R&D SOLUTIONS

NANOMATERIALS SYNTHESIS AND DEPOSITION

Solutions for dry synthesis and deposition of nanoparticles and nano materials for R&D, Academy and Research Institutes

vsparticle

CONTENT

INTRODUCTION

01

COMPANY

Empowering material pioneers

After more than 40 years of fundamental technology development, VSPARTICLE was established in 2014 as a spin-off company from Delft University of Technology. Since then, our ambition has been to provide academia and industrial researchers with the tools to rapidly advance fields based on nanotechnology 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.

At VSPARTICLE, we believe that generation of nanoparticles should be neither complex nor time-consuming. This is why we developed the VSP-P1 NanoPrinter. Our technology reduces the preparation time of advanced nanoparticle samples to matter of hours, enabling researchers to accelerate the process of developing novel materials and immediately investigate their unique properties. VSPARTICLE has based its technology on **spark ablation technique** invented by our co-founder. The company has become a world leader in this method. Spark ablation systems are already being used in research labs all over the world. The company headquarters in Delft, and has an international distribution network in the USA, Europe and Asia. Our research tools **empower material pioneers**!

01

Our Vision

Innovative technology for production of new materials to enable impactful solutions.

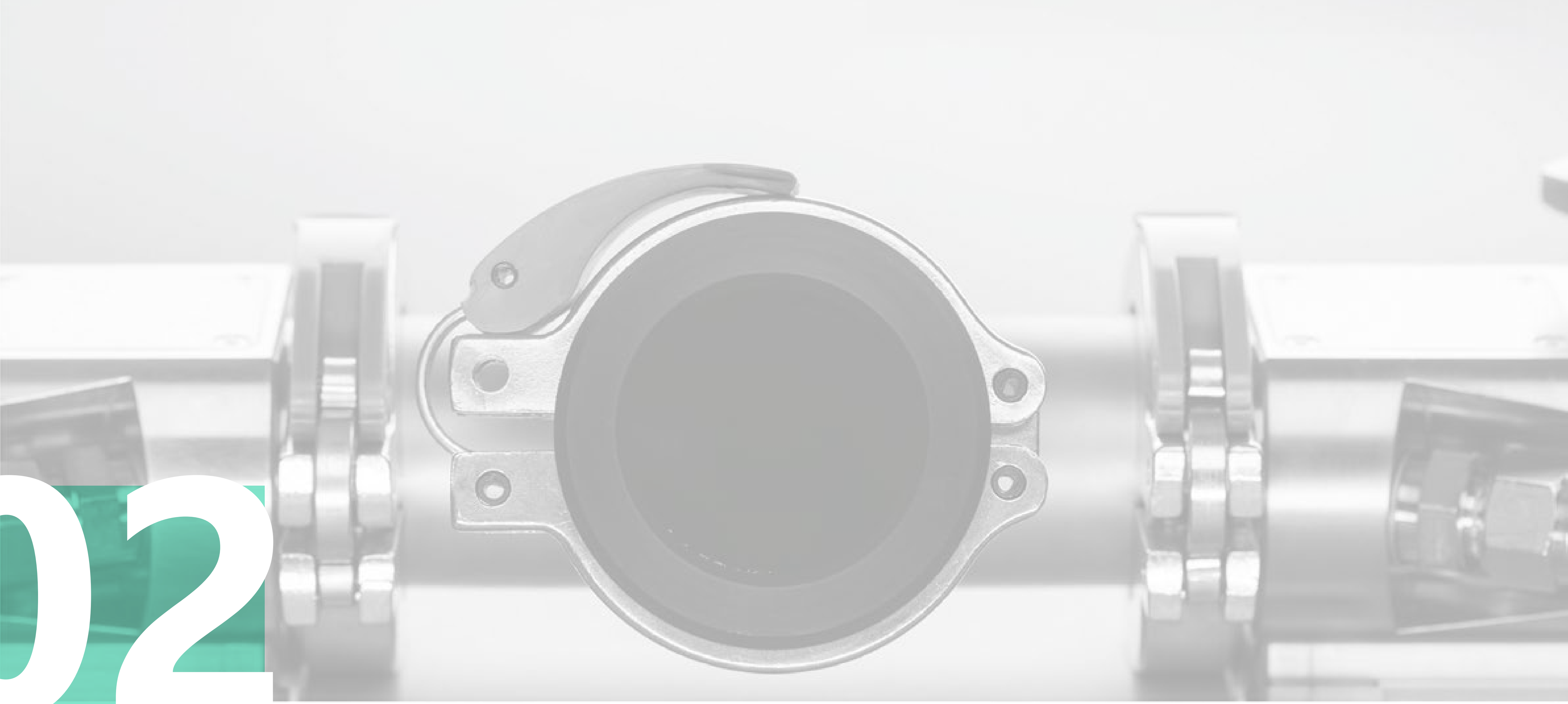
Users and Collaborators

01

Mission

To standardize nanotechnology by providing researchers, innovators, and industries with accessible tools to create, manipulate, and study nanoparticles effortlessly. We aim to enable breakthroughs across various fields, including materials science, electronics, healthcare, and energy, by making nanotechnology more intuitive and widely applicable.

SPARK ABLATION



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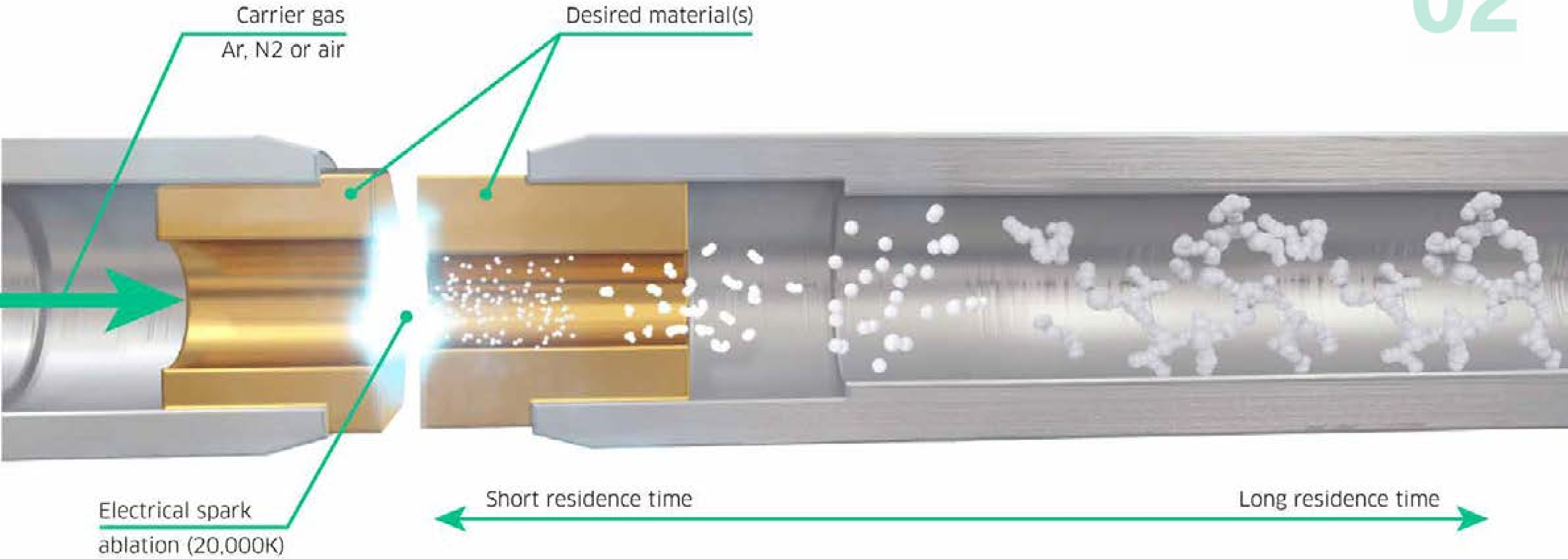
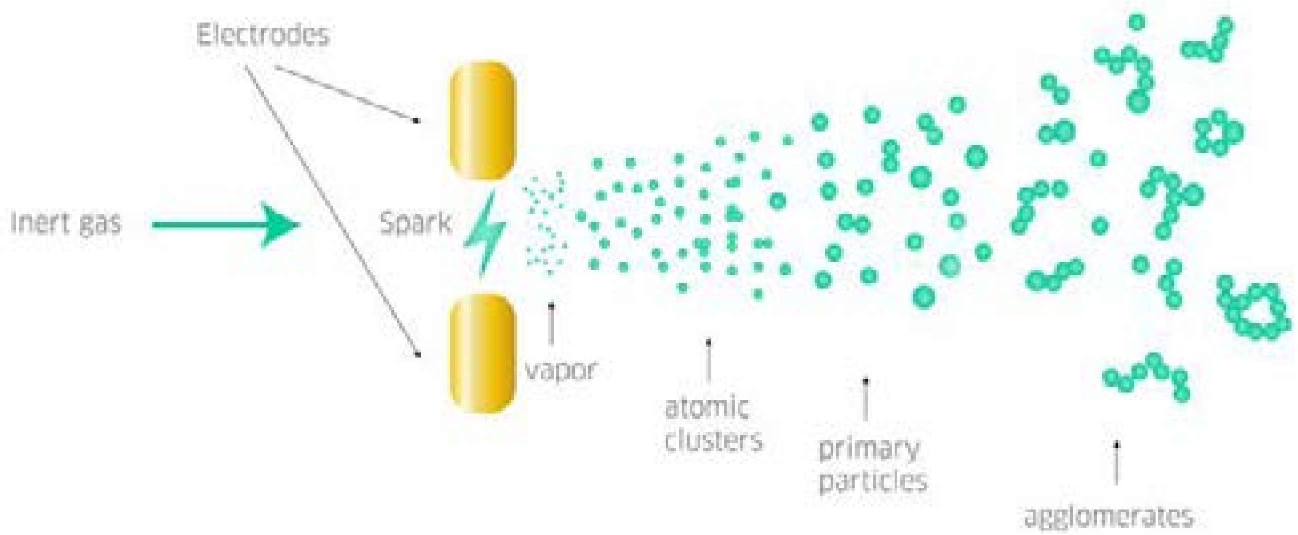


Spark ablation

Spark ablation technology is a physics based process, generating pure particles in a very controlled setting, without the use of chemicals. Our co-founder Andreas Schmidt-Ott invented the technology in 1988 and was then developed into an easy to use device. The spark ablation process used inside the VSP-G1 Nanoparticle Generator (VSP-G1) is a purely physical process that only requires electricity, a carrier gas and electrode material to produce clean nanoparticles. No additional chemicals are required for the production or to stabilize the particles in the aerosol. First, when the electrical discharge occurs, it creates an intense plasma arc between the electrodes, leading to the localized vaporization and ionization of the solid material. This process results in the formation of a highly energetic plasma containing vaporized atoms and ions of the target material.

Then, within the plasma, the vaporized atoms and ions undergo rapid nucleation and condensation processes, leading to the formation of nanoparticles with nanometer-scale dimensions. The precise size, composition, and morphology of the nanoparticles can be controlled by adjusting various parameters such as the applied voltage, discharge frequency, gas flow, and electrode configuration.

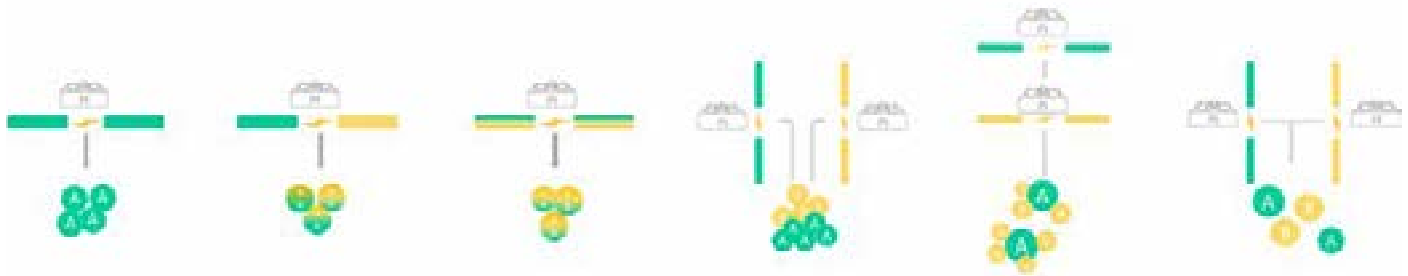


Schematic explanation of the spark ablation and nanoparticle growth process

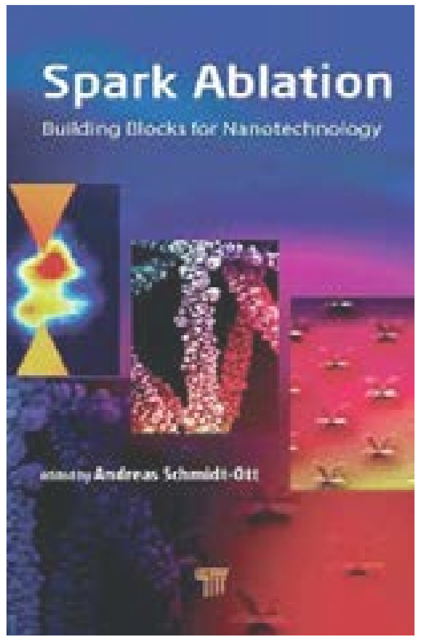
Key benefits

- Physics based process
- Start/stop at the push of a button
- No chemical waste
- Any (semi)conducting material
- Versatility of Spark ablation
- High control on particle size
- Operates at room temperature and pressure
- Scalable technology suitable
- Purity and Reproducibility
- Applications : catalysis, sensing, energy storage, biomedical applications and more

The produced nanoparticles can be directly incorporated into the next process step or applied in a product by, for example, impaction, electrostatic precipitation or filtering. This way the unique physical properties of the nanoparticles are directly available in the product. The carrier gas can simply be recirculated, minimizing the environmental impact of the process. The output is a highly concentrated aerosol of pure (metal) nanoparticles suspended in a clean gas at low temperatures (<50 °C).
With inert carrier gases such as Ar and N_2, pure metal nanoparticles are produced with surfaces free from (organic) contaminants. The carrier gas can simply be recycled by passing it through a filter and used again, minimizing the environmental impact of the process. Because no waste streams are produced, Spark ablation is uniquely suitable for integration into (existing) produc-tion
Because of the high temperature in the spark (>20.000K), there is **no practical limit** to the materials that can be processed. In the most basic form, the material is an elemental metal.
The technology is compatible with all conductive and semi conductive materials, with their alloys and combinations (See figure below).



