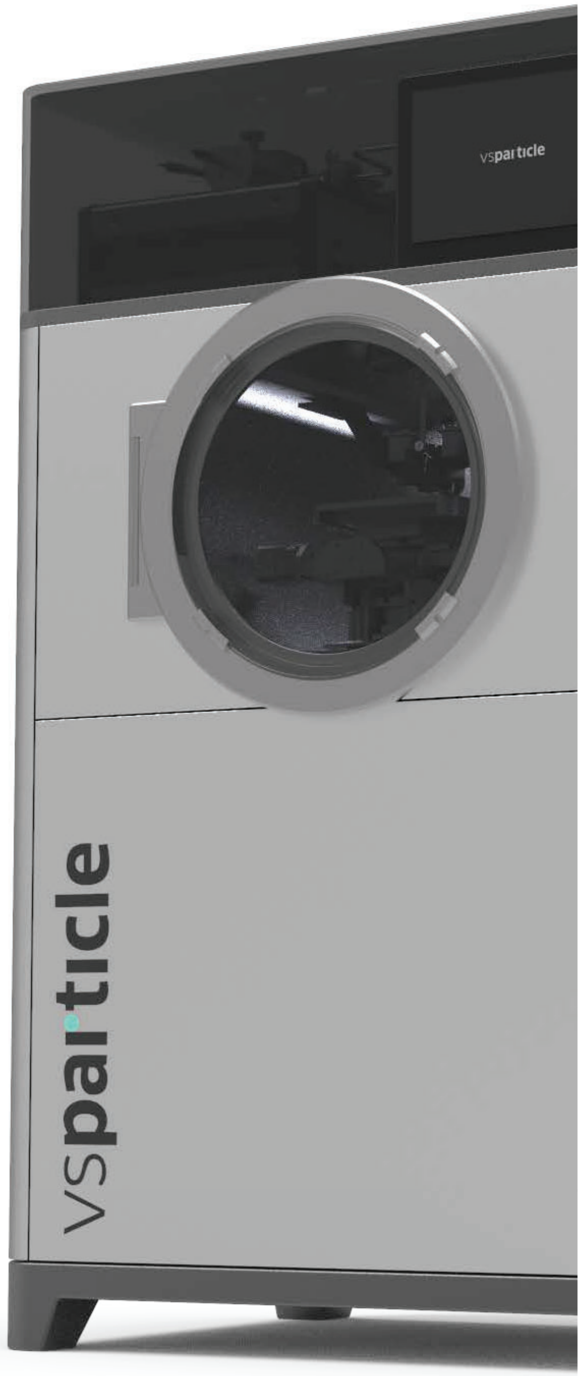


VSP-P1 NanoPrinter

The ultimate R&D platform for material development

vsparticle

Contents

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

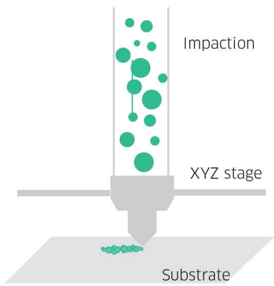
VSP-P1 NanoPrinter

Easy and controlled printing of nanostructured layers

Introduction

The approach of additive manufacturing can greatly simplify the production of nanoporous thin films with a high surface-to-volume ratio. The applications of such films are numerous and include among others applications within electrocatalysis, chemical, optical or biological sensing as well as the fabrication of batteries and microelectronics.

The VSP-P1 NanoPrinter (VSP-P1) enables you to locally print inorganic nanostructured materials with unique properties. The building blocks for the printed layer are gas-phase produced, sub-20 nm nanoparticles, free of surfactants or any other organic impurities. The whole process of nanoparticle production and printing is completely automated and thus there is no need to directly handle nanoparticles.



VSP-G1
Possibility of integrating two G1's in your VSP-P1 setup

Touchscreen
Fully control your experiments through the touch screen or remotely from another device.

Print chamber
Place your substrate on the 20x20 cm printing stage

VSP-P1 NanoPrinter

VSP-P1 NanoPrinter (VSP-P1)

This is possible due to the integration of the VSP-G1 Nanoparticle Generator (VSP-G1) - the nanoparticle production source - inside the VSP-P1. The technology which is used for the nanoparticle production is called spark ablation and it takes place under ambient temperature and pressure conditions.

