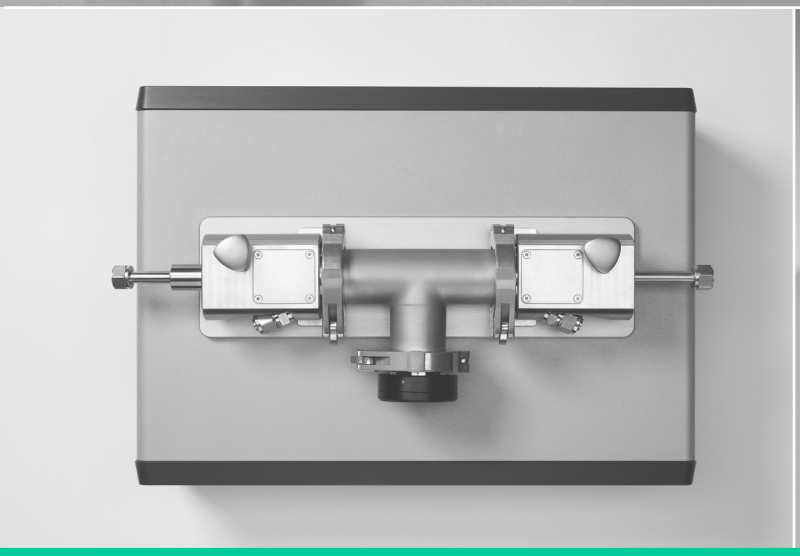


VSP-G1 Nanoparticle Generator
Brochure

Reproducible nanoparticle sample preparation for 0-20 nm pure (metal, metal oxide, alloy) particles of any (semi-) conductive material.

vsparticle

Contents

At VSPARTICLE, we believe that generation of nanoparticles should be neither complex nor time-consuming. This is why we developed the VSP-G1 Nanoparticle Generator. Our technology reduces the preparation time of advanced nanoparticle samples, ready for analysis to a matter of hours, enabling researchers to accelerate the process of developing novel materials and immediately investigate their unique properties.. Our products empower material pioneers!

Advantages

- Quick and easy to use
- Reproducible output
- Fast sample preparation time
- Compatible with all (semi)conductive materials
- Environmentally friendly process

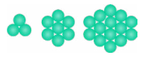
Easy, fast and reproducible generation of nanoparticles

VSP-G1

Nanoparticle Generator

Producing the desired nanoparticles becomes as easy as pushing a button.

VSP-G1 Nanoparticle Generator (VSP-G1) is a user-friendly, table-top product that allows the user to produce nanoparticles of the desired material in a controlled way. The production of nanoparticles takes place in the gas-phase and is based on a physical process, namely spark ablation. The process is reproducible, occurs at ambient temperature and pressure, and requires only a pair of (semi)conductive electrodes as the source for pure, surfactant-free nanoparticles. With safety, simplicity and automation being core features of the VSP-G1, our systems are easy to operate and require minimal training.



Aerodynamic size 0-300 nm particle size: 0-20 nm

Any (semi) conductive material

Stable & reproducible

Quick & Easy-to-use

Based on Spark Ablation Technology

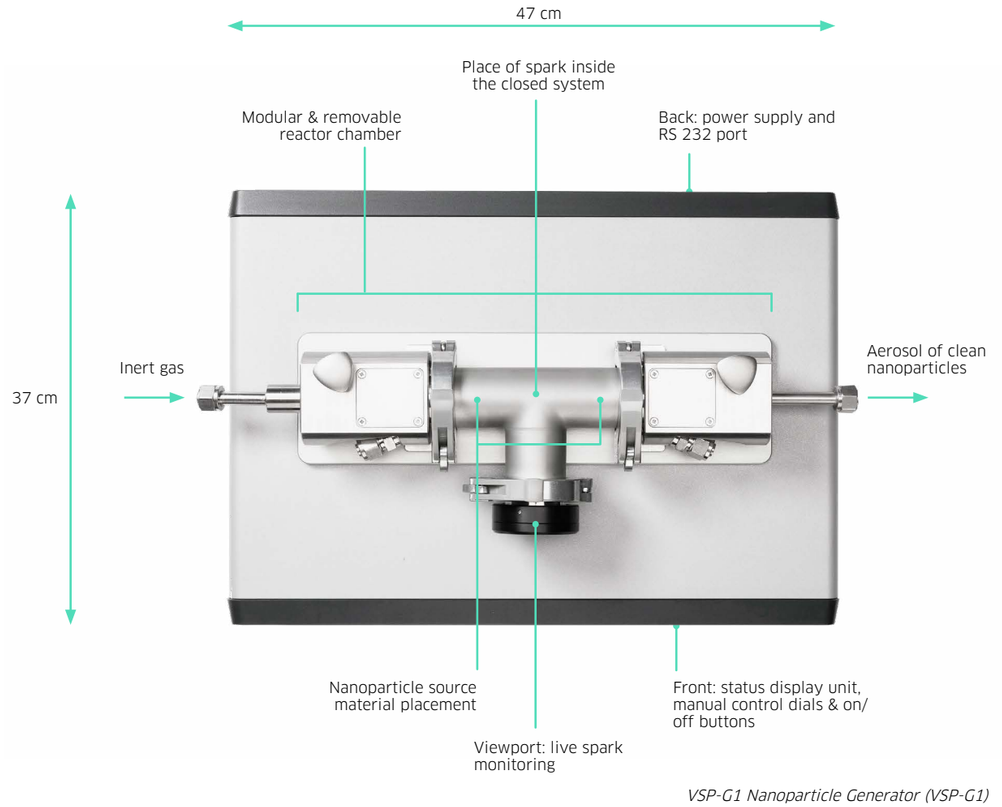
Clean process: no surfactants or precursors