Digital version



Andreas Schmidt-Ott is the **co-founder** of VSParticle where he is now working as an advisor. In 1988, during his Ph.D from Faculty of Mathematics and Physics of ETH in Zurich, Switzerland, he discovered the spark ablation technique. He was an Assistant Professor in Faculty of Electrical Engineering at Duisburg University, Germany and then became Associate Professor in the Mechanical Engineering Department of the same university. Subsequently, he accepted a full professorship in Nanoparticle Technology at the Chemical Engineering Department of Delft University of Technology, Netherlands, where he has an emeritus status since 2018.
He is also Adjunct Professor at The Cyprus Institute in Nicosia. His main areas of expertise are Nanoparticle and Materials Technology. He temporarily served as Secretary General of the German Aerosol Association (GAeF) and Board Member of the American Association for Aerosol Research (AAAR). He was a member of several Editorial Boards of journals and advisor to the Health Council of The Netherlands.

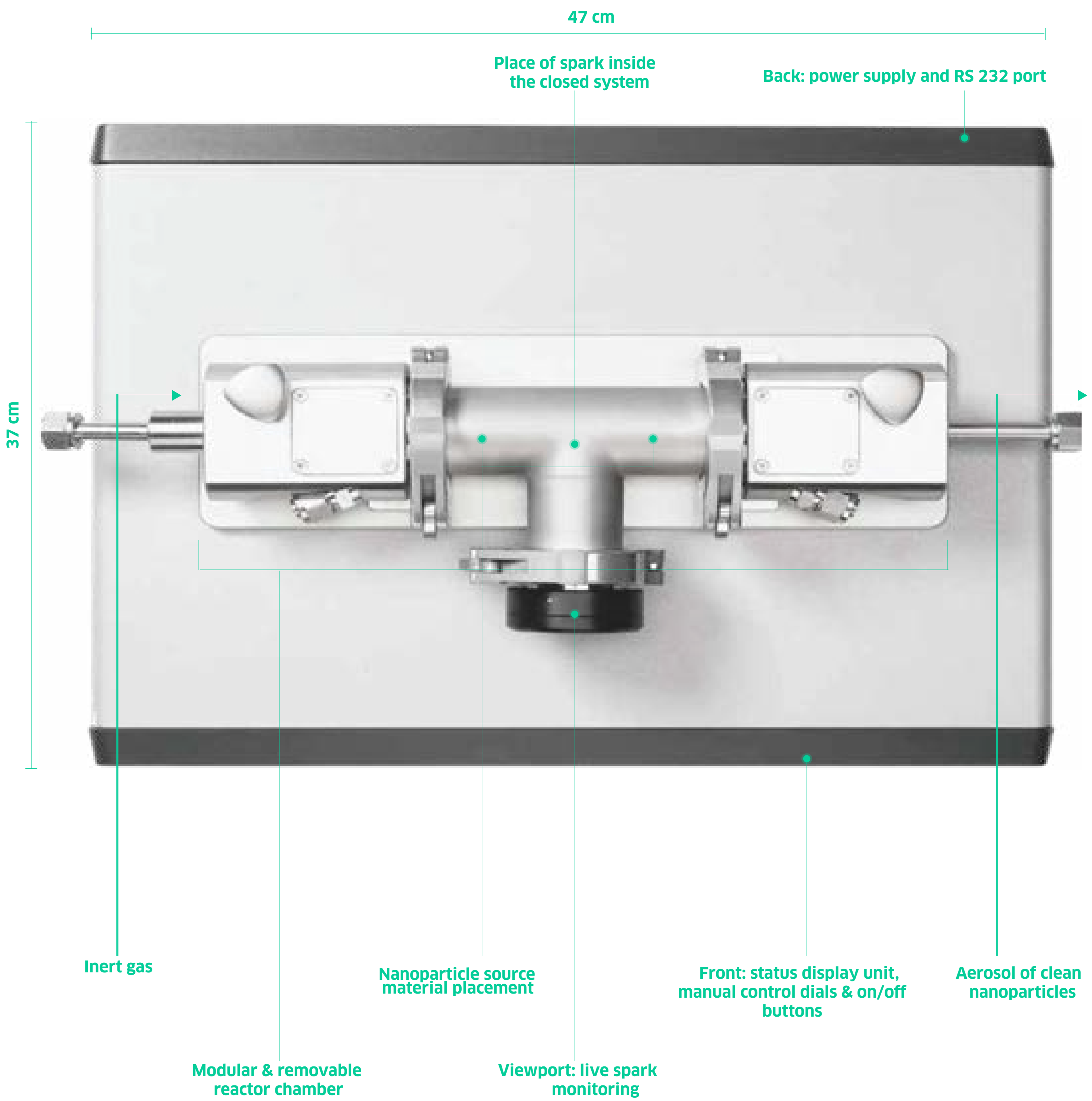
VSP-G1

Nanoparticle Generator

03

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



VSP-G1 standard setup

VSP-G1 Nanoparticle Generator (VSP-G1)

03

Automated experimentation

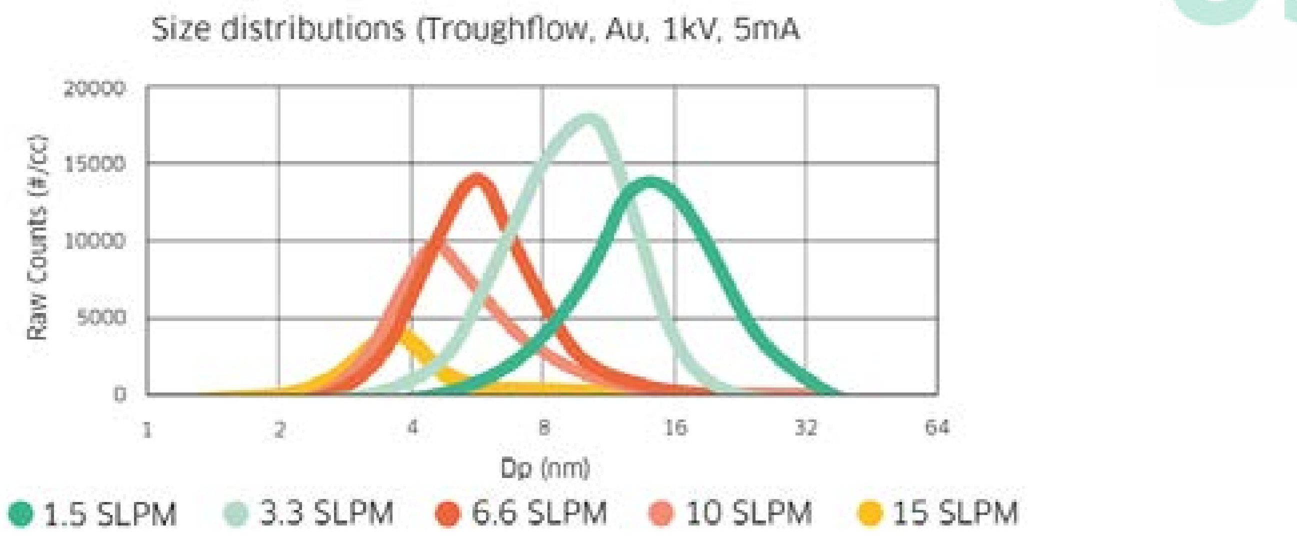
Every VSP-G1 system is equipped with a controller and software system that allows the user to control the VSP-G1's process parameters. This controller system (**VSP-C1**) enables the user to remotely and intuitively control the VSP-G1 process parameters. The controller is integrated with a user interface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

This makes the device **easy to use**, with remote control, automated experimentation and data visualization.

Controlling VSP-G1 output

Ablation rate: mg/h (material dependent) 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. Surface coverage on substrate (See accessories section) is controlled by varying the power output and deposition time.

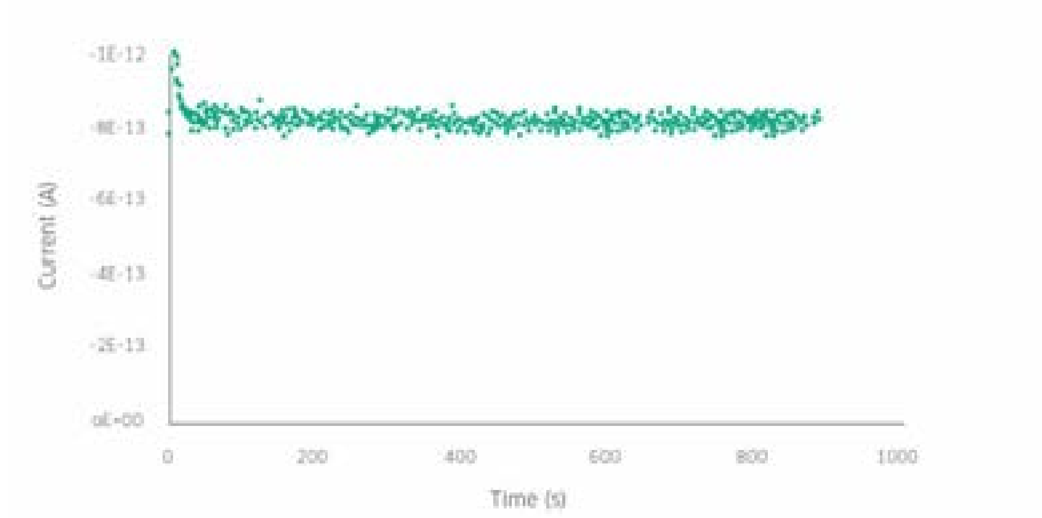
Output estimator



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

Controlling nanoparticle size

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.



Output stability over time

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 Aluminum 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 Roentgium 282	112 Cn Copernicium 285	113 Nh Nihonium 286	114 Fl Flerovium 289	115 Mc Moscovium 290	116 Lv Livermorium 293	117 Ts Tennessine 294	118 Og Oganesson 294

Lanthanoids	**57 La Lanthanum 138.91**	**58 Ce Cerium 140.12**	**59 Pr Praseodymi... 140.91**	**60 Nd Neodymium 144.74**	**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 Mendelevi... 258	102 No Nobelium 259	103 Lr Lawrencium 261

*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.

Material compatibility

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 Gener-ators 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

User journey

1
Contact with VSParticle

2
Presentation of the Technvo-logy and

3
Technical validation

4
Support in Funding application from our experts in national and European grants

5
Purchase of the VSP-G1 Nanoparticle generator

6
Delivery of the system within 3 months

7
Free installation and training at your location

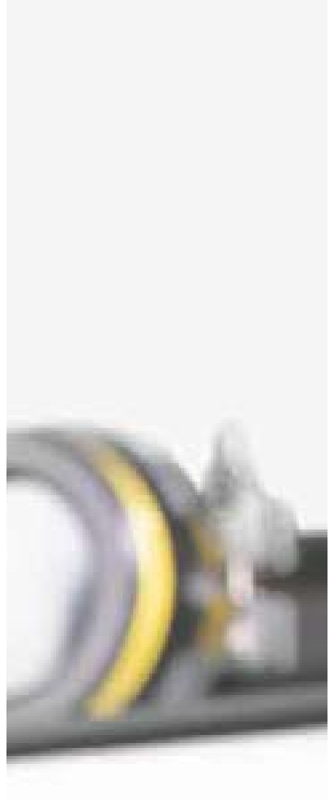
8
2 years warranty, free inspection and maintenance after 1 year (software update, cleaning, leak testing, motor control testing and calibration of the system), 5 year software update

Preparation 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 (See VSP-A Series Accessories) 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.

