High Voltage Pulse Crushing of Poly and Monosilicon

Overview

Comparison with current used crushing technologies like manual with W-hammer or with WC-covered jaw crusher, WC-covered roller crusher.

<table>
<thead>
<tr>
<th>For target particle size &gt;80% 2 – 40mm</th>
<th>W-Hammer</th>
<th>Jaw or roller crusher with WC covers</th>
<th>HVPC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Automation</td>
<td>None</td>
<td>Partial</td>
<td>Full</td>
</tr>
<tr>
<td>% Losses (&lt;2mm)</td>
<td>&gt;5%</td>
<td>&gt;5%</td>
<td>&lt;3%</td>
</tr>
<tr>
<td>Depth of Contamination</td>
<td>10 – 50µm</td>
<td>10 – 50µm</td>
<td>1 – 3µm</td>
</tr>
<tr>
<td>Metals</td>
<td>W, environmental contamination</td>
<td>W, WC, Co</td>
<td>Fe</td>
</tr>
<tr>
<td>Etching needed to reach &lt;1 ppb</td>
<td>Heavy</td>
<td>Heavy</td>
<td>Light surface only</td>
</tr>
<tr>
<td>Particle Shape</td>
<td>Needles, sharp edges</td>
<td>Needles, sharp edges</td>
<td>Rounded, no sharp edges</td>
</tr>
</tbody>
</table>
High Voltage Pulse Crushing of Poly and Monosilicon

**Completely automated process**

Our traceable, fully automated process provides reduced labour cost, safety and fast ROI.

**Reduced losses**

HVPC provides a tighter size distribution and less fine material meaning less losses for the same size product compared to mechanical crushing.

<table>
<thead>
<tr>
<th></th>
<th>Jaw Crusher (Pre crushing required)</th>
<th>Manual Crushing</th>
<th>HVPC (automated)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Undersize: &lt;0.5mm</td>
<td>1%</td>
<td>1%</td>
<td>0.5 – 1%</td>
</tr>
<tr>
<td>Small size: &lt;2mm</td>
<td>8%</td>
<td>4%</td>
<td>&lt;3%</td>
</tr>
<tr>
<td>Target Size: 2 – 30mm</td>
<td>60%</td>
<td>63%</td>
<td>&gt;72%</td>
</tr>
<tr>
<td>Large Size: 30 – 60mm</td>
<td>32%</td>
<td>33%</td>
<td>&lt;25%</td>
</tr>
</tbody>
</table>
The main metal contaminant involved in HVPC is Fe, which does not contact the silicon unlike the direct contact with WC coated jaws/roll crushers. W and Co have a negative influence on crystal growth and are difficult to remove in the etching process.

**Non-contact process**

The contact free process allows contamination only on top surface at 1 to 3µm depth, compared to mechanical crushing where contamination can be found up to 70µm depth due to direct impact.

**Reduced surface contamination**

- Contaminated layer up to 70 µm
- Contaminants forced into the material by physical contact of crushing equipment
- Conventional etching (HF/HNO₃) required, to remove contamination completely
**Reduced etching possibility**

Reduced penetration of surface contaminants from HVPC mean that less HF is required in the etching process.

**Conventional etching** using hydrofluoric acid (HF) and nitric acid (HNO₃) as oxidizer. This method is able to remove layers in the 10 μm range, but is **cost and equipment intense**. Used to remove deep contamination, mostly resulting from jaw crushing processes.

**Light etching** using hydrofluoric acid (HF) and peroxide/ozone as oxidizer. This method is able to remove layers in the 0.5-2 μm range, but is **favorable in terms of cost and complexity**. Used to remove thin layers of contamination, as resulting from SELFRAK HVP crushing method.

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**Improved Particle Shape**

HVPC produces particles with a smaller aspect ratio than manual or jaw crushing, with particles being more rounded than elongate or needle like. The rounded shape is easier to handle, consumes less reagent in the etching process and does not penetrate bags.
Based on a comparison of different technologies available, the payback time for a 4,000 ton per year HVPC installation is 8 – 12 months.

**Zero Dust Production**
Dangerous Si dust production is eliminated by the HVPC process which occurs entirely underwater.

**Increased Efficiency – lower total cost of ownership**

Assumptions for above calculations:

- Labor costs: 5.0 USD/hour
- Silicon costs (added value): 10.0 USD/kg
- Electric power cost: 0.06 USD/kWh
- Throughput per person with manual crushing: 88.8 tons/year
- Yield loss manual crushing: 2.0%
- Yield loss mechanical crushing: 1.2%
- Yield loss HV pulse SELFRAG: 1.0%