Direct deposition from aerosol stream to the desired substrate

The collection of nanoparticles produced using the VSP-G1 is readily achieved using a range of products in VSPARTICLE's portfolio including the VSP-A series deposition accessories and VSP-P1 Nanostructured Material Printer. If you want to discuss more about which of our current deposition options is most suitable to your research needs, please contact our sales team at sales@vsparticle.com or scan the QR code to the right to find more information on our deposition strategies and methods.

"The purely physical mechanisms resulting in the formation of particles without chemical reactions leads to pure aerosols that are ideal for the use as model particles for different studies. Furthermore, compared to other aerosol synthesis methods, the spark ablation and especially, the VSP-G1 Nanoparticle Generator, results in a stable and defined production even over longer time spans, which is important to draw meaningful conclusions."

Weber group - Institute of Particle Technology, TU Clausthal



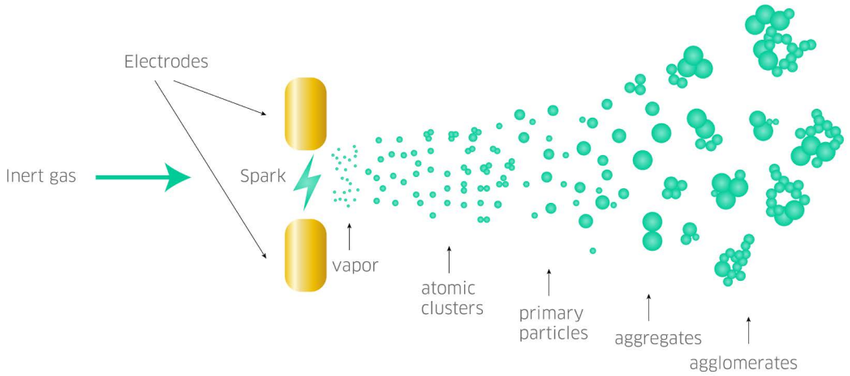
VSP-G1 Nanoparticle Generator (VSP-G1)

VSP-G1 Nanoparticle Generator (VSP-G1)

Spark Ablation
Working Principle

Nanoparticle synthesis in the gas phase

The VSP-G1 Nanoparticle Generator uses spark ablation to produce nanoparticles with primary particle sizes between 1–20 nm. These nanoparticles are produced exclusively in the gas-phase and without the use of any chemical precursors or stabilizing ligands. The spark ablation technology is a scalable, physical-based process which was first reported in 1988 by our co-founder Andreas Schmidt-Ott. Since its first publication, this innovative and facile nanoparticle generation technology is gaining increasing research interest each year within the field of nanotechnology.



Schematic explanation of the spark ablation and nanoparticle growth process.

Theoretical background of spark ablation

Spark ablation is unique in its simplicity. The only requirements to prepare a continuous aerosol of nanoparticles are electricity, an inert carrier gas and a pair of (semi)conductive electrodes. The electrodes of the desired material are connected to an electrical circuit. A high-purity inert gas is supplied in between the electrode gap and then a high voltage (kV) is applied across the two electrodes. Once the gas breakdown voltage is reached, a spark is generated between the two electrodes and the temperature rises locally (20,000 K), ablating material from the electrode surface. This results in the production of an aerosol of nanoparticles composed of the elements that are present in the bulk electrodes.

Due to the constant flow of the carrier gas, the output of the spark ablation process is a highly concentrated aerosol of nanoparticles (10^8 – 10^{11} cm^{-3}) at ambient temperatures (<50 °C). Since this nanoparticle generation process does not require any wet chemical synthesis steps, clean and stable nanoparticles that are free from contaminants (e.g. organic surfactants, solvents, etc.) can be prepared. The generated nanoparticles can either be used as a direct input for a subsequent process step (e.g. detector calibration, core-shell nanoparticle production) or be deposited on various substrates using VSPARTICLE's deposition accessories to prepare more specialized samples.