After nanoparticles are produced in the aerosol stream, they are accelerated through a nozzle using a rough vacuum and deposited via impaction on any type of substrate. The driving force for the deposition is the pressure difference between the deposition chamber and the VSP-G1 system (upstream of the nozzle). Printing of specific patterns is possible through XYZ-stage control, a microscope camera module and an intuitive user interface that allows control of the experimental parameter and patterning in an automated way.

Core technology

Producing the desired nanoparticles becomes as easy as pushing a button

Every VSP-P1 NanoPrinter comes with an integrated VSP-G1 Nanoparticle Generator (VSP-G1) which is the nanoparticle production source. In case more complex structures or material combinations are required, there is also the option to include a second VSP-G1 system in the VSP-P1 setup. VSP-G1 is a user-friendly, table-top product that allows the user to produce nanoparticles of the desired material in a controlled way.

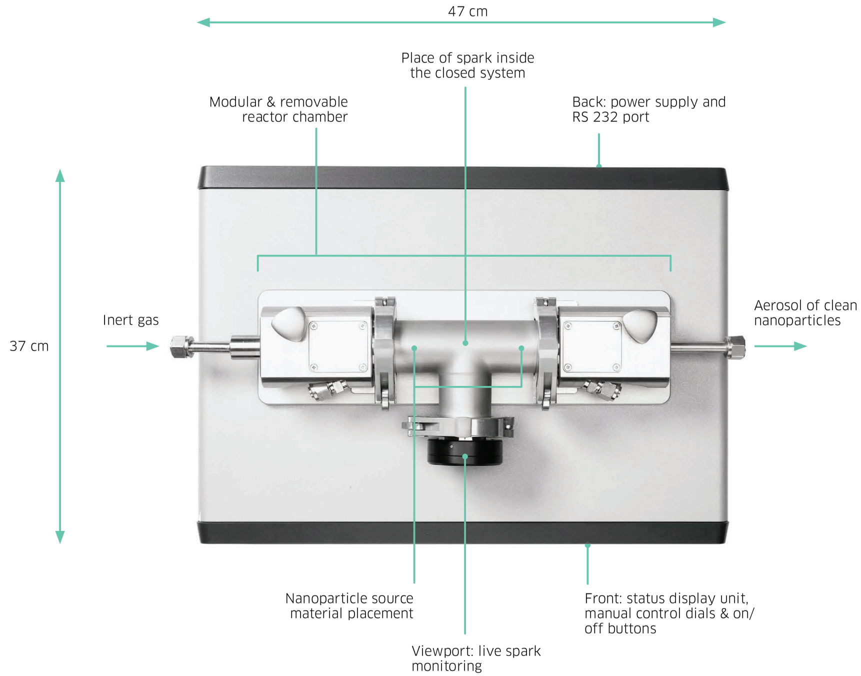
The production of nanoparticles takes place in the gas-phase and is based on a physical process, namely spark ablation. The nanoparticle production process is reproducible, occurs at ambient temperature and pressure, and requires only a pair of (semi)conductive electrodes as the source for pure, surfactant-free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

"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."

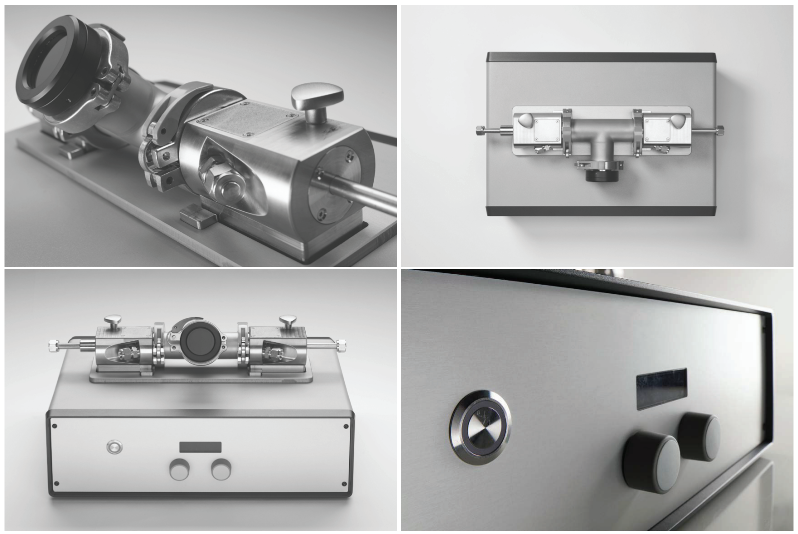
Weber group - Institute of Particle Technology, TU Clausthal

