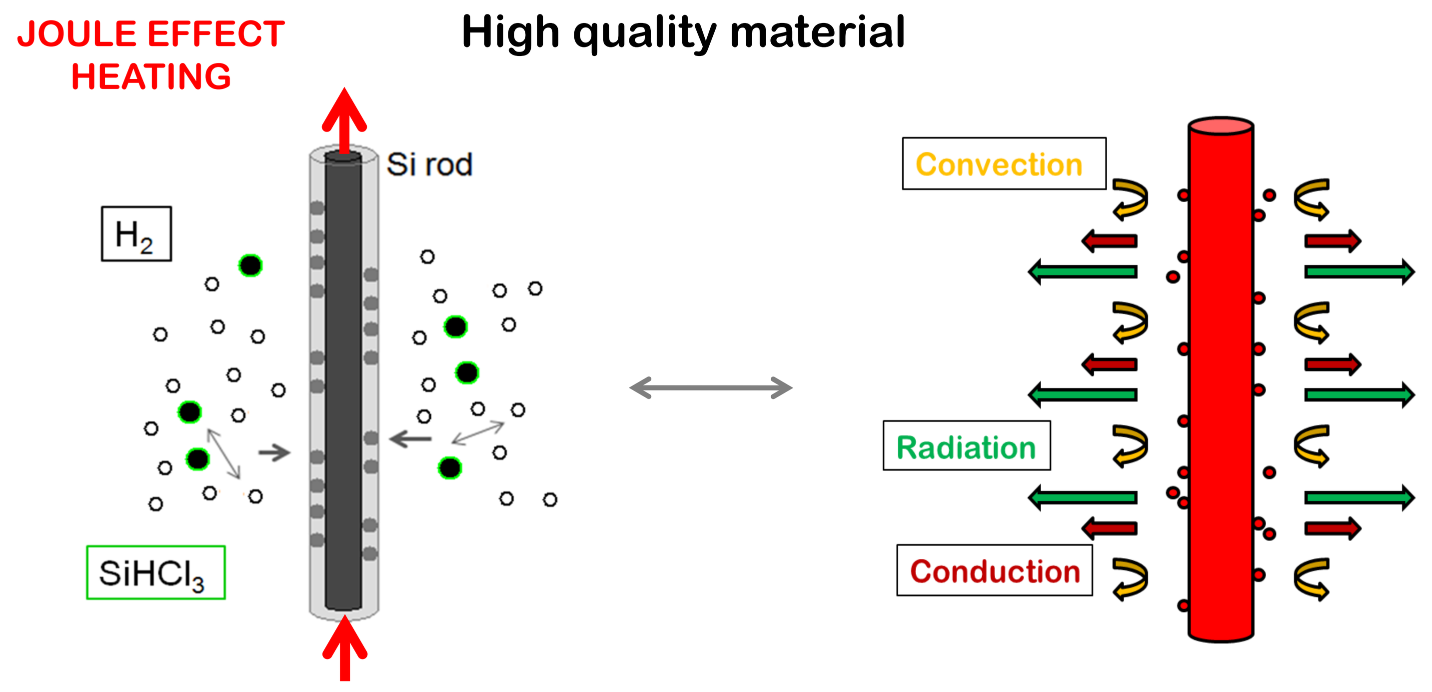
- Polysilicon production costs contribute approximately to 10 - 15% of the overall cost of the solar panels
- Polysilicon deposition technologies rely on the chemical vapor deposition process (CVD)



