ELECTRON BEAM-FIRED CONTACTS: A NOVEL APPROACH FOR REAR CONTACT FORMATION IN CRYSTALLINE SOLAR CELL PRODUCTION

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ABSTRACT

Improving solar cell efficiency while simultaneously reducing the production costs are the main tasks of research and development in the field of crystalline silicon solar cell production. The attempt presented in this paper combines both aspects: Using a focused electron beam (EB), an aluminum contact layer and the silicon wafer are molten and alloyed locally through an intermediate passivation layer. Advantages of the process are that very thin wafers can be processed due to the contactless electron beam tool and that wafer bow is prevented due to the localized firing. This helps reducing material costs. Additionally, very good surface passivation remains in a large area because of the locally restricted contacts, and local aluminum doping of the silicon in the contact area allows low contact resistances. Both mechanisms influence the cell efficiency positively. The electron beam is an inherently vacuum-based tool. Therefore, it is connectable to existing vacuum deposition modules in a solar cell production line. In this paper, first results of this new contact formation process are presented. Solar cell efficiencies of 12.7% have already been measured on solar cells with vapor-deposited metal backs and electron beam-fired contacts (EBFC).

MOTIVATION

Si-Solar cells: current approaches for increasing cell efficiency by improving the performance of the solar cell rear side

- passivation of the surface, as far as possible non-destructive opening of the passivation layer in the contact area
- increasing light utilization by anti-reflective coatings and surface texturing
- reducing resistance by additional (local) doping

State of the art: laser-fired contacts (LFC) process

The rear side of the solar cell is covered by a passivation layer or layer system and a following aluminum metallization. Contact formation occurs by local melting and alloying of aluminum and silicon through the passivation layer using a pulsed laser beam.

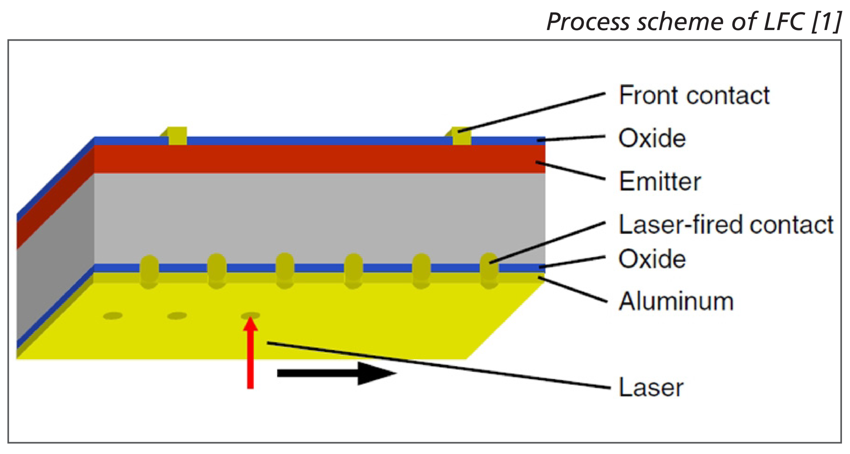
Advantages:

- no wafer bow → thin wafers can be processed
- very good surface passivation → low surface recombination velocity, high efficiency
- local doping in the contact area → low contact resistance
- no additional process steps

Disadvantages:

- near-surface application of energy due to the absorption characteristic of laser light
  - » problems in the case of thick metallic layers
  - » multi-pulse laser processes required
- problems with the use in vacuum chambers, e.g. in connection with deposition chambers