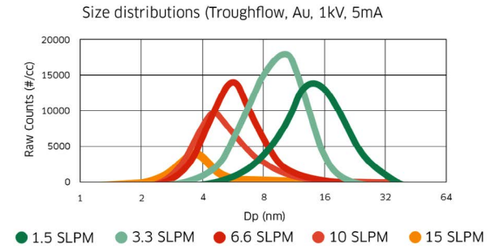
Process Control Parameters

Controlling VSP-G1 output

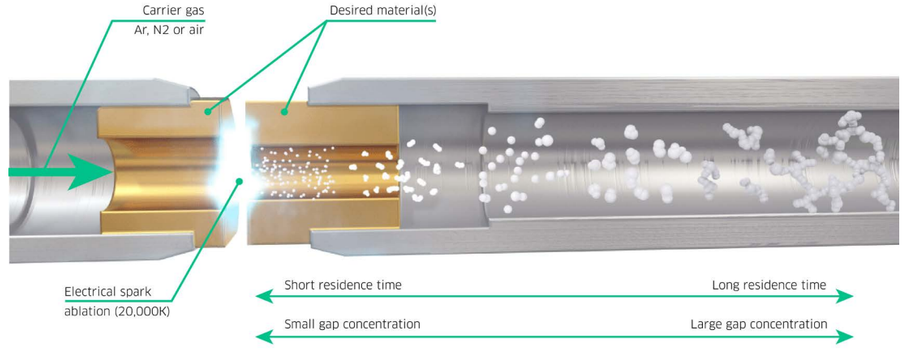
The VSP-G1 Nanoparticle Generator enables researchers to readily tune the average particle size of a nanoscale material, with particle sizes achievable between 1–20 nm. By adjusting the flow rate of the carrier gas (1–25 L/min for Ar), the voltage (up to 1.3 kV) and/or the current (up to 10.4 mA), the user is able to vary the average particle size. For researchers interested in depositing their nanoparticles on substrates using one of the many VSPARTICLE deposition strategies, the surface coverage of a substrate is controlled by varying the power output and deposition time. All the parameters can easily be controlled with the VSP-C1 controller and the integrated software that comes with every VSP-G1.

Effect of control parameters on the VSP-G1 output

The most significant parameter to tune the particle size distribution is the flow rate. Higher flow rates ensure that the ablated clusters have little time to agglomerate thereby yielding the smallest nanoparticles. Similarly, lower flow rates will increase the residence time of the ablated material inside the reactor, giving the clusters/particles more time to agglomerate into larger particles. Nevertheless, even at low flows the size distribution of the particles remains narrow. In addition, by adjusting the total power output (i.e. voltage/current) the material ablation rate is varied, with higher voltages/currents resulting in higher ablation rates and therefore generally larger particles.



Online particle size distributions (determined using a DMA) demonstrating the influence of gas flow on the average particle size.



Parameters that affect the nanoparticle formation and growth process - a view from the inside of the reactor

Material Versatility

Electrodes (source of nanoparticle production) of different materials

Endless possibilities for new material combinations

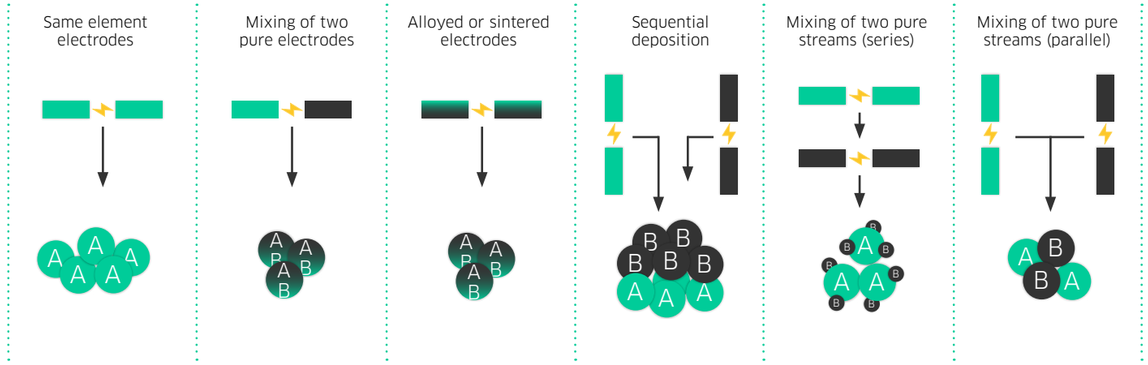
The VSP-G1 is compatible with any conductive or semiconductive material that can be processed into electrodes. That means that all the highlighted green elements of the periodic table are compatible* with the VSP-G1. This gives researchers the freedom to prepare, explore and create a wide range of nanomaterials. The boundaries of exploration are broadened even further by combining electrodes of two different elements/alloys in a single VSP-G1, or by using two VSP-G1 Nanoparticle Generators with different electrode materials in sequence or in parallel. This material versatility allows the production of bimetallic nanoparticles and diverse combinations of nanoalloys even from materials that are immiscible in their bulk form.