Filter after deposition The gas exhaust should be treated with a suitable HEPA or ULPA filter. VSParticle recommends using a large capacity HEPA pre-filter, followed by an ULPA end filter. For particles smaller than 20nm as generated by the spark generator, filter efficiency is typically >99.99%. Replace the pre-filter before the end-filter is filled. Dispose used filters according to your local disposal guidelines and any particular requirements outlined by the filtration system you choose for your setup. At a minimum, the filters should sealed and labelled in a sturdy plastic bag.

Customer support After purchasing a VSP-G1 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.



Operating the system

03

Technical specifications

Technical specs

Gas inlet/outlet : 10 mm tubes (with Swagelok connectors)

Dimensions of the apparatus : Casing ca. 370 × 470 × 237 mm

Weight : Base Unit 16kgs/ Reactor assembly 6kgs/ Mount plate 3kgs

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 : 108 - 1011 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 for non-reactive gases, O_2 or H_2 for oxidation or reduction of the particles (recommended purity 5.0)-Unsupported He, Ne, Xe, Kr

Material : Any conductive or semiconductive material

External circuit terminals

Terminal : RS232

Description : Serial connector

Connector : F-DE9 (sub-D, 9 pin)

Rating/specification : RS-232, only pins 2, 3, 5 connected

Voltage rating : Isolated 2.5kV

Environmental Conditions

The VSP-G1 is designed to be safe under the following normal environmental conditions:

-Indoor use;

-Altitude up to 2,000 m;

-Temperature 5 °C to 40 °C;

-Maximum relative humidity 80 % for temperatures up to 31 °C decreasing linearly to 50% relative humidity at 40 °C;

-Mains supply voltage fluctuations up to ±10 % of the nominal voltage;

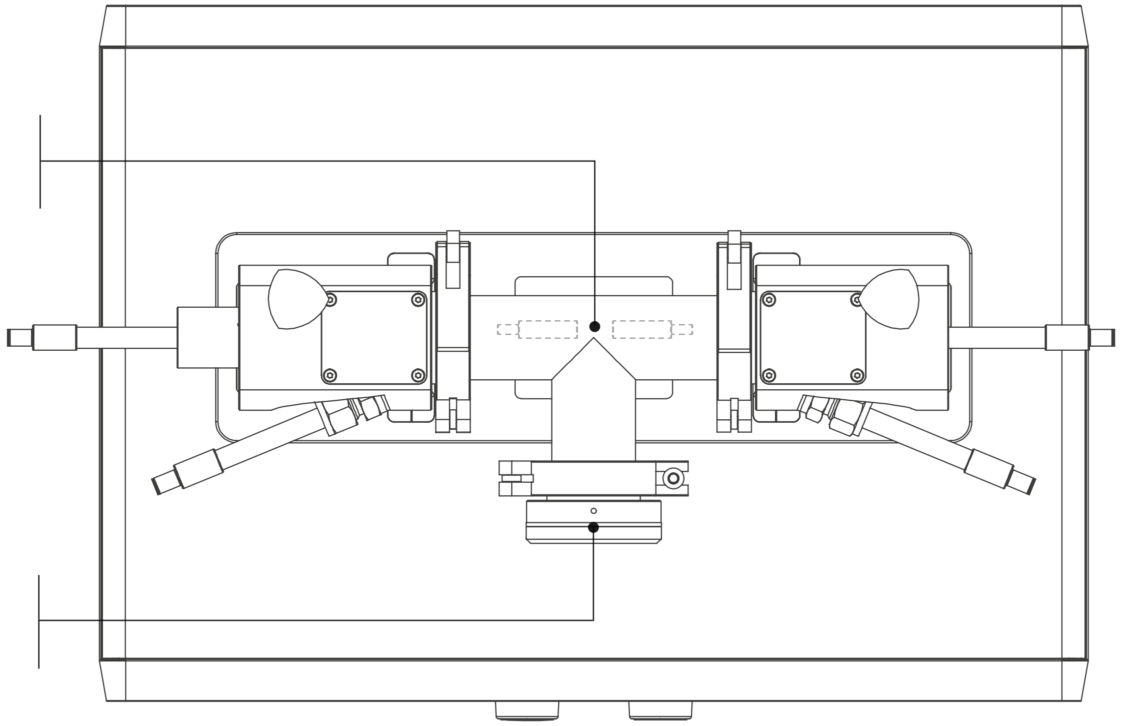
-Transient overvoltages up to the levels of overvoltage category II;

-Temporary overvoltages occurring on the mains supply;

-Pollution degree 2.

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.

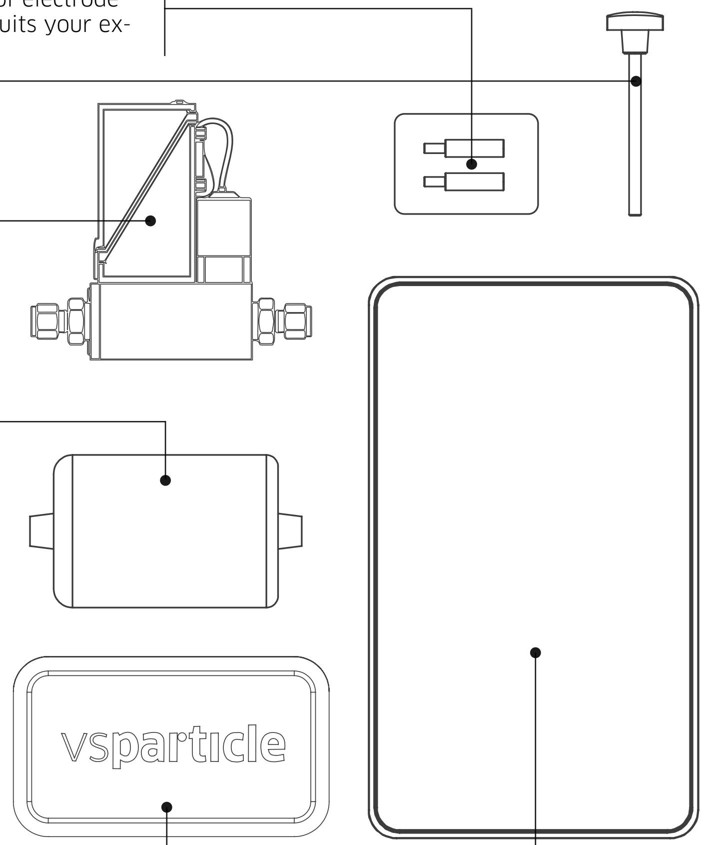


Alignment pins (2x) Use both the alignment pins to insure proper installation of the reactor.

Electrodes (2x) Choose from a wide variety of electrode materials that suits your experiment.

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

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



Delivered equipment

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 Nanopareticle 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 trool kit.

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

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

VSP A-Series:
Deposition

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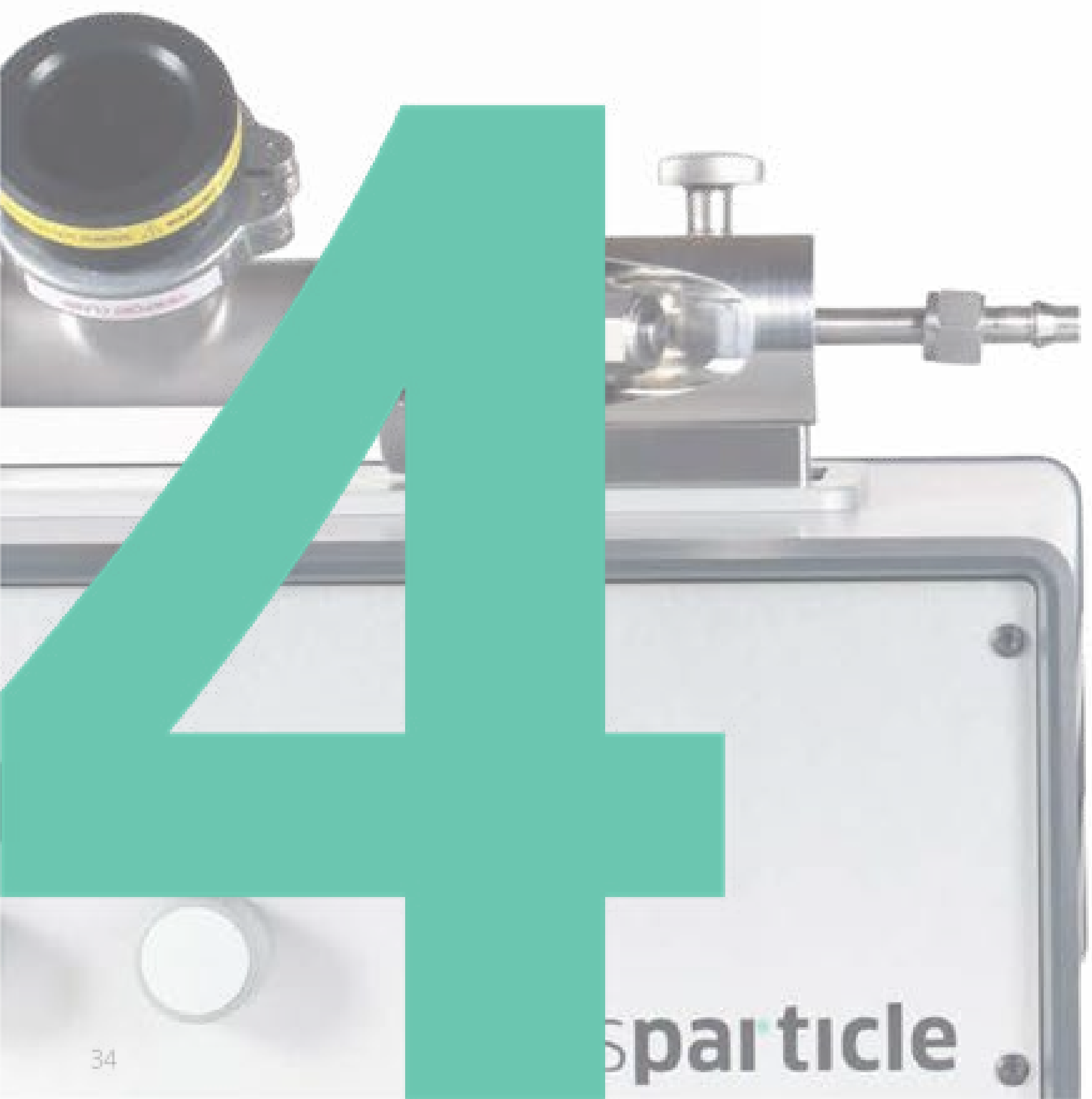


Once synthesis of the desired nanomaterials has been achieved with the VSP G1 Nanoparticle generator, R&D users can then collect and deposit the synthesized nanoparticles with the accessories designed by VSParticle.

04

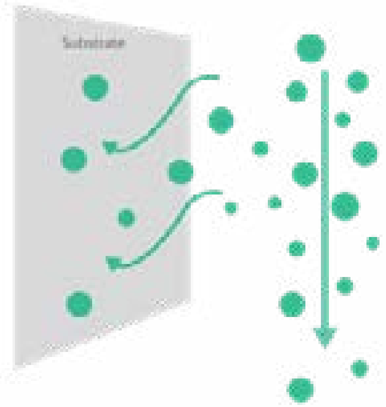
VSP-A1 : Diffusion Accessory

VSP-A1 Accessory has been designed for deposition of isolated **unagglomerated** particles on a substrate (placed in parallel to the flow of nanoparticles). This accessory allows low surface coverage (usually between 1 to 10%), which low impact and no particle deformation.

2D Substrates
- 10x10 mm
- Brownian motion
- Surface coverage 1-10%

Substrates
- TEM grids
- Si-wafer
- Coated wafers

Applications
- In situ TEM
- Electrocatalysis
- Photocatalysis
- In situ spectroscopy
- Materials research



Examples of deposition using the VSP-A1 Diffusion Accessory

04

EXAMPLE 1

Deposition of Au (Gold) Nanoparticles

Set up :
Electrodes : Au
Gas : Argon
Voltage : 1.3kV
Current : 8.1mA
Flowrate : 10 SLM
Deposition time : 30minutes

Results :
30 min deposition time gives a 20% surface coverage with some atomic clusters and large (15nm) particles. Coverage can be changed by varying the deposition time. A deposition of 1 to 2 min gives enough material on the sample for TEM Analysis.

Fig 1
Impact of the flow rate on particle size- Size analysis with SEM.

Fig 2 Images : SEM and TEM images of the same type of sample. Au on Silicon and Au on carbon TEM grid.

