CABRISS

New solutions for a PV circular economy:

results from the H2020 projects CABRISS and ECOSOLAR

Recycling of silicon kerf from PV

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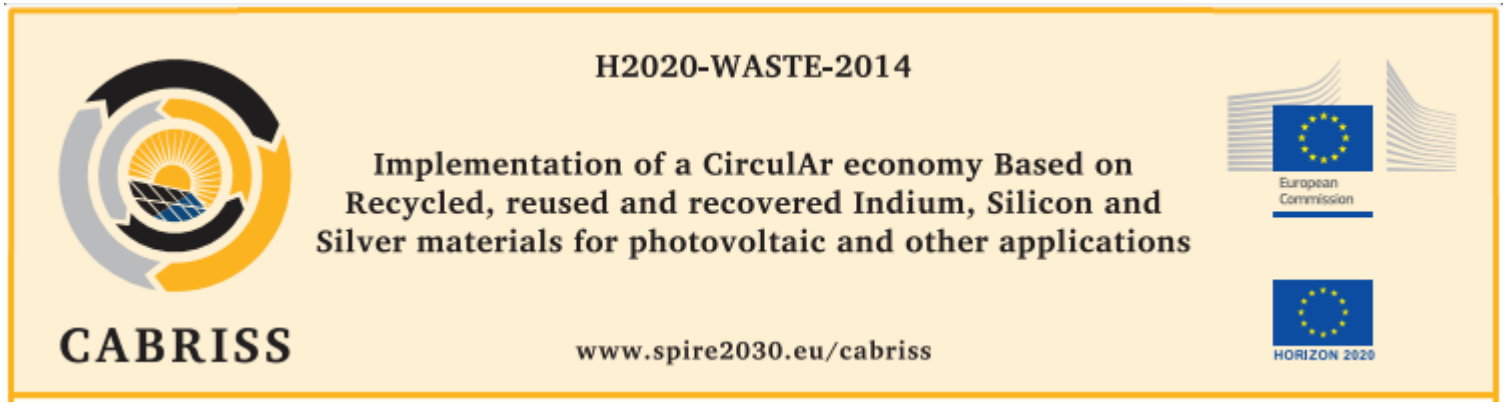
Recycling of silicon kerf from PV - Outline

- Cabriss project
  - ✓ Participants and scope
- Resitec as a recycler of silicon kerf from PV
  - ✓ Capacity and experience
- Silicon products recycled from kerf
  - ✓ Physical and chemical properties
- Safety issues related to large scale recycling of silicon kerf
  - ✓ Challenges and possibilities

Cabriss – Objectives



Cabriss – Objectives

List of Work Packages:

WP1: PV waste collection and dismantling, materials extraction

WP2: Purification of silicon recovered in PV wastes

WP3: Fabrication of silicon wafers using recycled materials

WP4: Fabrication of silicon solar cells using recycled materials

WP5: Transformation of recycled materials into usable products

WP6: Materials characterizations and qualifications

WP7: Life cycle assessment & life cycle cost, business models

WP8: Dissemination, exploitation and standardization

WP9: Project management

16 partners from 9 countries
6 SMEs, 5 Industries and 5 RTOs

Consortium

Acknowledgment:
This project has received funding from the European Union's Horizon 2020 research and innovation programme, under grant agreement No 641972.

- Partners in WP 2 are CEA, FerroAtlantica, Sintef, Fraunhofer THM, ECM Greentech and Resitec.
- This presentation will focus on Resitec results and capabilities
- Duration of the project: June-15 to June 18.

RESITEC – Recycler of silicon kerf from PV

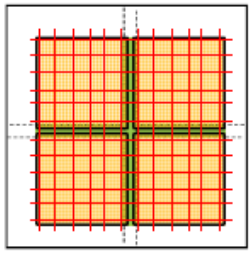
- Resitec is a technology company specializing in recycling of silicon and powder technology in general.
- Process Development for recycling silicon kerf from PV was started in 2011.
- Resitec has recycled silicon kerf in industrial scale since 2014. Capacity was doubled in 2016.

- Resitec is participating in the Cabriss project to further develop the process and adapt the recycled kerf for use in PV applications.

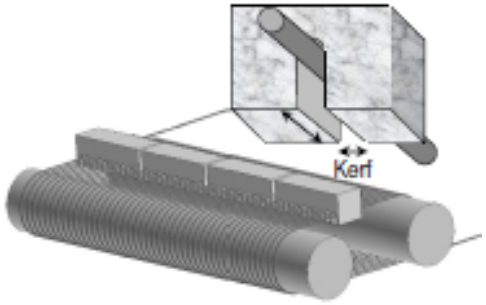
ReSiTec

RESITEC – Recycling of silicon kerf from PV

- Recycling of silicon kerf:
  - From cutting of silicon ingots, silicon blocks and silicon wafers.
  - Focus on water based systems with diamond wire cutting/ diamond wire wafering
  - Cabriss has *not* focussed on traditional cutting method with glycol and silicon carbide