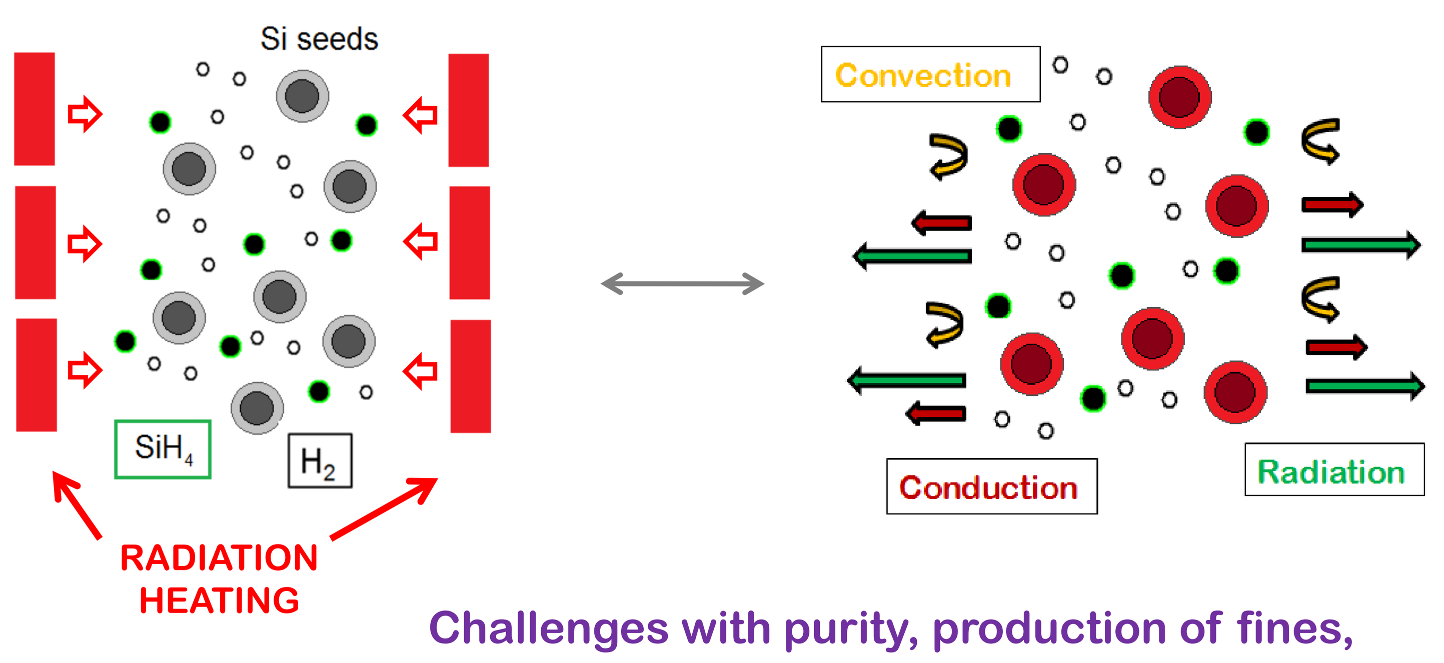
- Although a debate in the polysilicon community about the benefits and drawbacks of these different deposition technologies exists, there is a lack of reliable data, based on rigorous models, and contrasted experimentally in similar conditions
- The objective of the work is to build rigorous models for the analysis of both technologies. The developed models will be used as a tool to investigate the parameters that more strongly influence both processes

Deposition process and energy consumption in CVD reactors

Siemens reactor: Deposition temperature ~1100 °C
Energy consumption: 45 - 80 kWh/kg
High quality material



Fluidized bed reactor: Deposition temperature ~600 - 850 °C
Energy consumption: 4 - 16 kWh/kg



Challenges with purity, production of fines, appropriate gas and temperature control…

CFD modelling

The global CFD model accounting for all important aspects of heat transfer and gas flow has been developed using SiSim (*)

- Model equations for mass and momentum conservation are:

$$\frac{\partial u_i}{\partial x_i} = 0 \quad \text{and} \quad \frac{\partial u_i}{\partial t} + u_i \frac{\partial u_i}{\partial x_j} = -\frac{1}{\rho_0}\frac{\partial p}{\partial x_i} + \frac{\rho - \rho_0}{\rho_0} g_i + \frac{\partial}{\partial x_j}\left(\nu \frac{\partial u_i}{\partial x_j}\right)$$

- The conservation of energy equation is employed to calculate the temperatures:

$$\rho c_p \frac{\partial T}{\partial t} + \rho c_p u_j \frac{\partial T}{\partial x_j} = \frac{\partial}{\partial x_j}\left(\lambda \frac{\partial T}{\partial x_j}\right)$$

- The surface-to-surface (S2S) radiation model used to calculate thermal radiation:

$$B_i = \varepsilon_i \sigma T_i^4 + (1 - \varepsilon_i) \sum_{j=1}^{n} F_{ij} B_j$$

- The coupling between the thermal radiation model and the energy conservation equation: boundary heat flux of each element surface is calculated from:

$$q_i = \frac{\varepsilon_i \sigma T_i^4 - \varepsilon_i B_i}{(1 - \varepsilon_i)}$$

(*) software dedicated to silicon production processes developed in the frame of the Norwegian center Solar United