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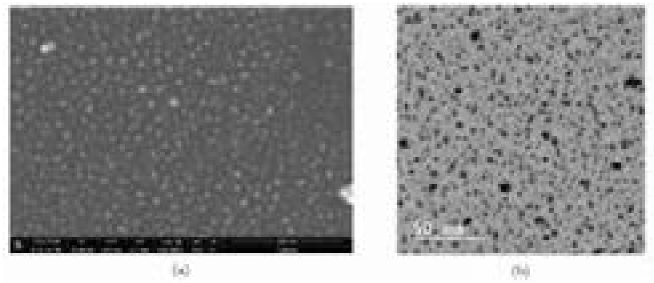

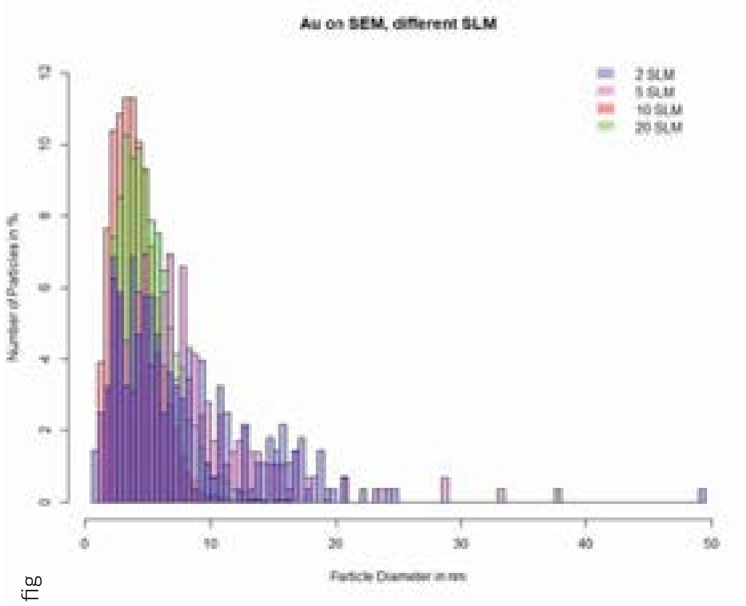

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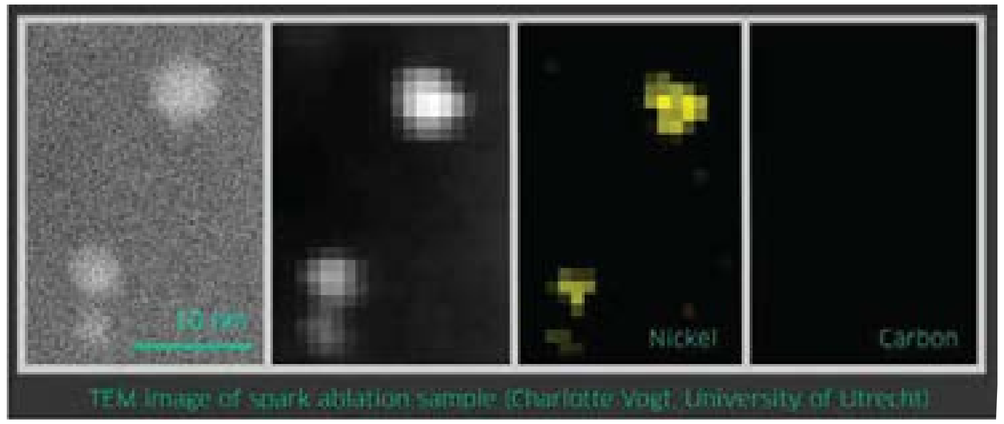
EXAMPLE 2

Deposition of Ni (Nickel) Nanoparticles

Set up
Electrode : Ni
Gas : Argon
Voltage : 1.3kV
Current : 8.1mA
Flowrate : 10 SLM
Deposition time : 5min



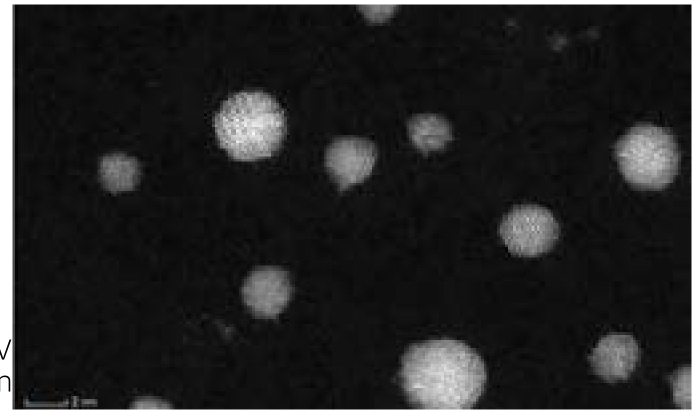
TEM images of Ni nanoparticles deposited by diffusion. Analysis by in situ TEM at Oak-Ridge National Laboratory.

EXAMPLE 3

Deposition of Au (Gold) Nanoparticles

Set up
Electrode : Au
Gas : Argon
Voltage : 1.3kV Current : 8.1mA
Flowrate : 10 SLM
Deposition rate : 5 minutes

Results
High resolution TEM images in collaboration with TU V
twins appear, even when produced at atmospheric con

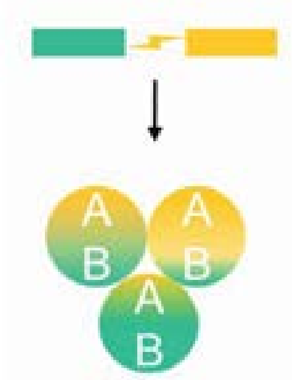


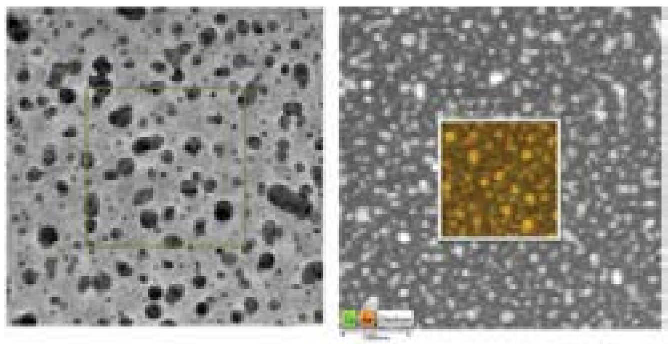
EXAMPLE 4

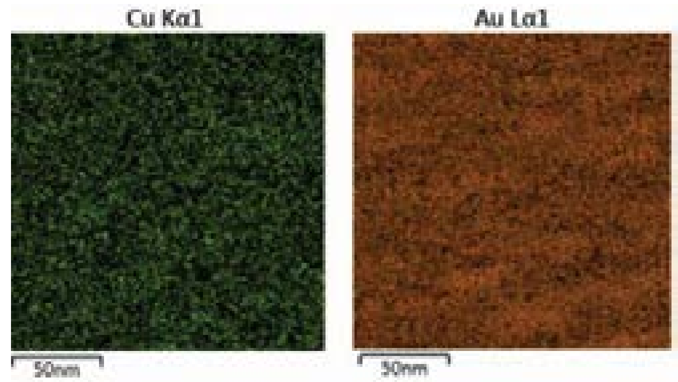
Au-Cu Alloys nanoparticles

Set up
Electrode : Au and Cu
Gas : Argon
Voltage : 1.3kV Current : 8.1mA
Flowrate : 10 SLM
Deposition rate : 1 to 4 hours

Results
Successful gas synthesis of Au-Cu nanoparticles using 2 different electrodes. The high gas glow meant the materials are well mixed in the gas phase, which produces alloyed nanoparticles from pure metal electrodes.







Images: Deposition on DENS climate chip and composition analysis

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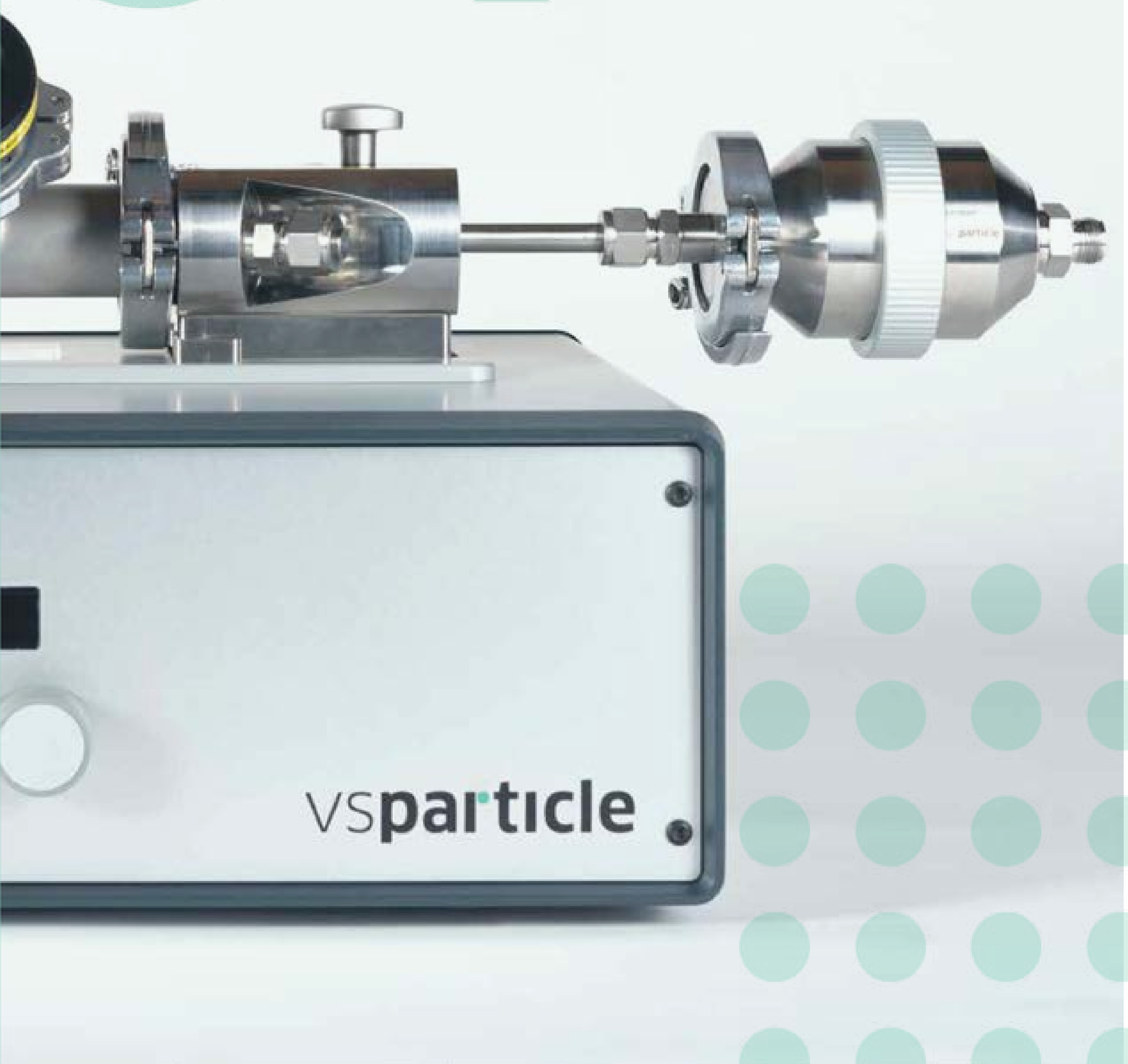
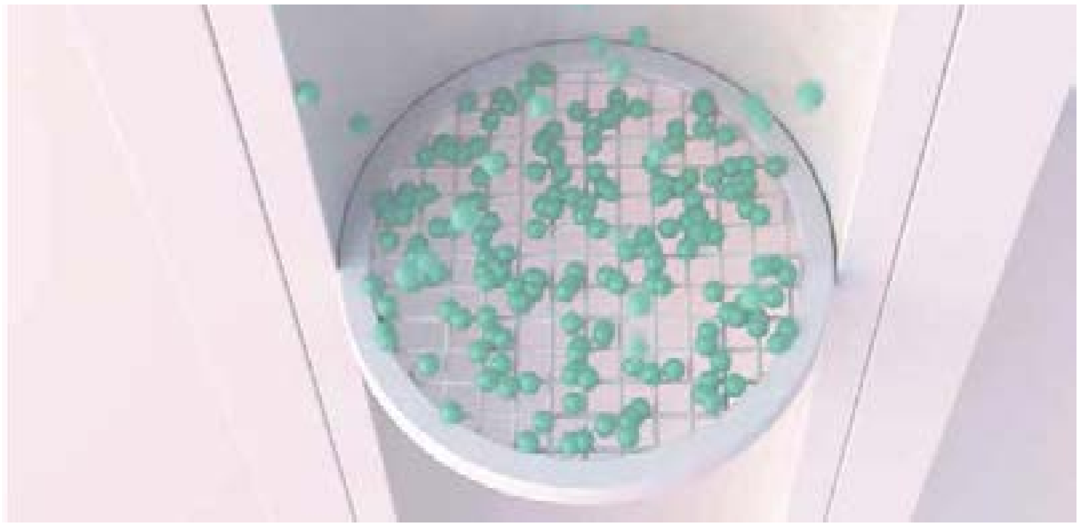




VSP-A2 : Filtration Accessory

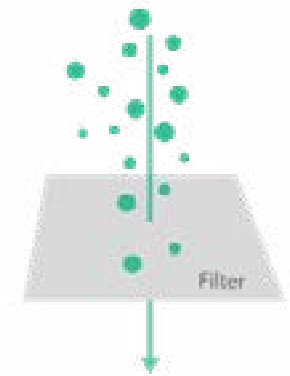
VSP-A2 Filtration Accessory has been designed for deposition of nanoparticles with high coverage on porous substrates. Examples of substrates are membrane filters, fibre filters and carbon cloths.