App. 4% kerf loss from block cutting



App. 40% kerf loss from wafering

RESITEC – Recycling of silicon kerf from PV

- Challenges with a recycling process:
  - Hydrogen formation – explosion hazards
  - Dust explosion hazards during handling and drying
  - Dust exposure to personnel

$Si + 2H_2O \rightarrow SiO_2 + 2H_2$
Traditional kerf has O level of >10%

  - Oxidation of fine silicon particles
  - Processing fine silicon powder from a diluted slurry
  - Additives to cutting fluid

  - Reduced PV silicon prices requires a cost efficient process
  - Targeting existing or new markets with a new product
  - Limited market for recycled silicon kerf (due to finness)
  - Low volumes – high logistics cost
    Requires tailor made process solutions

RESITEC – Recycling of silicon kerf from PV

- Resitec samples used in the Cabriss project:

Melting
Hot pressing
Plasma spray
Further purification

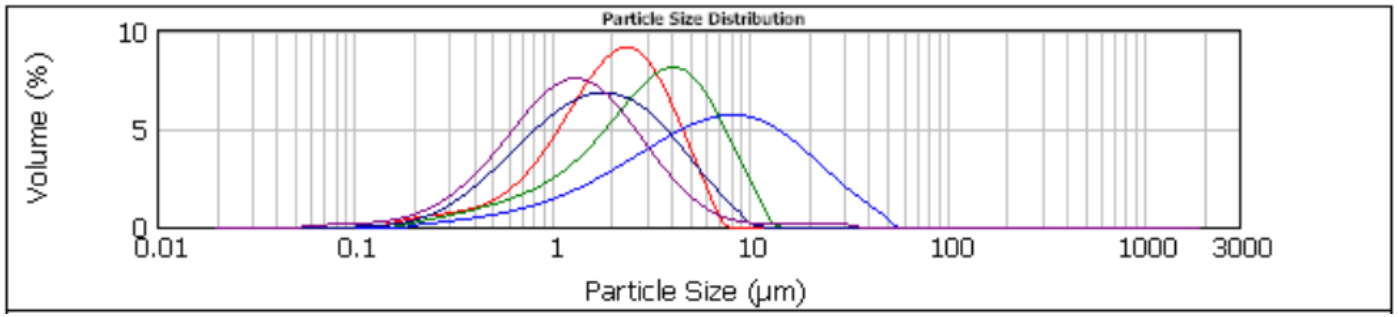
- Kerf from Fraunhofer THM and external sources outside Cabriss.
- Samples of <1kg up to > 1 tonn

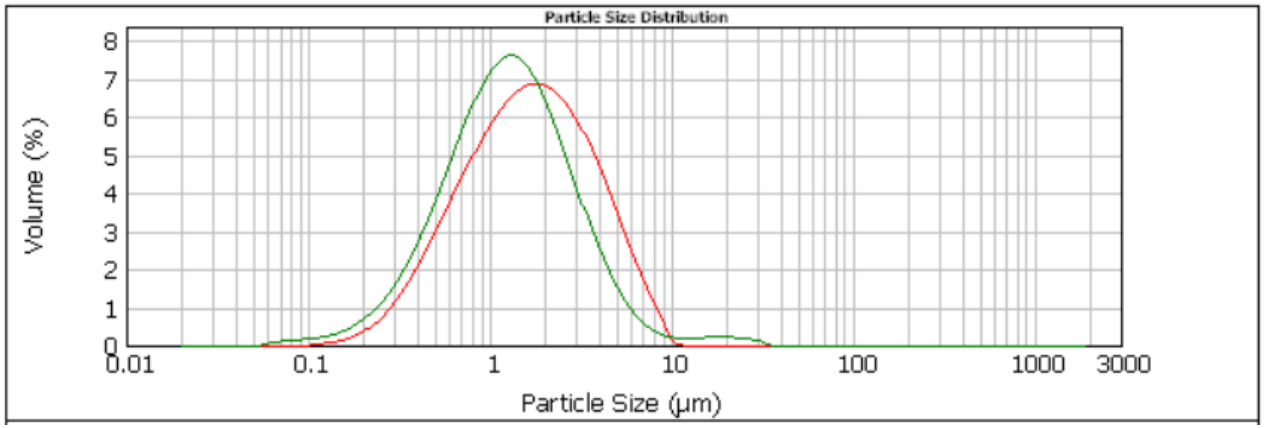
RESITEC – Recycling of silicon kerf from PV

- Resitec recycling process:
  - Resitec develops and adapt equipment and process for collection of kerf to fit each wafer producer. Purification and recycling is done at Resitec site.
  - Chemical and mechanical purification of silicon kerf to produce a silicon feedstock or silicon powder of 2-4N purity.
  - Further refining should be done by other purification steps.
  - Recycled kerf from Resitec appears as:
    - ✓ Silicon powder with 2-4N
    - ✓ Particle size distribution depends on feed with a D50 of typically 1-5µm.
    - ✓ Low B and P
    - ✓ Traces of Fe, Ni, Ca and others
    - ✓ 1-4% Oxygen depending on the product
  - Jet milling in inert atmosphere is used for size reduction and classification of silicon powder.