1 H Hydrogen 1.01																	2 He Helium 4
3 Li Lithium 6.94	4 Be Beryllium 9.01											5 B Boron 10.81	6 C Carbon 12.01	7 N Nitrogen 14.01	8 O Oxygen 16	9 F Fluorine 19	10 Ne Neon 20.18
11 Na Sodium 22.99	12 Mg Magnesium 24.3											13 Al Aluminium 26.98	14 Si Silicon 28.09	15 P Phosphorus 30.97	16 S Sulfur 32.06	17 Cl Chlorine 35.45	18 Ar Argon 39.1
19 K Potassium 39.95	20 Ca Calcium 40.08	21 Sc Scandium 44.96	22 Ti Titanium 47.87	23 V Vanadium 50.94	24 Cr Chromium 52	25 Mn Manganese 54.94	26 Fe Iron 55.84	27 Co Cobalt 58.69	28 Ni Nickel 58.93	29 Cu Copper 63.55	30 Zn Zinc 65.39	31 Ga Gallium 69.72	32 Ge Germanium 72.64	33 As Arsenic 74.92	34 Se Selenium 78.96	35 Br Bromine 79.9	36 Kr Krypton 83.8
37 Rb Rubidium 85.47	38 Sr Strontium 87.62	39 Y Yttrium 88.91	40 Zr Zirconium 91.22	41 Nb Niobium 92.91	42 Mo Molybdenum 95.94	43 Tc Technetium 98	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.91	46 Pd Palladium 106.42	47 Ag Silver 107.87	48 Cd Cadmium 112.41	49 In Indium 114.82	50 Sn Tin 118.71	51 Sb Antimony 121.76	52 Te Tellurium 126.9	53 I Iodine 127.6	54 Xe Xenon 131.29
55 Cs Cesium 132.91	56 Ba Barium 137.33	57-71 Lanthanoids	72 Hf Hafnium 178.49	73 Ta Tantalum 180.95	74 W Tungsten 183.84	75 Re Rhenium 186.21	76 Os Osmium 190.23	77 Ir Iridium 192.22	78 Pt Platinum 195.08	79 Au Gold 196.97	80 Hg Mercury 200.59	81 Tl Thallium 204.38	82 Pb Lead 207.2	83 Bi Bismuth 208.98	84 Po Polonium 209	85 At Astatine 210	86 Rn Radon 222
87 Fr Francium 223	88 Ra Radium 226	89-103 Actinoids	104 Rf Rutherfordi.. 262	105 Db Dubnium 262	106 Sg Seaborgium 264	107 Bh Bohrium 266	108 Hs Hassium 268	109 Mt Meitnerium 272	110 Ds Darmstadti.. 277	111 Rg Röntgium 282	112 Cn Copernicium 285	113 Nh Nihonium 286	114 Fl Flerovium 289	115 Mc Moscovium 290	116 Lv Livermorium 293	117 Ts Tennesine 294	118 Og Oganesson 294

Lanthanoids	57 La Lanthanum 138.91	58 Ce Cerium 140.12	59 Pr Praseodymi.. 140.91	60 Nd Neodymium 144.24	61 Pm Promethium 145	62 Sm Samarium 150.36	63 Eu Europium 151.96	64 Gd Gadolinium 157.25	65 Tb Terbium 158.93	66 Dy Dysprosium 162.5	67 Ho Holmium 164.93	68 Er Erbium 167.26	69 Tm Thulium 168.93	70 Yb Ytterbium 173.04	71 Lu Lutetium 174.97
Actinoids	89 Ac Actinium 227	90 Th Thorium 231.04	91 Pa Protactinium 232.04	92 U Uranium 237	93 Np Neptunium 238.03	94 Pu Plutonium 243	95 Am Americium 244	96 Cm Curium 247	97 Bk Berkelium 247	98 Cf Californium 251	99 Es Einsteinium 252	100 Fm Fermium 257	101 Md Mendeleviu.. 258	102 No Nobelium 259	103 Lr Lawrencium 261

All green elements are compatible with VSP-G1

**: Certain (semi)conductive materials may be compatible with the VSP-G1 but are excluded from this table due to their difficulty to manufacture into electrodes. If your desired material is not highlighted as being compatible with the VSP-G1, please contact us directly at sales@vsparticle.com.*



Different configurations of VSP-G1 resulting in a wide variety of material combinations. Each pair of electrodes represents one VSP-G1.

Ultimate control of your nanoparticle production:

The elemental composition of the generated nanoparticles is primarily determined by the composition of the electrodes. Combined with the lack of additional organic solvents and/or surfactants during synthesis, this allows the ultimate control of your nanoparticle composition. Preparation of oxides is also possible, simply by adding a small amount of oxygen in the gas flow.

In case multiple VSP-G1's are used or one VSP-G1 with electrodes of two different materials, different elemental combinations of the produced nanoparticles are achieved through different power and flow settings. If you want to discuss further the feasibility of a specific material combination, contact us at sales@vsparticle.com.