Deposition
- ø= 47mm
- Ideal for porous substrates

Applications
- Electrocatalysis
- Photocatalysis
- In situ spectroscopy
- Unsupported (clean) NP production
- Ground-up (electro) catalyst synthesis

Substrates
- Filter paper
- Carbon cloth
- Metallic mesh

The Filtration accessory enables high coverage deposition of nanoparticles on the substrate, which is placed perpendicular to the flow of nanoparticles.



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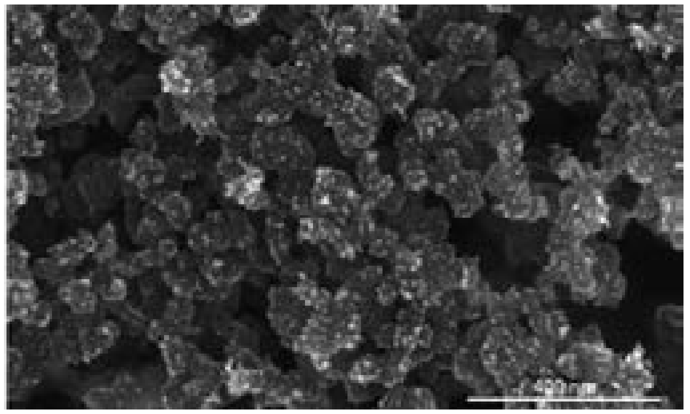
Examples of deposition on porous substrates using VSP-A2 Filtration Accessory

EXAMPLE 1

Catalyst Fabrication on Carbon cloth substrate

Set up Electrode : Gold
Gas : Argon
Voltage : 1.3kV
Current : 8.1mA
Flowrate : 3 SLM
Deposition time : 30 minutes

Results
Depositon of Gold nanoparticles on carbon cloth. Carbon acts as a support and Gold as a catalyst



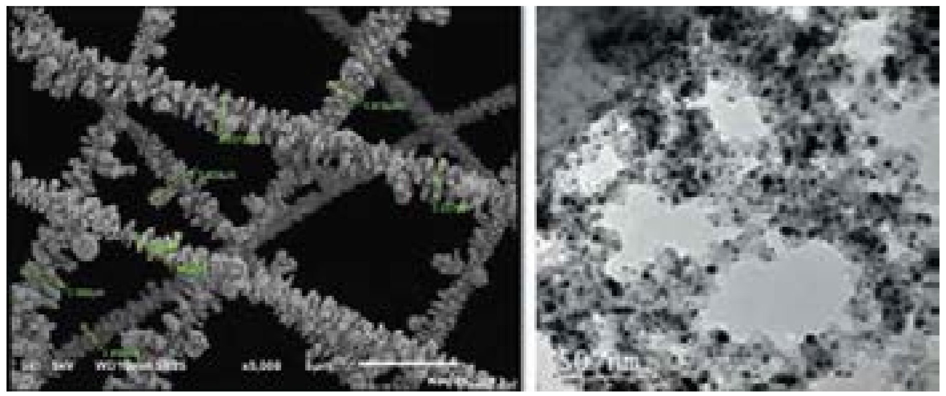
SEM picture of Gold nanoparticles deposited on carbon cloth for electrocatalysis studies using the VSP A2 Filtration Accessory.

EXAMPLE 2

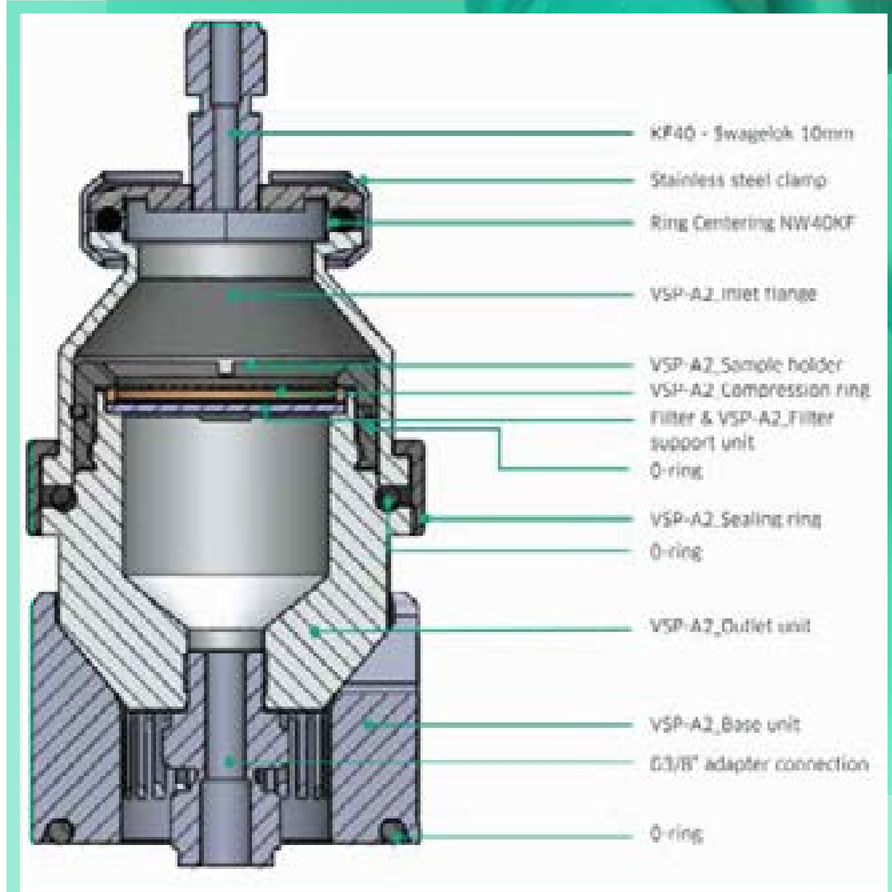
Catalyst Fabrication on Electrospin wires

Set up
Electrode : Au-Al
Gas : Argon
Voltage : 1.3kV Current : 8.1 mA
Flowrate : 3 SLM
Deposition time : 30 minutes

Results
Particles are deposited on the electrospun wires. They grow porous structures.



(Left) SEM pictures of porous structures
(Right) TEM image where Aluninium oxide particles are observed (grey) as well as gold particles (black). The fiber is on the top left of the image



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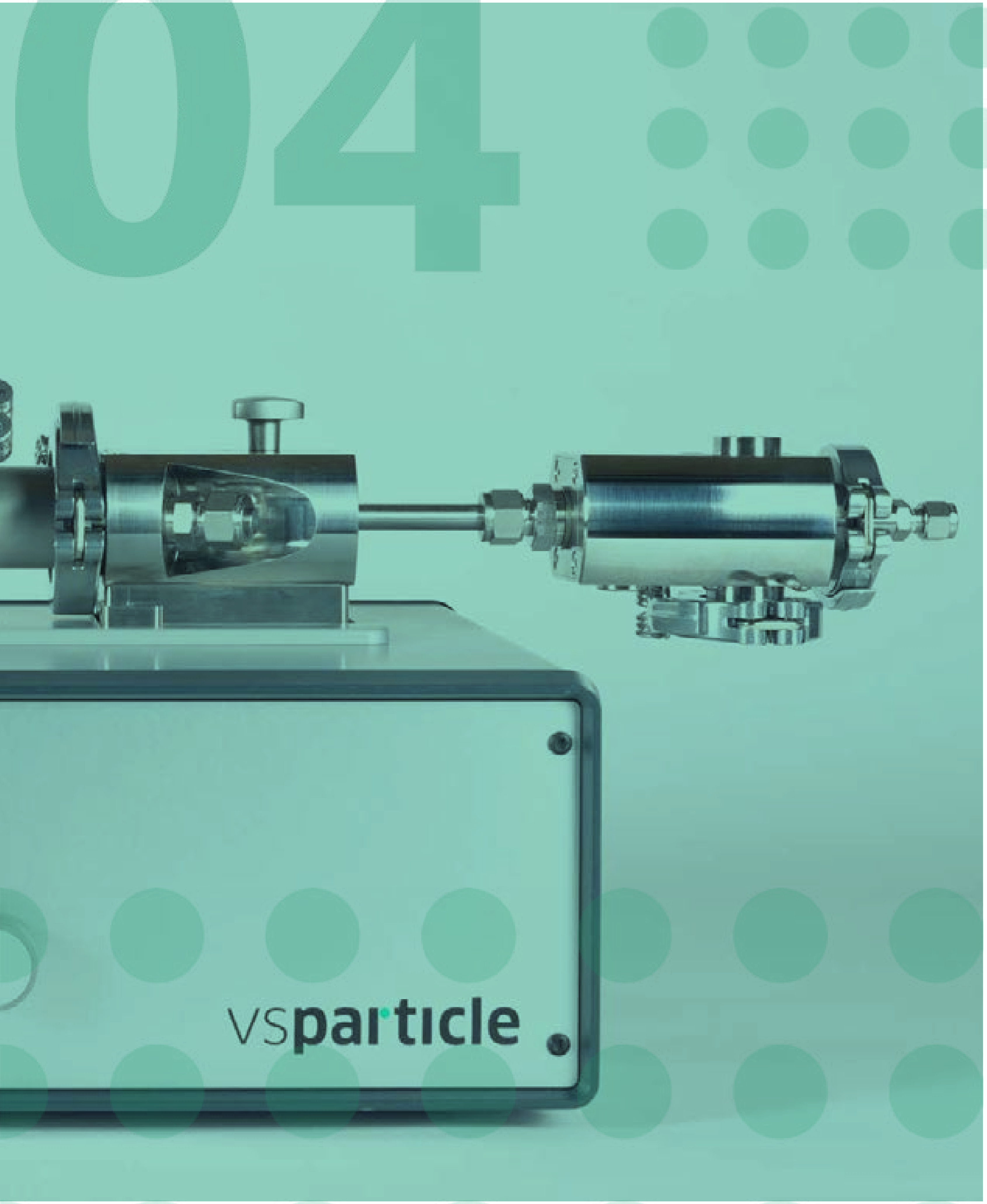


VSP-A3: Impaction Accessory

VSP-A3 Impaction Accessory has been designed for deposition of multiple layers of nanoparticles

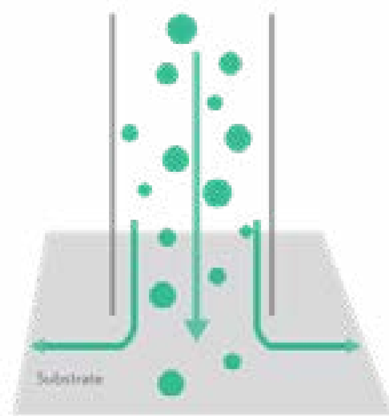
Deposition
- Adjustable spot size (up to 3 mm)
- Compatible with metal (e.g. Au) and metal oxides (e.g. Cu_xO)
- Operating conditions:
  - Room temperature -0.1 mbar

Applications
- Gas sensors
- Bio sensors
- Porous layers of nanomaterials

Substrates
- Si-wafer
- TEM grid

The flow of generated nanoparticles passes through a nozzle (Different nozzles with different sizes are provided with the accessory depending on the desired spot size), which creates acceleration before being impacted on the substrate, placed perpendicular to the flow of particles. When multiple layers of particles are deposited, **users can achieve growth of a stable nanoporous structure at ambient conditions.** (Metal oxide and noble metals for example)

This accessory has to be connected to an oil free Vacuum Pump, which can be provided by VSParticle on demand.