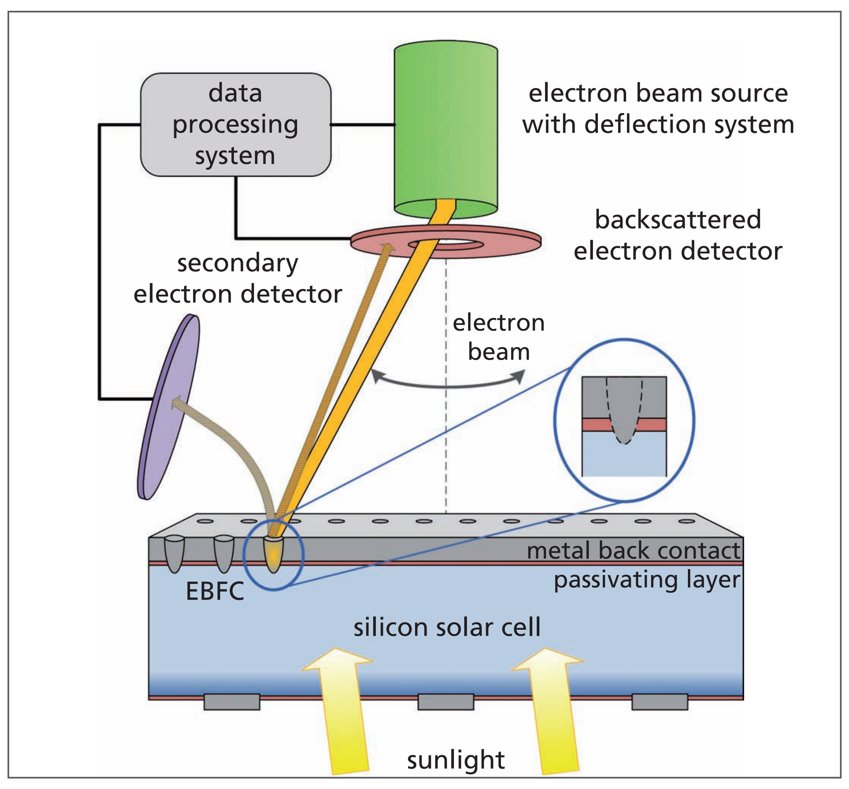
Process scheme of LFC [1]



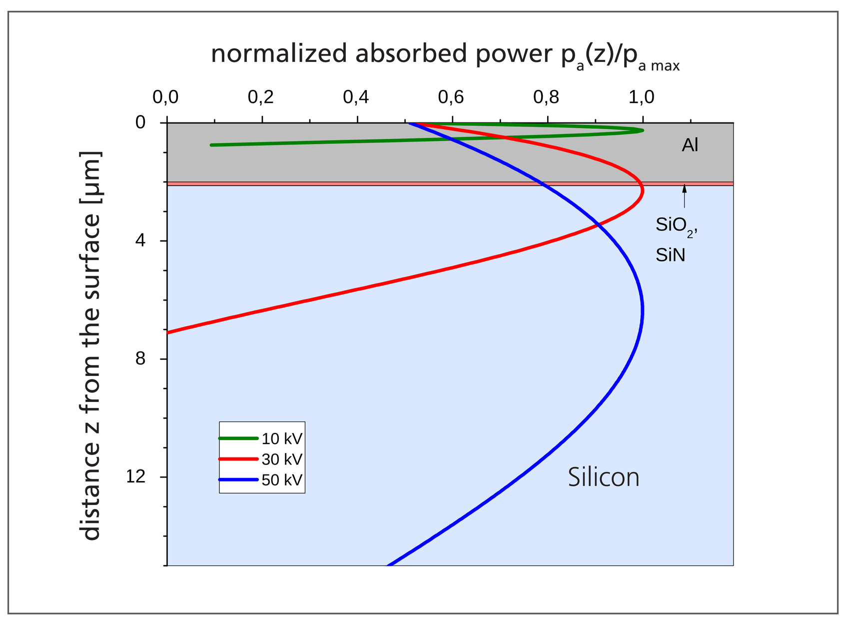
Contact formation by using the electron beam?

For this task the electron beam has some advantages over the laser:

- the EB is a particle beam with a characteristic and adjustable absorption profile
- the EB can bring high power to the work piece continuously
- inertialess beam deflection enables very fast processing (goal: 3600 cells/h)
- EB contact formation is a vacuum-based process. Therefore, it's connectable to existing vacuum deposition modules in a solar cell production line
- secondary effects (BSE, SE, X-ray, …) can be used for process monitoring



Manufacture of electron beam fired contacts (EBFCs)