VSP-C1 controller
User Interface

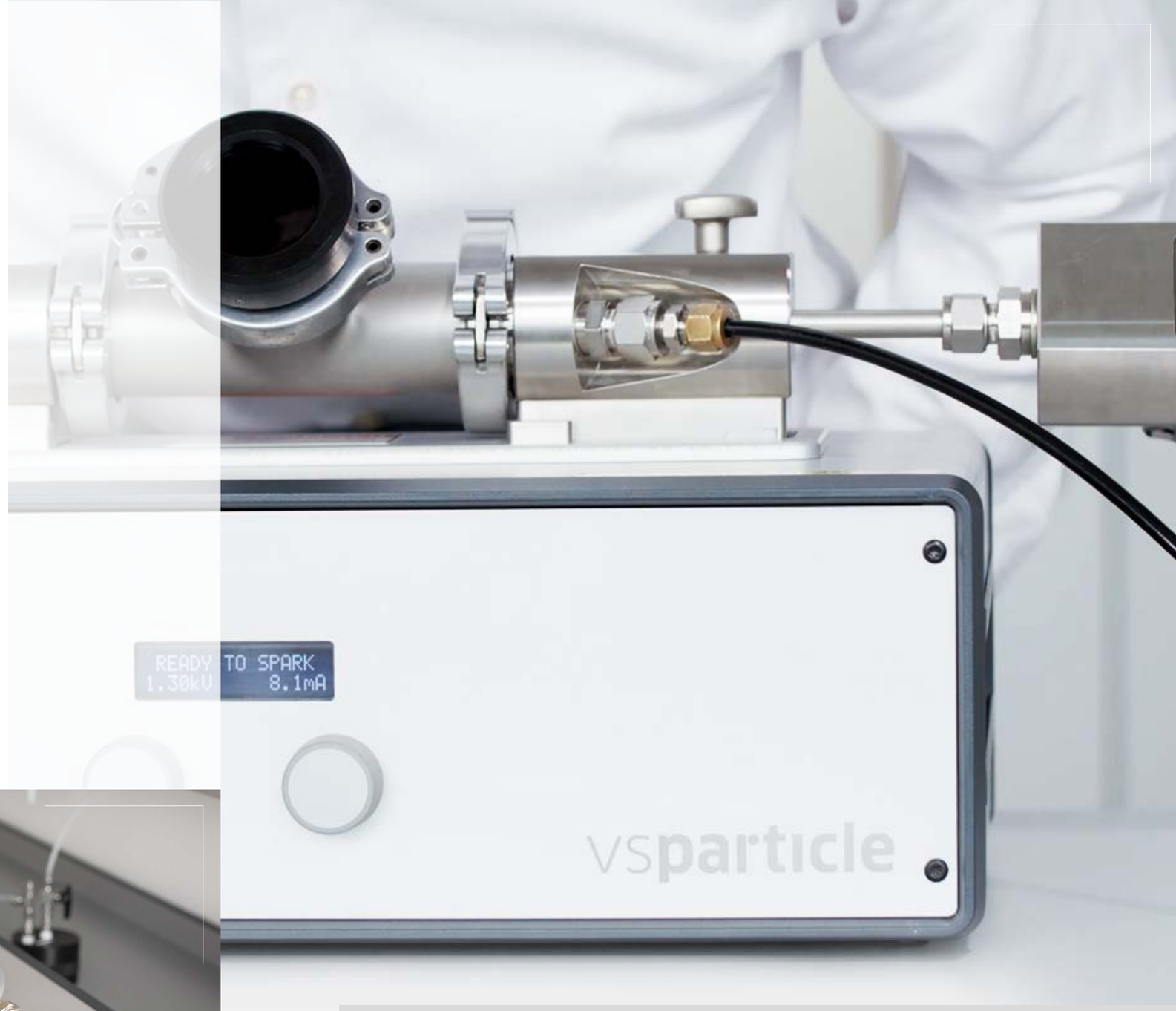
Automated experimentation

Every VSP-G1 system is equipped with a controller and software system that allows the user to control the VSP-G1's process parameters. This controller system (VSP-C1) enables the user to remotely and intuitively control the VSP-G1 process parameters. The controller is integrated with a user interface which allows the adjustment of experimental parameters as well as the visualisation and logging of data.

Advantages

- Automated experimentation
- Remote control
- Data visualisation
- Easy to use

Using the VSP-C1 for automated nanoparticle generation



"The VSPARTICLE tools enable you to combine different materials together on any substrate, changing their functionalities. At the Smith Solar Lab, we have used VSPARTICLE's machine in different ways, because you can make nanoparticles of different sizes and compositions. They have different optical properties, so you can actually tune which part of the solar light is absorbed by pushing a button. Which is something we have not been able to find in any other technology".

Associate Professor Wilson Smith - UC Boulder

VSP-G1
Getting started

Preperation

The workflow of operating VSP-G1 is a simple and fast process. First, the electrodes of the selected material are loaded in the reactor chamber. If collection of the nanoparticles is desired, the appropriate deposition accessory, equipped with a substrate, is also connected directly to the VSP-G1 outlet. Next, the process parameters (e.g. flow, voltage, current) are set and the system is ready for nanoparticle generation!

The required deposition time depends on the desired substrate coverage, the deposition method, and ablation rate of the selected electrodes. Typical deposition times range from a few minutes (e.g. TEM grids) to a few hours (e.g. filters). After the deposition stage is complete, the system is flushed with the carrier gas for approximately 2 minutes. Finally, the substrate with the loaded nanoparticles can be safely removed and is ready for characterization.

This simple workflow allows users to swiftly change substrates for subsequent depositions, and/or switch electrodes to prepare nanoparticles of a different elemental composition. This process, including the reactor cleaning, requires approx. 15 minutes, after which the system is ready to reconnect and start generating the next batch of nanoparticles

Maintenance and cleaning

Our convenient design and workflow are accompanied by easy cleaning protocols. The reactor head can be cleaned by wiping the reactor chamber, electrode holders, electrodes, and possible accessories with paper towels and pipe cleaners/cotton tips. We recommend using common lab solvents (e.g. water, ethanol, isopropanol, acetone) for the best results. Cleaning must be performed when changing the electrode materials. For best results, regular cleaning of the reactor head is advised.

"..making such new materials is challenging for us because very often we need to actually use very difficult chemical synthesis methods and we also produce a lot of unwanted chemical waste then. By using the nanoparticle generator (VSP-G1) and the size selector (VSP-S1) we can now actually just press a button and make these materials without producing any chemical waste so this makes our experiments much easier."

Iris ten Have - Bert Weckhuysen Group, Utrecht University

Customer support

After purchasing a VSP-G1 or requesting a free demonstration period to use it, our team will provide all the necessary training as well as technical support that is required at the initial stages of the project. We always try to maintain a close collaboration with our customers in order to assist them in getting the most out of our technology.