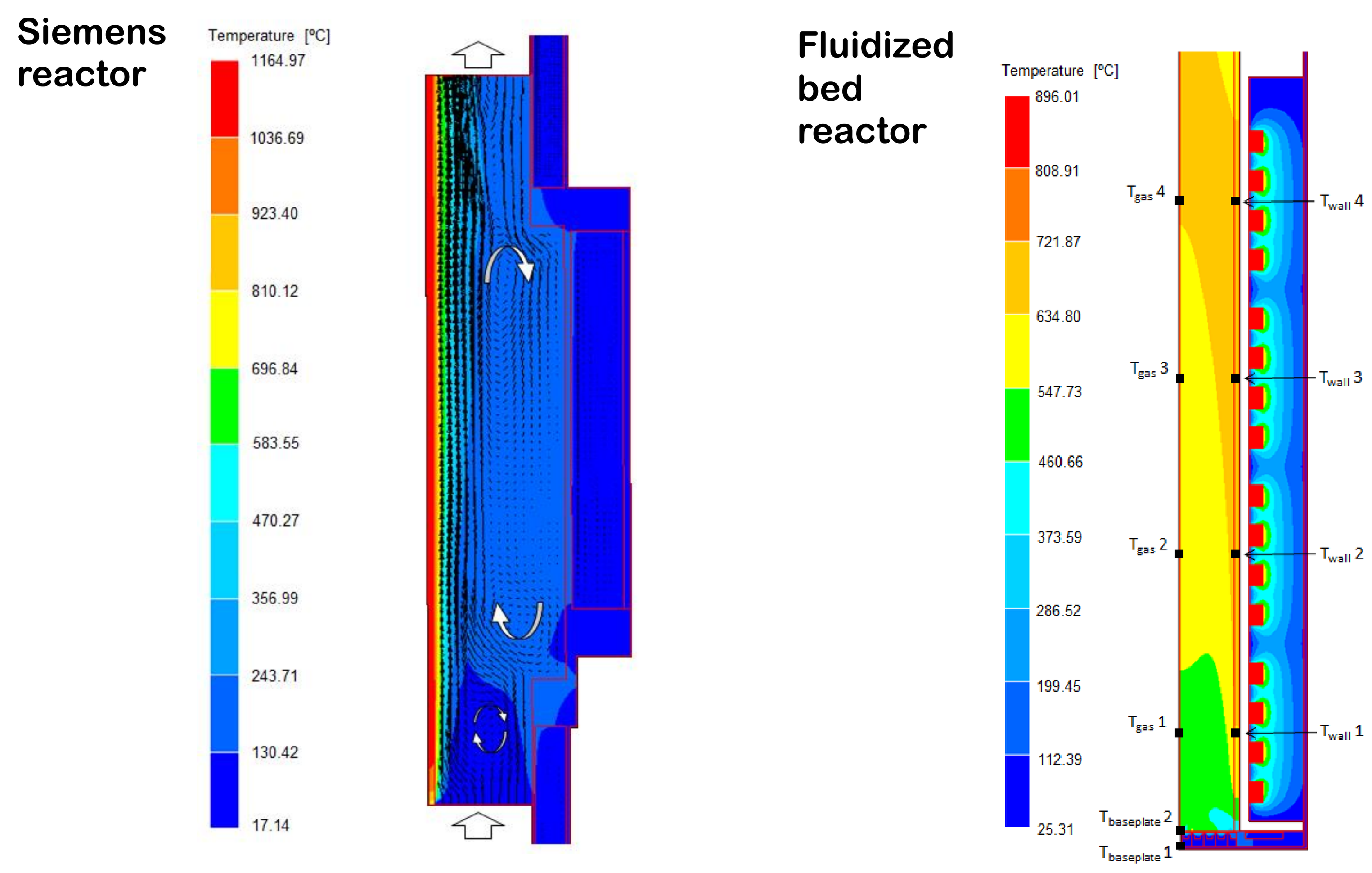
Experimental

At the IES there is a laboratory Siemens reactor and at the IFE there is a FBR prototype, and several experiments have been conducted in both prototype reactors to assess the validity of the models

Modelling results

2D Axi-symetric models of two CVD reactor prototypes

The CFD models have been validated: experiments conducted in both prototypes are compared with the simulation results with a high level of agreement



- Low wall emissivities and higher flow rates are desired in order to decrease the ratio kWh/kg in a Siemens type reactor
- Considering low thermal conductivity materials in the baseplate, the gas temperatures are only affected at the very bottom of the fluidized bed reducing the fines formation in FBRs
- The alleged advantages of the FBR -such as lower energy costs due to lower deposition temperatures- are not due to the FBR itself, but to the use of monosilane gas instead of trichlorosilane

Conclusions

- Temperature distribution is related to material quality. CVD Polysilicon quality directly affects the solar cell performance and the higher material quality -up to a limit- the higher cell efficiency
- Siemens reactors have room for improvement the ratio kWh/kg, fulfilling purity requirements of the solar cells market
- For the FBRs promising future is foreseen if temperture distribution is controled and fines formation decreased

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Acknowledgements: NILS Science and Sustainability project; The Spanish Ministerio de Economía y Competitividad through the project IPT2012-0340- 120000; Comunidad de Madrid through the project MADRID- PV S2013/MAE-2780; The Norwegian Research Council, project 193829 and P. A. R. acknowledges partial support to the work by the Solar Energy Research Institute for India and the U.S.(SERIIUS) funded jointly by the U.S. Department of Energy subcontract DEAC36- 08G028308.