Volume-absorbed power for three different acceleration voltages

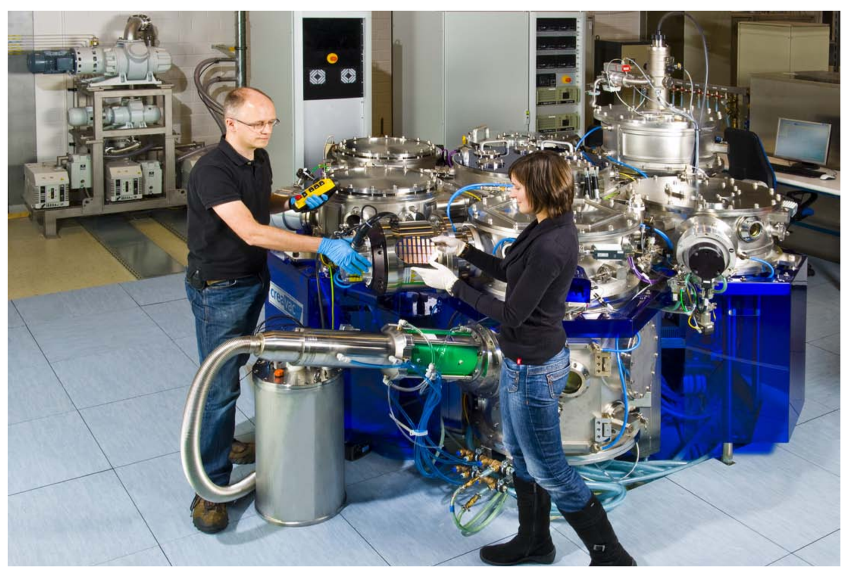
EXPERIMENTAL WORK

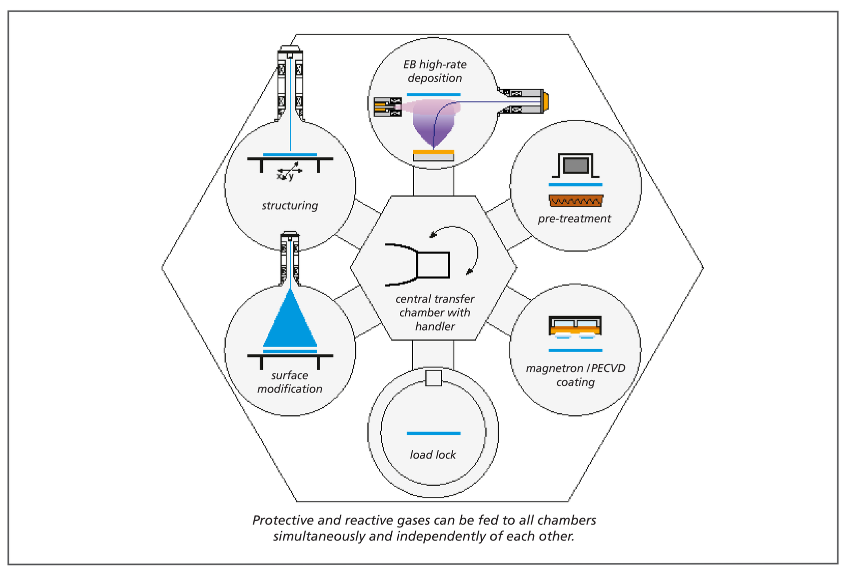
SETUP

Processing results were obtained with the Electron Beam Cluster Tool "ERICA" (including high-rate deposition and structuring).

Parameters of the structuring module:

accelerating voltage:	≤ 60 kV
beam current:	≤ 33 mA
focus diameter (@ 1 mA):	≈ 30 µm
deflection angle:	≤ ±35°
dwell time per point:	≥ 4 µs