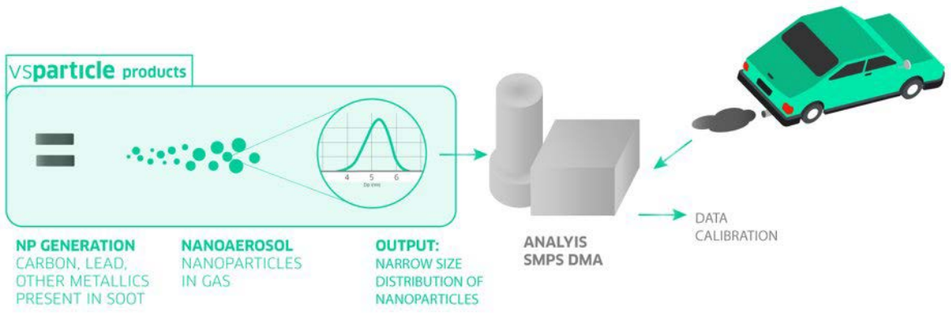
Applications

Nanoparticles produced with spark ablation can have applications in a variety of fields depending on the setup that is used. These applications are continuously expanding as we develop new products to meet the needs in various fields.

Using only VSP-G1 Nanoparticle Generator

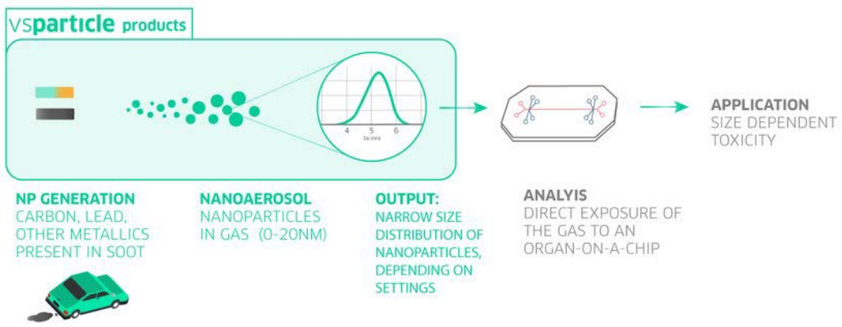
Emissions testing

The VSP-G1 in combination with carbon electrodes can be used to produce an aerosol that mimics the ultrafine components of soot. The high stability of the device's output makes the VSP-G1 ideal for a potential application as a standard calibration tool as well as a more general tool for a wide range of emissions testing.



Nanotoxicology

The ability of the VSP-G1 to produce pure nanoparticles smaller than 20 nm with a very narrow size distribution can also have various applications in nanotoxicology research. An example is direct exposure of cell cultures to the VSP-G1 output. After exposure for the desired amount of time, cells can be studied to understand the toxicology effects of airborne nanoparticles.

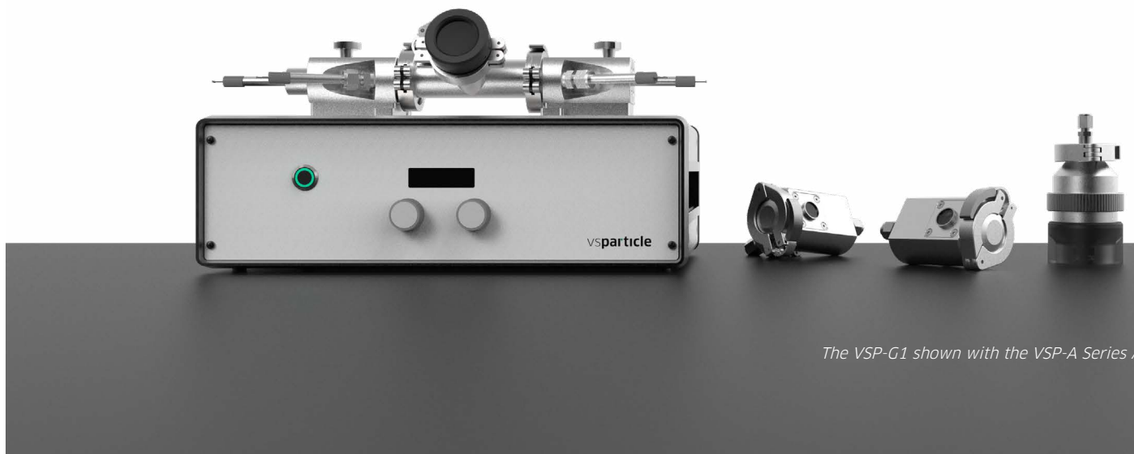


"For our research in the safety of airborne nanomaterials, VSPARTICLE's VSP-G1 enables us to generate very small particles. We use this both as a reference method, as well as for our research into the distribution of very small nanoparticles in the body after inhalation"

Flemming Cassee - Utrecht University & RIVM (National Institute for Public Health and the Environment)

Using VSP-G1 with deposition accessories

By using VSP-A series deposition accessories, the range of materials that can be prepared with VSP-G1 is expanded . This allows the use of VSP-G1 in (electro)catalysis, sensors development, healthcare, energy and fiber/fabric applications. To find out how the VSP-G1 with VSP-A series accessories can accelerate your research, please visit our applications overview page at https://vsparticle.com/applications/applications-overview.