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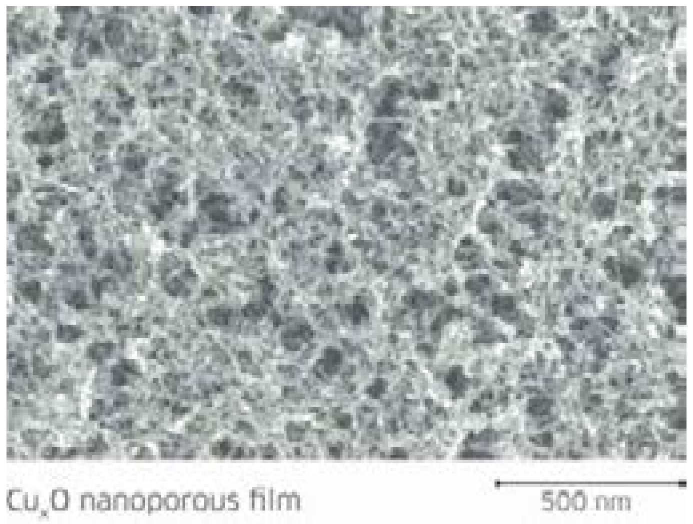
Examples of deposition of layers of nanoparticles Using the VSP-A3 Impaction Accessory

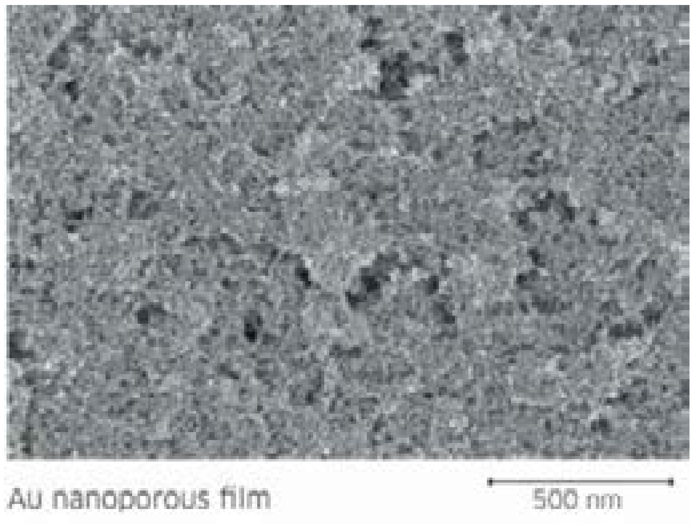
EXAMPLE 1

Deposition of porous layers of Cu_xO and Au

Set up 1
Electrode : Cu
Inert gas : Argon
Voltage : 1kV
Current : 4mA
Flowrate : 1SLM
Deposition time : 1min

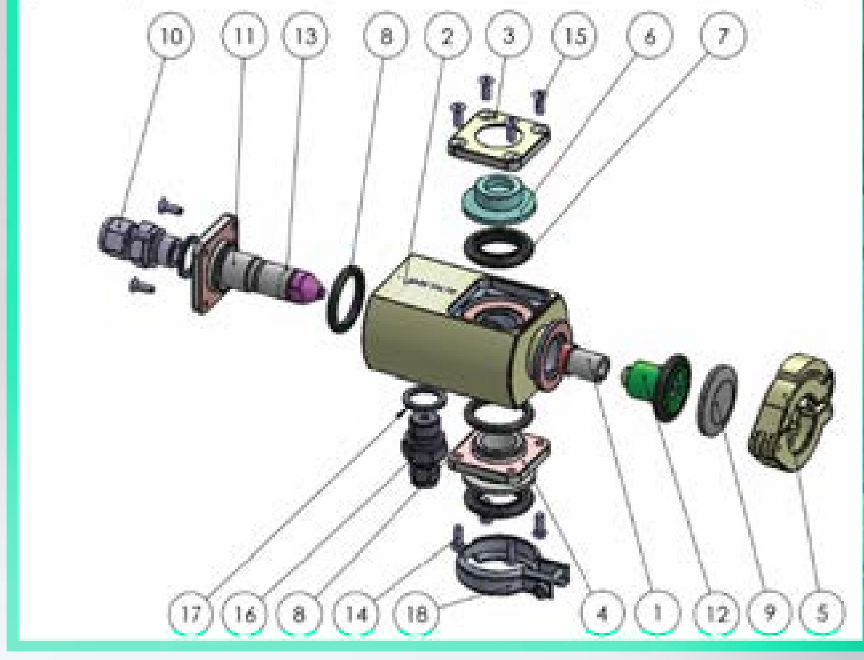
Set up 2
Electrode : Au
Inert gas : Argon
Voltage : 1kV
Current : 4mA
Flowrate : 1SLM
Deposition time : 1min





SEM picture of Cu_xO nanoporous film (upper) and Au nanoporous film (lower). It is possible to tune the deposition parameters such as spot size (0.1um-3mm), porosity, layer thickness (50nm to multiple microns)

ITEM NO.	PART NUMBER	QTY.
1	105.01-009 Sample holder assy	1
2	105.01-011 Chamber	1
3	105.01-012 Flange window	1
4	105.01-023 Outlet flange DN25KF	1
5	Quick hinged clamp DN2025KF_1306AL Demaco	1
6	Viewport 7056 Glass DN25KF Demaco VP-NW-25	1
7	Viton seal DN25KF Demaco 12244	2
8	Viton seal DN25KF Demaco 1284	2
9	Blank flange DN25KFDN20KF_14244 Demaco	1
10	Stainless Steel Swagelok Tube Fitting_SS-10M0-1-6RS	1
11	105.01-005 Inlet flange Lechler assy	1
12	105.01-008 Linear adjustment assy	1
13	O-ring 15x1.5 Viton	1
14	Hexagon socket button head cap screw M4x12	4
15	Hexagon socket flat head cap screw M4x12	8
16	Stainless Steel Swagelok Tube Fitting_SS-6M0-1-6RS	1
17	SS-6-RS-2V-SwagelokCompany-3D-09-24-2020	2
18	Stainless steel clamp, DN25KFDN20KF_1312_Demaco	1



05

VSP-P1 Nanoprinter

05

VSP-P1 product video

VSP-P1 Nanoprinter

Connected to one or two VSP-G1 Nanoparticle generator(s) as a nanomaterial source, the VSP-P1 Nanoprinter enables you to locally print inorganic nanostructured materials with unique properties (all semi conductive and conductive materials compatible with the VSP-G1).
The building blocks for the printed layer are gas-phase produced, sub-20 nm nanoparticles, free of surfactants or any other organic impurities. With the VSP-P1 NanoPrinter, automated printing of nano porous layers of different composition and/or layer thicknesses is possible.

Nanoprinter mechanism

Particle generation happens within the VSP-G1. Using the spark ablation method, nanoparticulate material is ablated from the electrodes and captured in a gas stream. This gas stream is then directed into the VSP-P1 Nanoprinter. This aerosol is redirected towards the nozzle of the device. From the nozzle, the aerosol flow impacts upon a substrate inside the print chamber (Rough vacuum chamber between 0.1 and 0.8 mbar) The pressure difference and the opening constraints of the nozzle accelerates the flow of nanoparticles, which allows adhesion of the material on your sample due to high kinetic energy. The mechanism is called supersonic impaction.

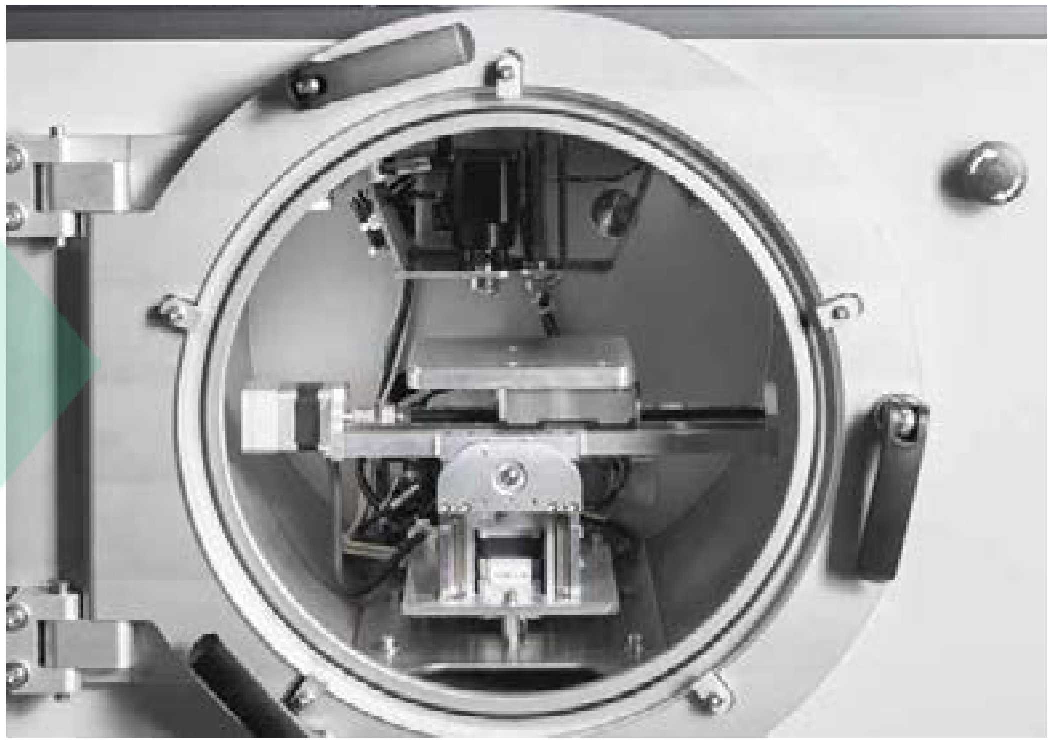
VSP-P1 Nanoprinter coupled with two VSP-G1

System overview and main components

The main components of the VSP-P1 are the print chamber with the print stage and printhead inside, the gas infrastructure and the control system. The VSP-G1 spark generator(s), that consist of a base unit and reactor chamber, is necessary to run the printer.

VSP-G1 Nanoparticle generator
The VSP-G1 creates the nanoparticle aerosol by repetitively evaporating a small amount of electrode material with electric discharges (sparks). While mounted on a VSP-P1 nanomaterial printer, the VSP-G1 can be controlled completely by the VSP-P1.

Print stage (Where your sample is placed)
The print stage consists of an XYZ stage mounted in the print chamber. This stage accounts for all the movement made during deposition, as the nozzle is fixed and does not move. The stage operates using a threaded system intermeshing stepper motors with axes. The stage can move in three dimensions and allows coordinated motion.



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Camera
The VSP-P1 is equipped with 2 camera's. One overview camera for quality control of the printed substrates (optical zoom 2x) and one precision camera for alignment of the substrate and print pattern (optical zoom 10x).

Nozzle
The VSP-P1 is delivered with three nozzle sizes. Smaller nozzles allow printing with a smaller spot size. Because of the different flow rate, the chamber pressure also depends on the nozzle.

Print chamber
The print chamber is a rough vacuum chamber (0.1 to 0.8 mbar) that is connected to a vacuum pump where the deposition of the nanomaterial takes place.

Vacuum Pump
The VSP-P1 uses a Leybold Ecodry 65 oil free vacuum pump to create the necessary low vacuum for deposition while avoiding contamination.

Automated deposition of nanoparticles

The VSP-P1 NanoPrinter can be controlled directly through the on-device touch-screen, as well as remotely through the hybrid control interface accessible from any device with an internet connection. By controlling the movements of the XYZ stage on which the sample lies, users can achieve automated deposition of any type of pattern of layer. All experimental parameters can be controlled via the User Interface using VSP Software.

Patterning

You can determine the desired printing pattern by running a script through the user interface. Both complex patterns and in-series production of more than one samples are possible using different or modified scripts.

Controlling layer width, thickness and porosity

Different layer thicknesses from sparse agglomerates to continuous layers up to a few microns thick are possible using the VSP-P1. The parameters that impact the layer thickness are:

- **Nozzle distance to substrate**
- **Power of ablation**
- **Printing speed**

Delivered equipment

Every standard VSP-P1 system includes the VSP-G1 Nanoparticle Generator and all the necessary components for the system's operation (e.g Bronkhorst mass flow controller, vacuum pump, 3 different nozzle sizes, Copper electrodes and the user interface to control the experimental parameters). The user is responsible for providing the gas supply and power (standard power connection). Installation and training at your laboratory are free of charge and included in the VSP P1 system package.

Workflow

The workflow of operating VSP-P1 is a simple and fast process. First, the electrodes of the selected material are loaded in the reactor chamber of the integrated VSP-G1. Next, the nozzle and substrate are placed inside the vacuum chamber. To start the experiment, power, flow and by-pass flow values are set. Then the appropriate patterning script is selected and the chamber is brought under vacuum. After that, the system is ready to start deposition, The whole preparation process before the experiment requires approximately 30 minutes. The required deposition time depends on the desired substrate coverage, the desired pattern and the ablation rate of the selected electrodes. Typical deposition times range from a few minutes or even seconds (e.g dots, lines,sparse layers) to a few hours (e.g full layers covering cm^2 range of area). After the deposition is complete, the system is flushed with the carrier gas for approximately 2 minutes. An automated purging cycle takes place to remove any remaining nanoparticles from the vacuum chamber. The whole process after the end of the experiment requires approximately 15 minutes.

Maintenance and cleaning

Our convenient design and workflow are accompanied by easy cleaning protocols. The reactor head of the VSP-G1 system can be cleaned by wiping the reactor chamber, electrode holders and electrodes with paper towels and pipe cleaners/cotton tips. We recommend using common lab solvents (e.g. water, ethanol, isopropanol, acetone) for the best results (See VSP-G1 Nanoparticle Generator section) Cleaning must be performed when changing the electrode materials. For best results, regular cleaning of the reactor head is advised. To avoid clogging, regular cleaning of the nozzle using common lab solvents and sonication is also recommended. Finally, the VSP-P1 system comes with a fully automated flushing protocol which ensures the safe opening of the chamber after the end of the experiment.

05

Customer support

After purchasing a VSP-P1, our team will stay in close collaboration with you. The system will be installed by VSPARTICLE engineers who will also provide the essential training to the users. After the successful installation and training our team will continue to provide technical support that may be required especially at the initial stages. of the project. We always try to maintain close collaboration with our customers in order to assist them in getting the most out of our technology. By offering expertise and by constantly listening to the needs of the customers, VSPARTICLE promotes innovation and encourages the concept of co-development.