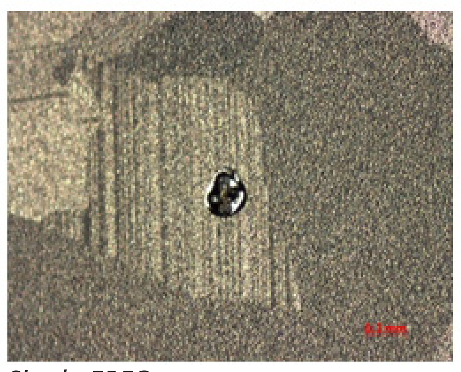
RESULTS

(1) Test structure for basic electrical characterization

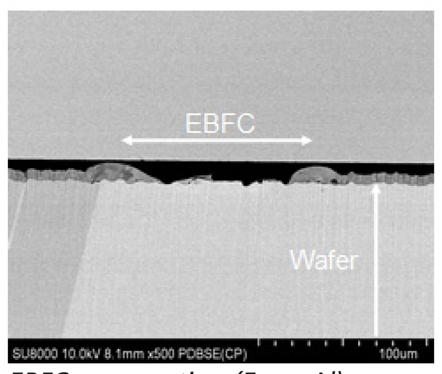
First basic experiments on Si wafers:

- polycristalline Si, 52 × 52 mm², 1.5 … 2 Ω·cm with passivated surfaces (SiO+SiN)
- creation of a test structure by masked EB vapor deposition of aluminum, layer thickness in the range of 2 … 7 µm
- EB contact firing with different parameters
  - » "single-shot processing"
  - » point to point repetition frequency: up to 50 kHz

EBFC test structure with Al pads



Single EBFC (diameter approx. 200 µm)



EBFC cross section (5 µm Al)

Electrical characterization of the contacts by measuring the resistance between 2 contact pads:

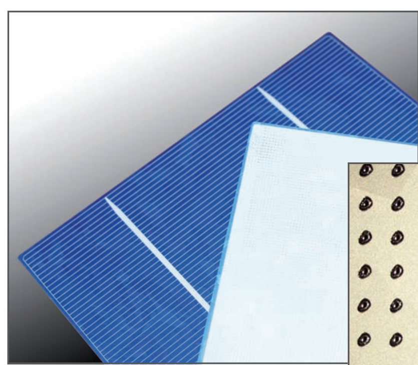
- after Al deposition
  → insulation resistance (10^7… 10^9 Ω)
- after EB processing
  → "contact resistance" (45 … 100 Ω)
- transfer length methode
  → contact resistance R_{FC} of one EBFC

	R_{FC} [Ω]
EBFC	70 … 90
LFC [2]	55 … 70

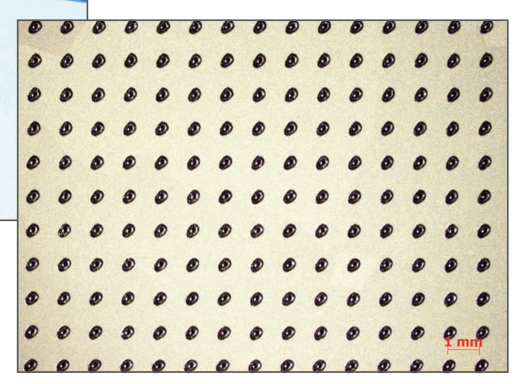
(2) First EBFC solar cells for efficiency measurements

First tests of the EBFC-technology on large-sized solar cells (polycristalline, 156 × 156 mm², 1.5 ... 2 Ω·cm) with passivated surfaces (SiN and AlO+SiN):

- Al EB evaporation for rear side metallization
  - » high deposition rates
  - » layer resistance in the range of the bulk material
  - » low thermal loads (220 °C @ 3 µm Al metallization)
- EB-fired contacts (EBFC) on solar cell rear side:
  - » approx. 20 100 point contacts, pitch 1 mm
  - » process time: 5 ... 30 s for 8" wafer (NOT OPTIMIZED YET)
- first results of the test solar cells:



Solar cell with EBFC back contact



EBFC grid

	U_{OC} [V]	I_{SC} [A]	R_{SE} [Ω]	R_{SH} [Ω]	FF [%]	η [%]
without FC	0.21	0.8	18820	63	1	0.0
best FC	0.60	7.1	0.021	60	63	12.7
goal	>0.62	>8.6	<0.003	>20	77	>16.5

CONCLUSIONS AND FURTHER WORK

- successful trials of the EBFC-process on test structures ("single-shot processing" for Al layer thickness in the range of 2 … 7 µm, 50 000 contacts/second) and solar cells (12.7% efficiency) → proof of concept
- optimization is necessary and possible
  - » increase of the solar cell efficiency at least to 17%
  - » decrease in processing time to 1 s per wafer or less

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