Direct deposition from aerosol stream to the desired substrate

The collection of nanoparticles produced using the VSP-G1 is readily achieved using the VSP-P1 NanoPrinter. If you want to discuss more about which of our current setup 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.



VSP-G1 Nanoparticle Generator (VSP-G1)



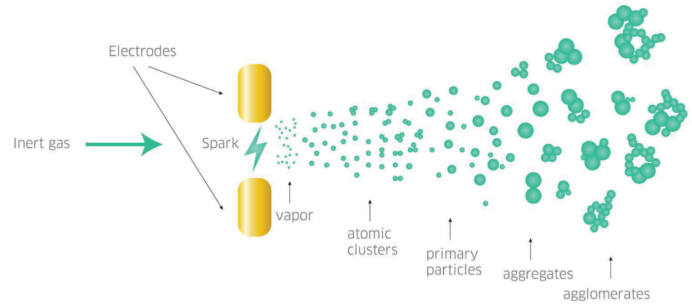
VSP-G1 Nanoparticle Generator (VSP-G1)

Core technology
Spark ablation – Nanoparticle Synthesis

Nanoparticle synthesis in the gas phase

The nanoparticle production in the VSP-P1 takes place inside the incorporated VSP-G1 Nanoparticle Generator (VSP-G1). The VSP-G1 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 which include the VSP-P1. The VSP-P1 NanoPrinter is currently the only deposition accessory that allows patterning and deposition in larger substrates.

Process Control Parameters

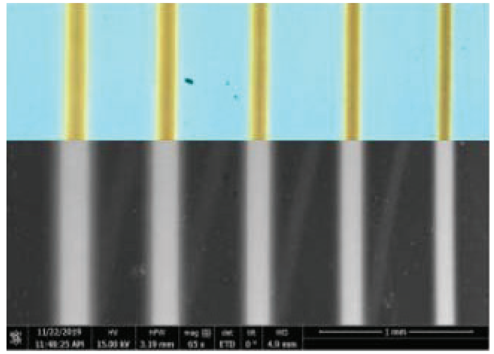
Controlling nanoparticle primary size

The achievable primary nanoparticle sizes from which the layer will consist of, are within the range of 1–20 nm. By adjusting the flow rate of the carrier gas (1–5 L/min for Ar), the voltage (up to 1.3 kV) and/or the current (up to 10 mA), the user is able to vary the average particle 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.

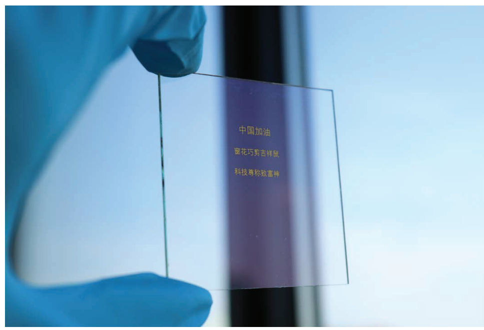
Similarly, lower flow rates will increase the residence time of the ablated material inside the reactor, giving the clusters/
particles more time to agglomerate into larger particles. All the parameters can easily be controlled with the VSP-C1 controller and the integrated software that comes with every VSP-P1 system. Primary particle size can affect both the impaction efficiency as well as the structure of the deposited layer.

Controlling layer thickness

Different layer thicknesses from sparse agglomerates to continuous layers up to a few microns thick are possible using the VSP-P1. There are three parameters that significantly affect the layer thickness. The first one is the nozzle-to-substrate distance and the second one is the power. Using higher power values will lead to higher material output and thus to thicker layers. The third parameter is the printing speed. Higher speed will lead to sparse, thinner layers whereas slower speed will result in a more continuous layer. If the desired pattern is more complex, then there is also the option of varying the stitching distance in order to adjust the density of the produced layer.