RESITEC – Recycling of silicon kerf from PV

- Particle sizes depends on cutting technology, wire type, thickness etc:



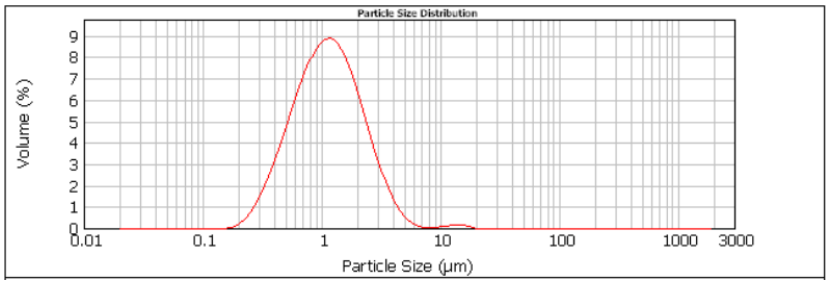


RESITEC – Recycling of silicon kerf from PV

- Silicon kerf can be recycled into fine powders or agglomerated to reduce dusting and dust explosion hazards
  - Agglomerated material can be suitable for introduction to furnaces for melting

Resitec activities – kerf recycling

- Results from pilot test in Cabriss
- Recycled kerf from diamond wire wafering with water based cutting fluid



Element	Concentration [% wt]
C	0.56*
N	0.042
O	4.3

- Analysis done by GDMS an d IGA at EAG Laboratories, France

Element	Concentration [ppm wt]	Element	Concentration [ppm wt]
Li	< 0.005	Pd	< 0.005
Be	< 0.005	Ag	< 0.01
B	0.09	Cd	< 0.01
C	-	In	Binder
N	-	Sn	< 0.1
O	-	Sb	< 0.05
F	1.1	Te	< 0.01
Na	6.7	I	< 0.001
Mg	8.0	Cs	< 1
Al	3.4	Ba	0.25
Si	Matrix	La	0.17
P	5.7	Ce	0.24
S	13	Pr	0.08
Cl	2.1	Nd	0.10
K	2.9	Sm	< 0.005
Ca	62	Eu	< 0.005
Sc	0.04	Gd	< 0.005
Ti	0.31	Tb	< 0.005
V	0.01	Dy	< 0.005
Cr	0.35	Ho	< 0.005
Mn	0.19	Er	< 0.005
Fe	7.4	Tm	< 0.005
Co	0.05	Yb	< 0.005
Ni	62	Lu	< 0.005
Cu	2.7	Hf	< 0.05
Zn	2.7	Ta	< 1
Ga	0.10	W	0.25
Ge	1.1	Re	< 0.01
As	0.17	Os	< 0.005
Se	< 0.05	Ir	< 0.005
Br	< 0.01	Pt	< 0.01
Rb	< 0.01	Au	< 0.01
Sr	0.24	Hg	< 0.05
Y	0.01	Tl	< 0.005
Zr	0.06	Pb	0.71
Nb	0.02	Bi	< 0.005
Mo	0.09	Th	0.01
Ru	< 0.001	U	0.007
Rh	< 0.001		

RESITEC – Safety issues

- Dust explosion issues
  - Measured P_max and minimum ignition energy was measured by Gexcon
  - Results are comparable with regular silicon powder

- Exposure to personnel
  - Fine dust down to < 1µm requires good process solutions to avoid exposure to personnel.
  - PPE is required

- Additives to cutting fluid (water based)
  - High TOC values in liquid as well as residues in the silicon kerf
  - Fumes and smell from additives to cutting fluid causes a challenge during drying of recycled kerf.

RESITEC – Safety issues

- Hydrogen formation/ oxidation of silicon powder
  - The oxidation of fine silicon kerf in water slurry is exothermic and forms hydrogen gas.
  - If cutting fluid is concentrated to high solid loads, there will be a temperature increase and high oxidation rates unless the silicon powder is properly passivated.

- Drying of fine silicon powder
  - The traditional method to produce dry silicon powder is by drying coarse material and dry milling into fine particle sizes
  - Challenge with drying fine powders are both dust explosion hazards and a continuous formation of hydrogen
  - Drying is either done in inert atmosphere or under continuous hydrogen monitoring

Conclusions

- Cabriss has made good progress towards use of wastes from PV industry in existing or new solar cell systems.
- Resitec has developed a cost efficient method for recycling of silicon kerf from diamond wire cutting processes.
  - The recycled material is 2-4 N in purity
  - The recycled material is a powder, 1-5µm as D-50
  - Oxidation levels are acceptably low, 1-4%
- There are a number of safety issues related to silicon kerf recycling that has to be addressed:
  - Hydrogen formation
  - Dust explosion issues
  - Dust exposure to personnel and environment
  - Drying of fine silicon powders
  - Additives behavior

Thank you for your attention.

Any questions?