REFINING OF SILICON

BIA-NFR Hydromet Seminar, Lillestrøm, 7th of March 2017

Anne Gry Messenlien, Elkem Technology
The second most common element in the crust of the earth (27%)
Elkem in brief

- Founded in 1904 by Sam Eyde
- Owned by China National Bluestar since 2011
- 110 years of history as a technology provider

3800 employees  
(1530 in Norway*)

24 plants worldwide  
Headquarter in Norway

14,5 BNOK  
Revenue in 2015

370 R&D people  
Global R&D centres in Norway and Lyon

*the number includes 280 employees in Elkem Solar
Focus on continuous R&D

Close to 370 people working with R&D in Elkem.

CORE COMPETENCIES ARE:
• High temperature processes and equipment
• Particle technology
• Chemical analysis and characterization

Elkem’s innovative and technology-intensive environment has resulted in both radical and incremental improvements in products and in production processes.
Our products are vital for modern societies

**QUARTS**
- SILICON AND MICRO SILICA

**COAL**
- SILICONES

**BIOCARBON**
- FOUNDRY PRODUCTS

**POWER**
- CARBON PRODUCTS

Low cost sustainable input factors
High temperature / chemical production processes
Examples of high value applications and markets

- Windmills
- Automotive
- Electronics
- Solar
- Infrastructure
- Cooking utensils
- Airbags
- Release coating
- Solar
- Airbags
Elkem AS – our four business areas

**Silicon Materials**
Global producer and provider of silicon, microsilica and specialty materials

**Silicones**
One of the foremost fully integrated silicones manufacturers in the world

**Foundry Products**
Leading producer of specialty-alloys for the foundry and steel industries

**Carbon**
Leading producer of electrode paste and other carbon products
The journey from Quartz to High Purity Silicon
Selecting Raw Materials
The carbothermic production process

Raw materials:
- Quarts
- Coal
- Charcoal
- Coke
- Wood chips

Overall reaction:
\[ \text{SiO}_2 + 2 \text{C} = \text{Si} + 2 \text{CO} \]
The carbothermic production process

Raw materials:
- Quartz
- Coal
- Charcoal
- Coke
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Overall reaction:
\[
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Phase diagram Ca-Si

From A.Schei et al, Production of High Silicon Alloys

Details of the phase diagram Ca-Si (Schürmann et al. 1975)
Casting – making a leaching alloy

<table>
<thead>
<tr>
<th>Element</th>
<th>[g/mol]</th>
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<tbody>
<tr>
<td>Si</td>
<td>28.1</td>
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<tr>
<td>Ca</td>
<td>40.1</td>
</tr>
<tr>
<td>Fe</td>
<td>55.8</td>
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</table>
Disintegration of Silicon alloy

Examples of elements in the Intermetallic phase

Hydrochloric acid (HCl)
(feedstock disintegrates)

Hydrofluoric acid (HF)
(“polishing” the surface of the Si-grains)

Impurities on the surface, ex. Fe$_2$Si

Product
The Silgrain ® - process

- Hydrometallurgical process developed in the 1960s
- Production facilities in Bremanger
Silgrain process - Disintegration

H₂ → FeSi from furnace 5

HR → UR → VT → ST → Beltfilter

Cl₂
Silgrain process – Classification

From BF 2 → +2 mm → Silgrain 

From BF 1 → +2 mm → Milling 

Dryer 2 → Dryer 5 

To air → To - 45 m.

control control control control 

Milling 

Dryer 5 

To air 

control control control control 

Silgrain 

control control control control 

control control control control 

control control control control 

To - 45 m.
Silgrain process HQ – Removing more impurities
# Chemical analysis - Silgrain® products

## Silicon 97

<table>
<thead>
<tr>
<th>Analysis</th>
<th>Si wt%</th>
<th>Fe wt%</th>
<th>Al wt%</th>
<th>Ca wt%</th>
<th>Ti ppmw</th>
<th>P ppmw</th>
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<tbody>
<tr>
<td>Max</td>
<td></td>
<td>2.0</td>
<td>0.30</td>
<td>0.05</td>
<td>1000</td>
<td>50</td>
</tr>
<tr>
<td>Min</td>
<td>97</td>
<td>1.5</td>
<td></td>
<td></td>
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<tr>
<td>Typical</td>
<td>97.5</td>
<td>1.7</td>
<td>0.20</td>
<td>0.02</td>
<td>700</td>
<td>35</td>
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## Silgrain® CG

