Sub 20 nm generation of soot particles using the VSP-G1 nanoparticle generator

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We make machines that produce nanostructured materials. Our philosophy is that these machines should be simple to operate and based on a scalable principle.
VSPARTICLE timeline

1988
Invention of spark ablation by Andreas Schmidt-Ott

2014
Start of VSPARTICLE, development of the G1

2017
3 Launching customers
Full management team covering all angles of business

2018
International expansion to research oriented markets in the Americas, Europe and Asia
<table>
<thead>
<tr>
<th>Category</th>
<th>Frequency Range</th>
<th>Measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Research</td>
<td>1-300 Hz</td>
<td>~ milligrams</td>
</tr>
<tr>
<td>Industry</td>
<td>10,000-25,000 Hz</td>
<td>~ 100s milligrams</td>
</tr>
</tbody>
</table>
Technology

Spark ablation

• Ablation/evaporation and condensation
• Electric discharge
  \[ \approx 10^4 \text{ K}, \approx 10^{-5} \text{ s} \]
• Rapid quench
  \[ \approx 10^7 \text{ K s}^{-1} \]
• ‘Mild’ conditions
• Versatility
  • Metals
  • Carbon
  • Oxides
  • Alloys

Fig. 1. Schematic of the generator.

How particle growth works in the system

Particle Production inside G1

The process takes place under atmospheric conditions.
Technology
Particle formation in sparks

• Smoluchowski:

\[ \frac{dN}{dt} = -\frac{1}{2} \beta N^2 \]

\[ dp \propto N^{-\frac{1}{3}} \]

• Controlled through voltage, current and flow

\[ N_0 \propto \frac{m}{Q} \propto \frac{UI}{Q} \]

\[ \bar{t} = \frac{V}{Q} \]

\[ dp \propto \left( \frac{Vm}{Q^2} \right)^{\frac{1}{3}} \]

Possibilities with G1
VSP-G1 design
Flexible flow configurations
VSP-G1 design
Flexible flow configurations

(a) A pair of hollow, silver electrodes.
(b) The spark chamber, connections are numbered from 1 to 4.
(c) Configuration 1.: Flow through the electrodes.
(d) Configuration 2.: The classical crossflow configuration.
VSP-G1 design
Au, Ar, Crossflow

Ag, 1.7kV, 4 mA, 4 slm

- Tuneable size distribution
- Crossflow highest concentration
- Throughflow smallest mean diameter
Size-selected stability

Output VSP-G1 example

Material: Copper
Carrier Gas: Argon
Flowrate: 1 L/min
Voltage: 1.0 kV
Current: 5.0 mA
Stability of 5 nm particles
StDev: <2%

Measured with DMA (Differential Mobility Analyzer) + Electrometer & FD/C

Results
Size-selected stability measurement

Results

Stability measurement

Warm up
Measurement

μ, σ

σ = 3.4%
σ = 1.5%
σ = 1.7%
σ = 1.3%

0E+0
1E+5
2E+5
3E+5
4E+5
5E+5
6E+5

0 500 1000 1500

0
500
1000
1500

0
500
1000
1500

0 500 1000 1500

Particle count [cm⁻³]
Time [s]
Gap Voltage [kV]

Particle Count Voltage setpoint Gap Voltage

• Particle Count
• Voltage setpoint
• Gap Voltage
VSP-G1 emission experiments

Carbon output

Results

- 1.3 kV, 8 mA, 20 SLM
- 1.3 kV, 8 mA, 15 SLM
- 1.3 kV, 8 mA, 10 SLM
- 1.3 kV, 8 mA, 5 SLM
- 1.3 kV, 8 mA, 2 SLM
VSP-G1 emission experiments

Carbon output

Results
Who is already using it

Some of our customers

TU Delft

Universiteit Leiden

TU Clausthal

Universiteit van Amsterdam

UNIVERSITY OF TWENTE.

Utrecht University

MESA+ INSTITUTE FOR NANOTECHNOLOGY
VSP-G1 Nanoparticle Generator

• R&D scale generator
• Commercially available
• Outputs an aerosol of nanoparticles
• Specifications:
  • Particle size between few atoms to 300 nm
  • Particle generation rate approx. 1 ~ 10 mg/h
  • Particle concentration $10^8 \sim 10^{11} \text{ cm}^{-3}$
Thank you!

The VSPARTICLE team
vspanicle
Carbon output

(Dekati Elpi+)
Spark ablation Setup
Self-charging

No neutralizer in setup

- Self-charging in plasma
- Electrostatic precipitation
- Electrostatic force towards HV Electrode
- Small particles overpresented

Tabrizi et al. 2015
Flow configuration

Influence on Size distribution

- Tuneable size distribution
- Crossflow highest concentration
- Throughflow smallest mean diameter

Ag, 1.7kV, 4 mA, 4 s/lm
Flowrate
Influence on size distribution

- At highest flowrate only primary particles
- Dilution at higher flowrate
- Current, Voltage Influence