The VSP-G1 shown with the VSP-A Series Accessories

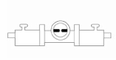
VSP Products

Product portfolio

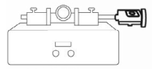
Deposition of nanoparticles produced from VSP-G1 is now also possible by using one or more of the rest portfolio's products. VSPARTICLE is continuously working towards the development of new deposition systems in order to accommodate the every expanding research needs within academia and industry. The VSP-G1 Nanoparticle Generator is at the heart of VSPARTICLE setups, and has been designed to easily connect to any VSPARTICLE product. This degree of flexibility and modularity will ensure that researchers are free to assemble the custom setup that meets their research needs.

Modular system

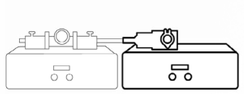
Easily connect the VSP-G1 to VSP deposition modules



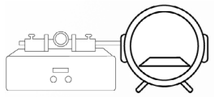
VSP-Electrodes



VSP-A series
(accessories)



VSP-S1
(Size selector)



VSP-P1
(Nanoporous printer)

"The sample preparation is applicable for a wide range of materials as well as metal nanoparticle sizes. This ensures that valuable time on TEM machines is well used. In addition, tuning particle size with settings prior to deposition allows us to study the size dependency of the metal nanoparticles for a given catalytic reaction. In total, it takes less than an hour to make a sample and the same MEMS devices can be used."

Charlotte Vogt - Debye Institute. Utrecht University

VSP-G1
(Nanoparticle Generator)

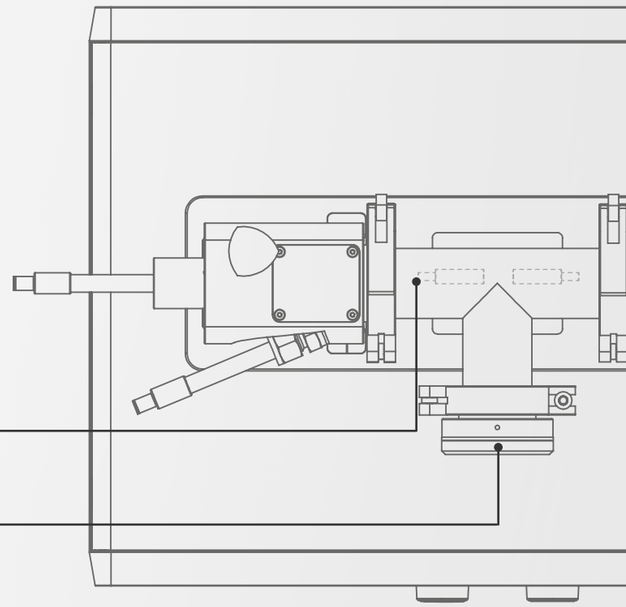
VSP-S1
(Size selector)

VSP-P1
(Nanoporous Material Printer)

VSP-A series
(Accessories)

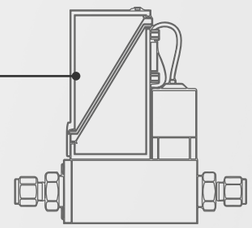
Delivered equipment (standard)

After purchasing a VSP-G1 system, you will receive a setup that is ready to be used in an instant. In addition to the basic VSP-G1 Nanoparticle Generator, a complete VSP-G1 setup also contains a mass flow controller, HEPA filter, necessary Swagelok connections and tubing as well as the VSP-C1 controller that you will need in order to properly set and log your experiment. A pair of copper electrodes is included in all orders, with additional electrodes available upon request. The only requirements that your lab needs to have for a smooth installation and training process are the gas supply and a basic wrench tool kit.



Electrodes
Choose from a wide variety of electrode materials that suits your experiment.

Spark viewport
By looking through the viewport you can safely view the spark.



Mass Flow Controller
Accurately measuring and controling the flow ranges that are set by the VSP-C1

VSP-C1
Easily control the output parameters, visualise and retrieve data from your experiments.

HEPA filter
Installing the HEPA filter at the exhaust of your setup will guarentee a safe way of working.

MFC+ unit
The MFC+ unit makes the connection with the MFC and the pressure sensor within your setup.

Technical specs

Gas inlet/outlet	10 mm tubes (with Swagelok connectors)
Dimensions of the apparatus	Casing ca. 370 × 470 × 237 mm
Weight of the apparatus	19 kg
Power	120 – 240 V AC *a power plug based on your country of residence will be provided with every VSP-G1 system*
Spatial requirements	Access to lab ventilation system Not necessary to be placed in a cleanroom

Operating window

Mass production rate order	0.01 – 100 mg/hr (material dependent)
Typical Particle Concentration	10^8 – 10^{11} cm^{-3} (material dependent)
Primary Particle Size	1 – 20 nm (depending on settings and material)
% of charged particles at the output	< 10 %
Operating Conditions	Standard temperature and pressure
Flow rate	1–25 L/min *Higher flows are also possible on customer request*
Gas supported	Ar or N_2 (recommended purity 5.0)
Unsupported	He, Ne, Xe, Kr Contact VSPARTICLE for use of reactive gases such as O_2, H_2.
Material	Any conductive or semiconductive material *See page 8 for specifications*

Delivered equipment

- **VSP-G1 Nanoparticle Generator basic unit**
- **VSP-C1 Controller unit**
- **Mass Flow Controller**
- **HEPA filter**
- **Copper electrodes**

Relevant literature

Generation of nanoparticles by spark discharge,

Tabrizi, N. S. et al., Journal of Nanoparticle Research (2009), doi: 10.1007/s11051-008-9407-y