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<th>Analysis</th>
<th>Si wt%</th>
<th>Fe wt%</th>
<th>Al wt%</th>
<th>Ca wt%</th>
<th>Ti wt%</th>
<th>P ppmw</th>
<th>B ppmw</th>
<th>Size</th>
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<tbody>
<tr>
<td>Max</td>
<td>0.20</td>
<td>0.25</td>
<td>0.050</td>
<td>0.020</td>
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<tr>
<td>Min</td>
<td>0.08</td>
<td>0.13</td>
<td>0.013</td>
<td>0.008</td>
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<tr>
<td>Typical</td>
<td>99.6</td>
<td>0.11</td>
<td>0.022</td>
<td>0.011</td>
<td>25</td>
<td>30</td>
<td>0.2-0.8 mm</td>
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</tr>
</tbody>
</table>

## Silgrain® HQ

<table>
<thead>
<tr>
<th>Analysis</th>
<th>Si wt%</th>
<th>Fe wt%</th>
<th>Al wt%</th>
<th>Ca wt%</th>
<th>Ti wt%</th>
<th>P ppmw</th>
<th>B ppmw</th>
<th>Size</th>
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<tbody>
<tr>
<td>Max</td>
<td>0.05</td>
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<tr>
<td>Min</td>
<td>0.02</td>
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<td>0.005</td>
<td>0.001</td>
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<tr>
<td>Typical</td>
<td>99.8</td>
<td>0.04</td>
<td>0.013</td>
<td>0.001</td>
<td>25</td>
<td>30</td>
<td>0.2-0.8 mm</td>
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</tr>
</tbody>
</table>
Refining strategy High Purity Silicon: Combining Pyrometallurgy and Hydrometallurgy

- No need for high purity raw materials
- Lower energy consumption
- Larger furnace size
- Higher furnace yield
- Lower total yield
- Process complexity
- More ready made sizing
- High and consistent purity in product!
Elkem Solar - Kristiansand

- Investment: 4,2 BNOK
- Capacity: 7000 ton/year
- Employees: 200 people
Elkem Solar® production process

- **Silicon**: metallurgical silicon is produced from quartz in an electric arc furnace, at temperatures above 2,000 degrees C.

- **Slag treatment**: a purification process, in which the molten silicon is mixed with slag, in order to extract further impurities, especially boron.

- **Leaching**: a “wet” chemical refining process that removes phosphorous and metallic impurities from silicon in solid form.

- **Solidification**: the silicon is melted and directionally solidified through which impurities are segregated and thereafter removed in the subsequent post-treatment process.

- **Post treatment**: cutting and surface washing.
## Chemical Analysis

<table>
<thead>
<tr>
<th>Element</th>
<th>Unit</th>
<th>Max</th>
<th>Min</th>
<th>Typical</th>
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<tbody>
<tr>
<td>Si</td>
<td>ppmw</td>
<td>&lt; 2.0</td>
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<td>Matrix</td>
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<tr>
<td>Fe</td>
<td>ppmw</td>
<td>&lt; 0.4</td>
<td>&lt; 0.15</td>
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<tr>
<td>Al</td>
<td>ppmw</td>
<td>&lt; 10</td>
<td>&lt; 3.0</td>
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<tr>
<td>Ca</td>
<td>ppmw</td>
<td>&lt; 0.4</td>
<td>&lt; 0.08</td>
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</tr>
<tr>
<td>Ti</td>
<td>ppmw</td>
<td>0.68</td>
<td>0.60</td>
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<tr>
<td>P</td>
<td>ppmw</td>
<td>0.26</td>
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<tr>
<td>B</td>
<td>ppmw</td>
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</table>
Elkem Solar in the value chain

**ELKEM SOLAR SILICON (ESS)**
- Silicon
- Slag treatment
- Leaching
- Solidification
- Post treatment

**ELKEM SOLAR FISKAA**

**ELKEM SOLAR HERØYA**
- Ingot(Blokk) solidification

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**SILICON**
- Fiskaa

**BLOCK**
- Herøya

**WAFER**
- REC Solar Singapore

**CELL**
- REC Solar Singapore

**MODULE**
- REC Solar Singapore
Silicon - a fantastic element......

...and thank you for your attention!
ADVANCED MATERIALS
SHAPING THE FUTURE