Free installation
Free training
2 years warranty
5 years software update
Free inspection and maintenance after 1 year

05

Technical specifications

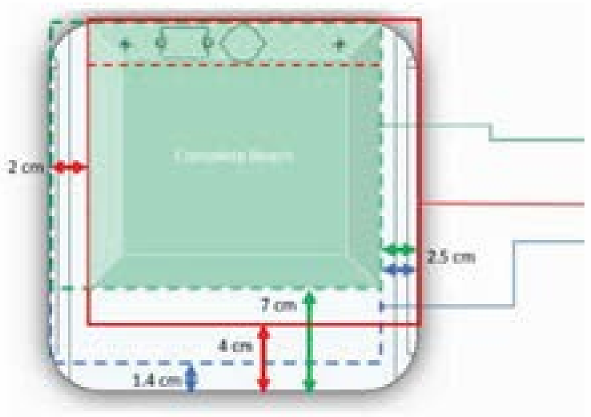
Technical specs

Gas inlet	6 mm tubes (with Serto connectors)
Gas exhaust	NW16KF or 10mm Swagelok
Dimensions of the apparatus	147 x 90 x 70 cm
Weight of the apparatus	Approx. 220 kg
Input voltage range	200 – 240 V AC a power plug based on your country of residence will be provided
Maximum power consumption	1.85 KW
Spatial requirements	Access to lab ventilation system Not necessary to be placed in a cleanroom

Operating window

Mass production rate order	0.01 – 10 mg/h
Primary Particle Size	1 – 20 nm (material dependent)
Operating Conditions	Room temperature and rough vacuum (0.2 mbar – 1 mbar)
Gas supported	Ar or N_2 (recommended purity 5.0) Combination with reactive gases such as O_2 or H_2 is possible after consultation with VSPARTICLE
Material	Any conductive or semiconductive material
Substrate size	Max. 20 x 20 cm
Max printable area	15 x 17 cm (only with nozzle)
Layer thickness	From sparse agglomerates (100 nm) up to a few microns
Layer morphology	Nano porous
Spot size	100 μm up to 1 cm (material dependent)
Position Accuracy	10 μm

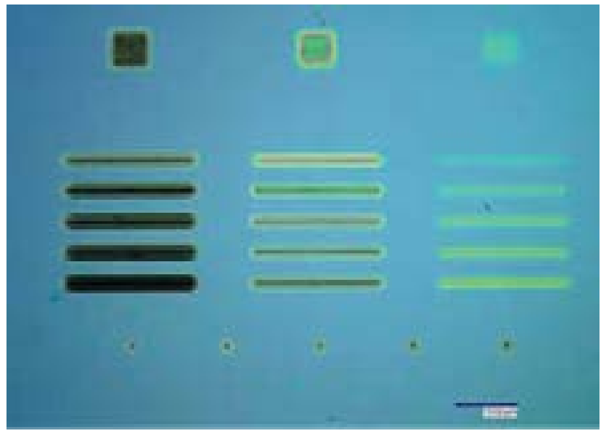
Nozzle type	*Bore size*	*Flow rate (Ar)*	*Chamber pressure (Ar)*
004	0.1 mm	< 0.08 slpm	0.1 - 0.2 mbar
054	0.2 mm	0.2 – 0.3 slpm	0.3 - 0.4 mbar
125	0.35 mm	0.8 – 0.9 slpm	0.7 – 0.8 mbar



VSP-P1 Nanomaterial deposition examples

EXAMPLE 1

Tungsten

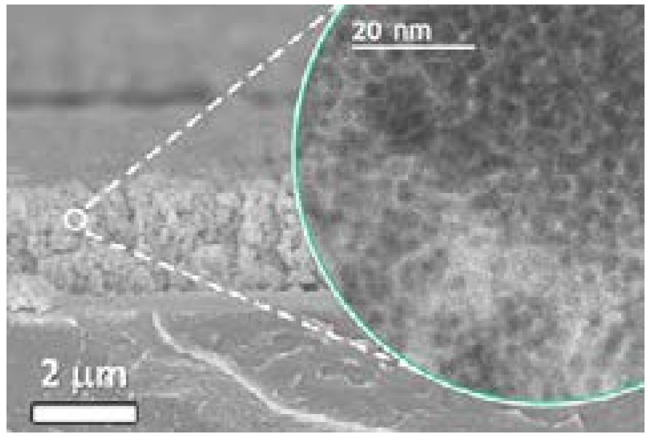


Print W on Si/SiO_2 with different geometries

For the line, we need to show on the side, from top to bottom : 2 passes. 4 passes. 6 passes, 8 passes, 10 passes (for the 3 columns of lines)

EXAMPLE 2

Iridium Oxide coating on Nafion membrane



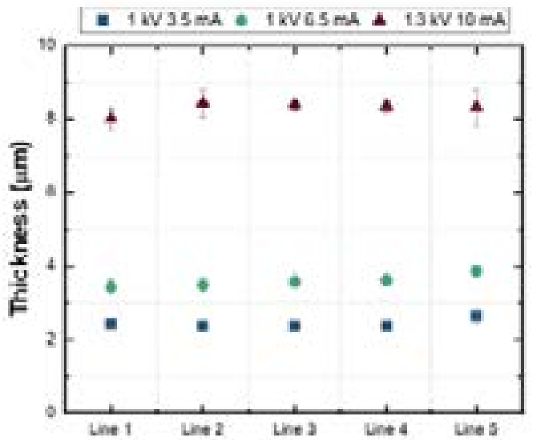
Source: Dutch institute for Fundamental Energy Research (DIFFER)

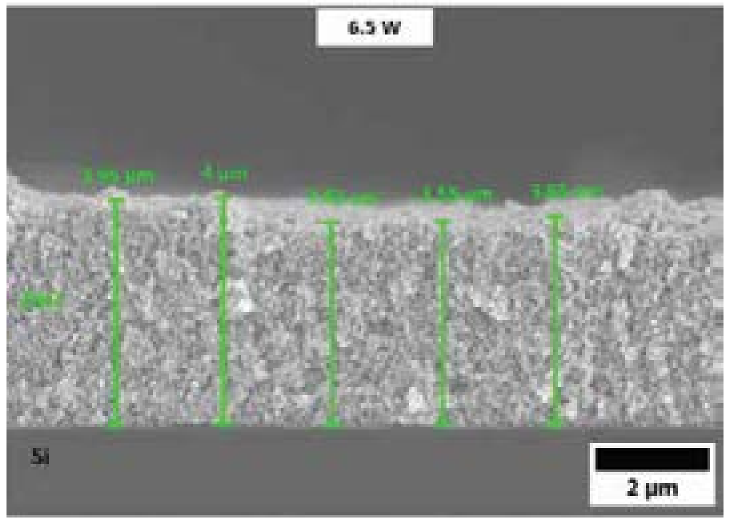
Cross section of IrOx coating on Nafion membrane, applied with the VSP-P1 nanoprinter (TEM) Zoomed-in section shows nanoporous IrOx material with high surface to volume ratio (SEM).

EXAMPLE 3

with Zinc Oxide

Printing properties of ZnO lines
Lines reproducibility



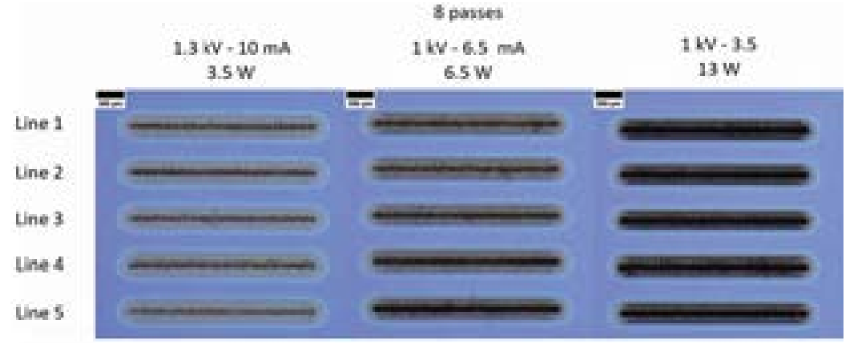


EXAMPLE 3

with Zinc Oxide

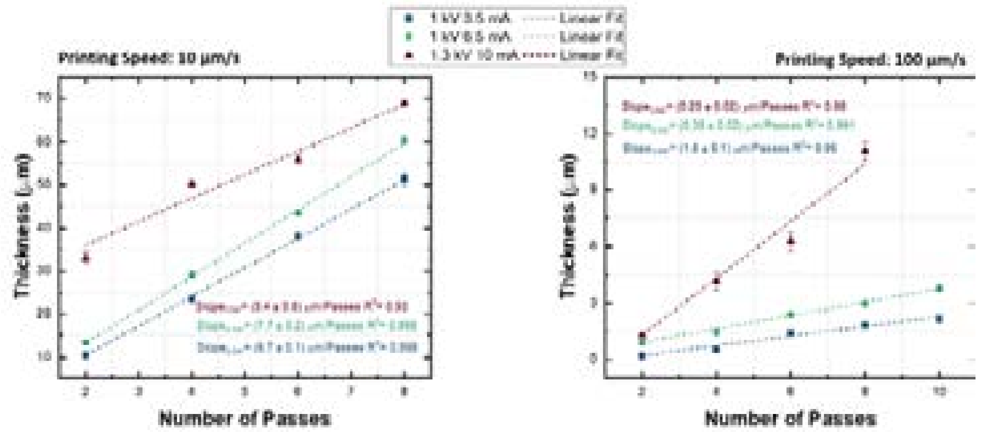
Printing properties of ZnO lines

- 5 lines at different powers were printed.
- 8 passes were printed in each line.
- The samples were cleaved at the center of the lines.
- SEM cross-section measurement were performed to measure the line thickness.

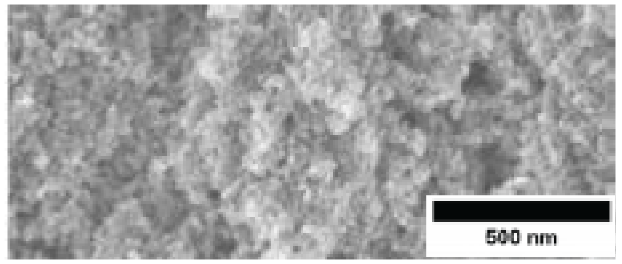


Printing properties of ZnO lines

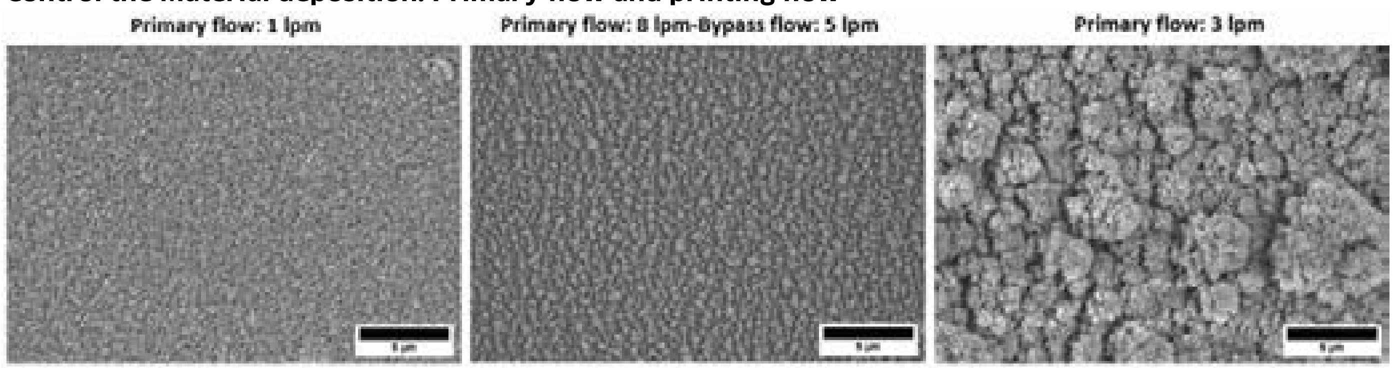
Control the thickness:
Number of passes, Sparking power and Printing speed.



SEM cross-section showing the nanoparticle distribution across the nanoporous layer



Control the Material deposition: Primary flow and printing flow



- The material distribution can be tuned adjusting the flow at the G1 (primary flow) and the flow reaching the nozzle printer.
- The primary flow also plays a major role on the nanoparticle size.
- Both the primary flow and the flow reaching the nozzle are critical on the porosity tunning of the nanoporous layer.