New developments in spark production of nanoparticles

Pfeiffer, T. V. et al., Advanced Powder Technology (2014), doi: 10.1016/j.apt.2013.12.005

Atomic Cluster Generation with an Atmospheric Pressure Spark Discharge Generator,

Maisser, A. et al., Aerosol Science and Technology (2015), doi: 10.1080/02786826.2015.1080812

Spark Ablation: Building Blocks for Nanotechnology

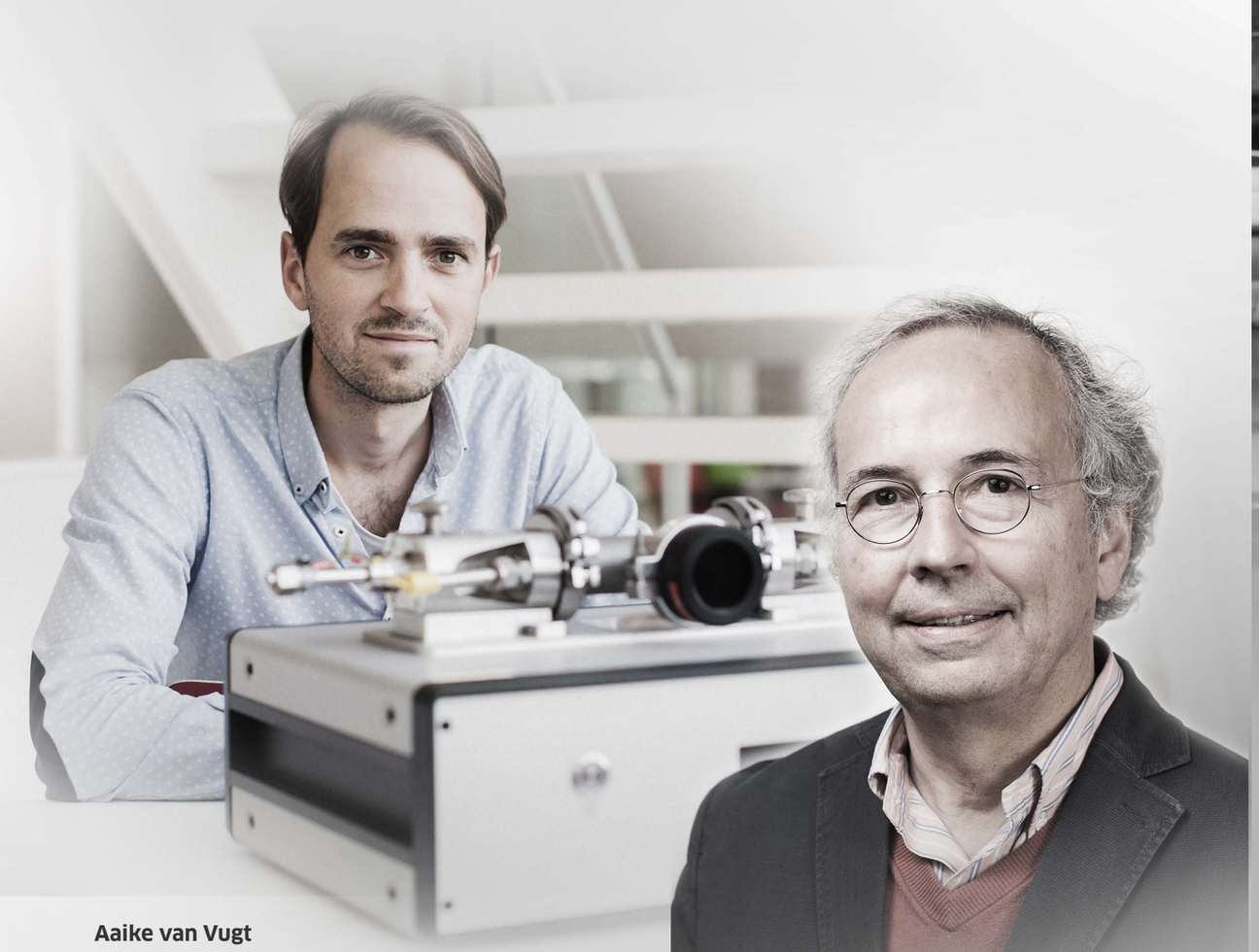
Edited by Schmidt-Ott, A., CRC Press (2019)

Reducing material development time from months to days with the VSP-G1

Our Company

Empowering material pioneers

VSPARTICLE was founded in 2014 as a spin-off company from Delft University of Technology. Since then, our ambition has been to provide academic and industrial researchers with the tools to rapidly advance fields based on nanotechnology in order to accelerate the discovery of new materials and products.
With over 20 years of experience in the synthesis of aerosols and with the help of a young and passionate team of scientists and engineers, VSPARTICLE's technology is unlocking a whole new world of possibilities at the nanoscale. As we all start to understand these possibilities it will enable researchers to reshape production processes and develop novel materials to drive innovative applications.



Aaike van Vugt
Co-founder & CEO

Prof.dr. Andreas Schmidt-Ott
Co-founder & Advisor

Nanoparticles at the push of a button.

If you have questions or want to request a demonstration in your own lab contact our sales team today at
sales@vsparticle.com

Alternatively, fill in the request a demonstration form at
www.vsparticle.com

VSparticle