Substrates
(max 15x15cm)

Gas sensors

- Si/SiO_2-based
- Silicon nitrides (SiN_x)
- Alumina (Al_2O_3)

Others

- vQuartz

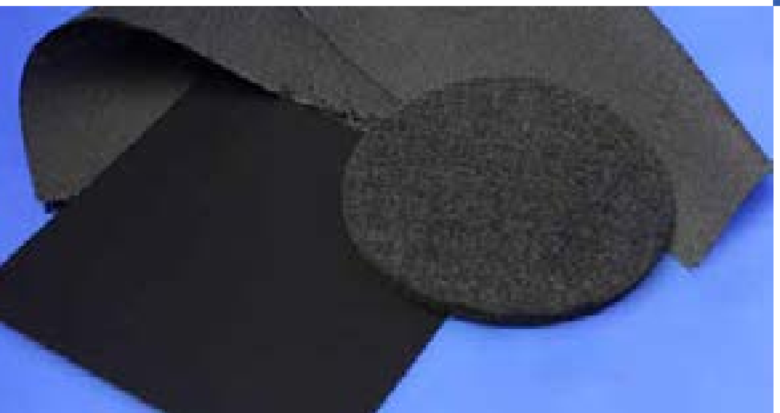
Electrocatalysis

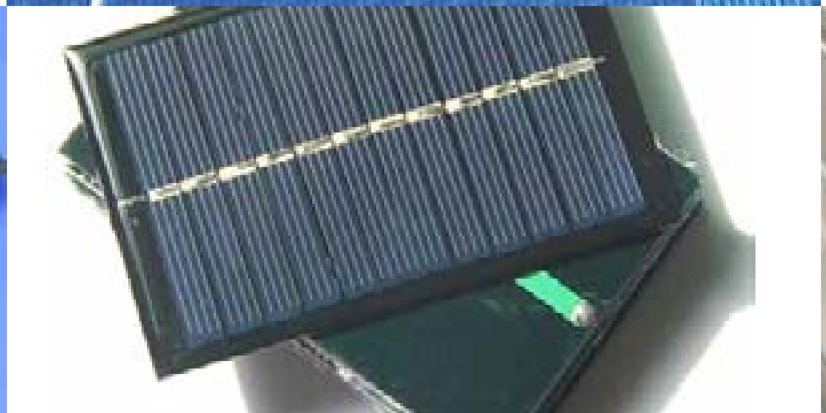
- PTLs (often made of Titanium granules compressed or Titanium fibres pressed or Ni mesh and Ni foam like structures – almost like an Al sponge but pressed to a few hundred microns)
- Transparent CCMs: Nafion, Sustanion, Piperion (+ potentially other names with -ion in it)
- GDLs (almost always made of Carbon and Graphite).

- CO_2 electrolysis: PTFE, PEEK and PET, PP type of filter like papers (some reactions like hydrophobicity thus we may apply conductive + catalytic films….)
- Batteries: Cu and Al foils (as thin as a kitchen Al foil)
- Solid oxide catalysis: ZrO_2 ceramics
- Supercapacitors / capacitors: Metal foils (Al or Cu), PE (mylar) & PP films, Tantalum pellets.
- Thermoelectrics: Alumina, SiNi films, SS and Cu foils
- Solar cells: Si wafers, Glass, Flexible substrates (PET, ultra slim SS)

Others

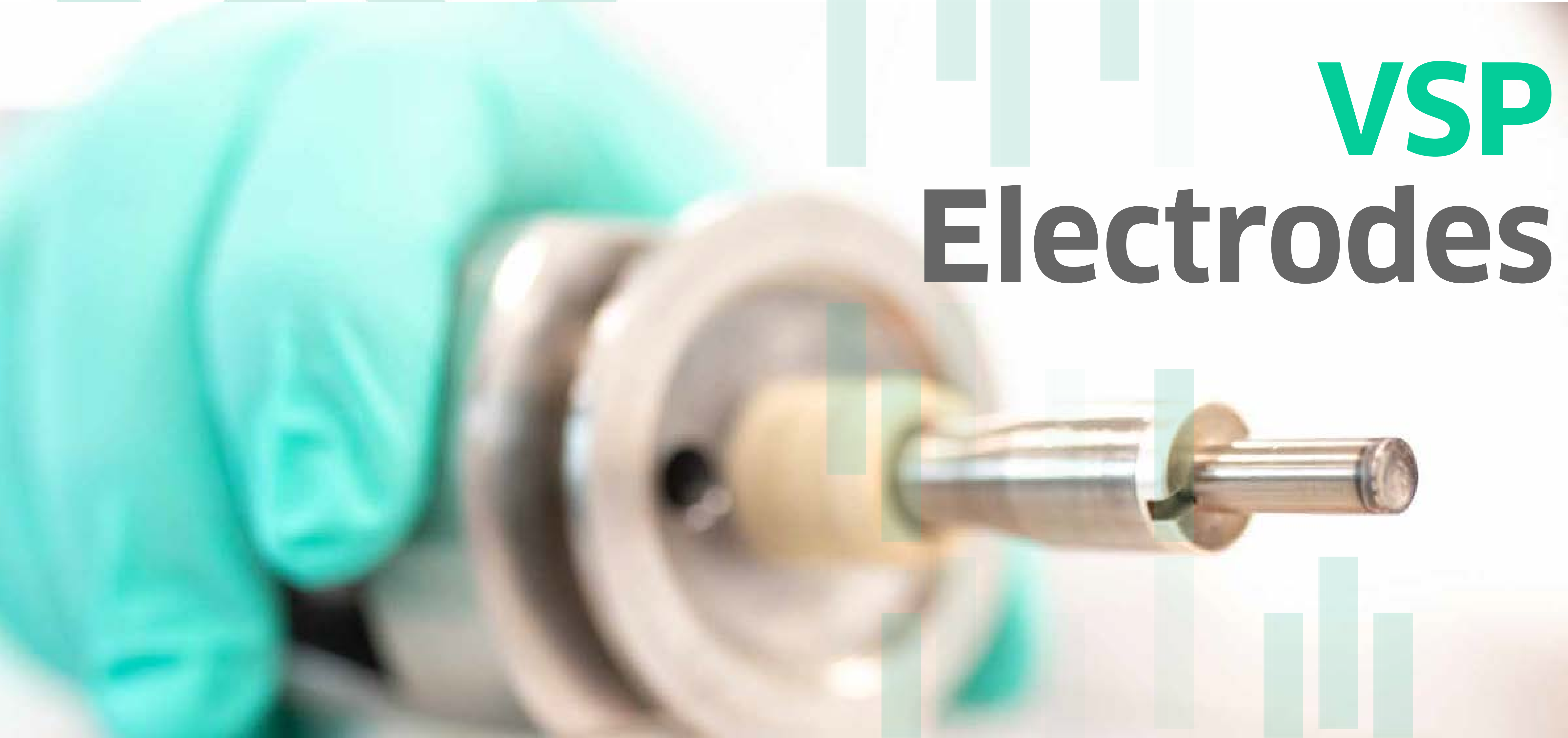
- Fundamental lab research for water electrolysis: Silicon wafer, 100 nm thin SiC film, a few layer thick Graphene sheets, Conductive Oxide coated Glass Slides (FTO, ITO), Mirror polished Glassy Carbon (which is very popular…)

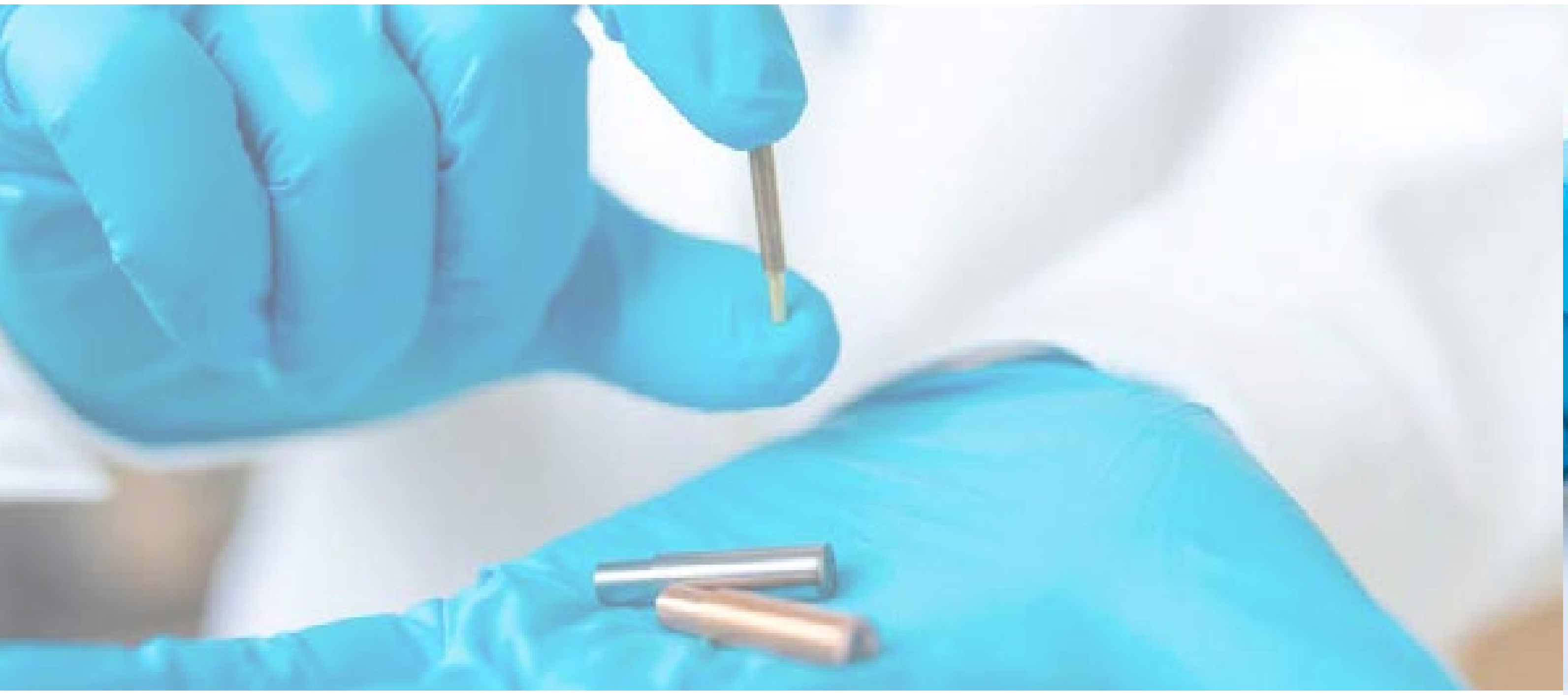




06

VSP Electrodes





VSP Electrodes

VSParticle technology is compatible with **more than 30 materials**. All semi conductive and conductive, their combinations and alloys can indeed be used with the VSP-G1 Nanoparticle generator and the deposition devices (VSP-A Series and VSP-P1 Nanoprinter).

Plug and Play system

The easy **plug & play system** means switching from one material to the next can be done in a matter of minutes. High-level engineering empowers the user to experiment with different electrode types and logging of electrode history. VSPARTICLE electrodes are available in **5 different configurations** for different materials and modes of operation. The number indicates the diameter of the functional surface of the electrode (3,6 or 9), the letter indicates either solid (S) or hollow (H).

Different options are possible for ordering electrodes :

Option 1

Order your electrodes directly to VSParticle and receive them within 4 weeks.

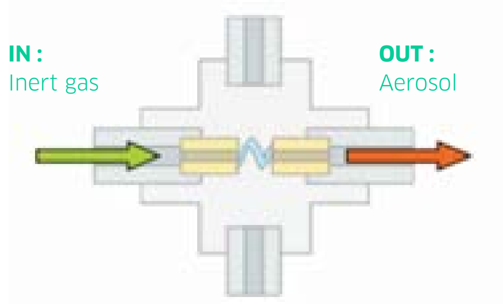
Option 2

Order your electrodes to a local supplier.

Option 3

Manufacture your own electrodes and VSParticle can provide you with the design plan.

Configuration



Cleaning procedure

Switching materials is fast and easy and only requires a 10 min cleaning procedure of the reactor chamber of the VSP-G1 Nanoparticle generator to avoid contamination :

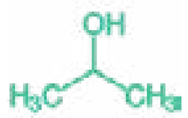
1 **Disassemble reactor in a fume hood**

(On a wet tissue to catch falling particles)

2 **Clean every part with H_2O**

- Small metal nanoparticles may be pyrophoric or catalytically active. Water passivates them.
- Strong oxidizing metals (e.g. La, Ce...) may react with water. Wipe with a dry cloth instead.

3



Clean every part with 2-propanol (IPA)

For more information see our Health and Safety Brochure.

At VSPARTICLE, our mission is to share innovation, drive progress, and shape a sustainable future together. Through collaboration and our cutting-edge technology, we aim to unlock a century of material innovation, paving the way towards a decarbonized society. Our aspiration is to leave a lasting legacy in the history of inorganic materials, marking a significant shift in progress for generations to come.

As high-school student Aaike van Vugt was already thinking about the new energy system if society needs to stop using Fossil Fuels.

During his time at Delft University of Technology he realized the scale and speed of innovation needed in the space of advanced materials to be able to move away from fossil fuels.

During his final year at the University Aaike co-founded VSPARTICLE with a clear goal in mind. Unlocking a century of material innovation in the next decade.

VSPARTICLE started with a unique technology developed at the TU Delft but is currently combining it with most of the exponential technologies of this time (e.g. robotics, AI, Big Data). Aaike has been recognised by Forbes in 2019 for his contribution in the material space.

AAIKE VAN VUGT

CEO & co-founder of VSPARTICLE

Global Network

DISTRIBUTORS	CUSTOMERS
7	45+
	CITIES 70+

- NORTH AMERICA
- SOUTH AMERICA
- AFRICA
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