Lines of different width are achieved using the same printing speed and varying nozzle distance. Results are courtesy of H.J. van Ginkel from TU Delft



Printing of very complex patterns is possible through the user interface

Patterning

The user 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.

Material Versatility

Electrodes (source of nanoparticle production) of different materials

Endless possibilities for new material combinations

The spark ablation technology 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-P1 system. 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 (in a single VSP-P1 system) with different electrode materials in sequence or in parallel. This material versatility allows the production of bimetallic nanoparticle, metal oxides and diverse combinations of nanoalloys even from materials that are immiscible in their bulk form.

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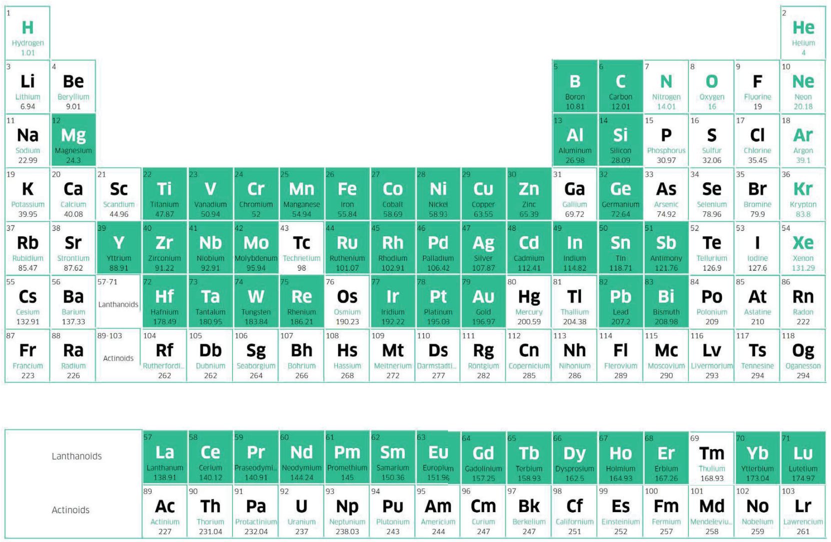
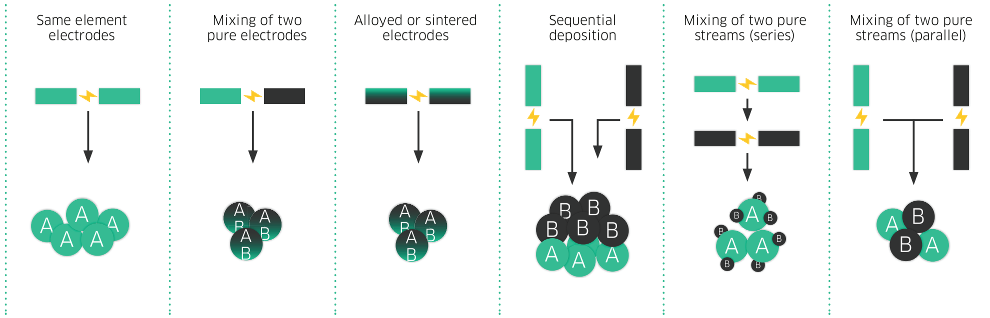


All green elements are compatible with VSP-G1

: 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.

Material High-Throughput Screening

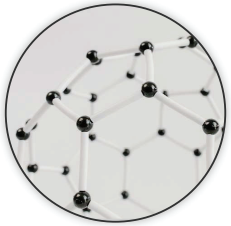
Accelerate your material development

Accelerating the Design-Build-Test-Learn cycle for new materials with the VSP-P1

The need for more advanced materials with optimum properties for specific applications is constantly growing. To obtain such materials, a vast array of potential material combinations will need to be screened. Considering the increased possibilities for material combinations that the nanoscale offers, the number of potential compositions increases even more. Therefore, high-throughput techniques for both synthesis and characterization of nanostructured materials are of high importance.

With the VSP-P1 NanoPrinter, semi-automated printing of nano porous layers of different composition and/or layer thicknesses is possible. You can read multiple examples that illustrate the value of the VSP-P1 for high-throughput screening within the fields of electrocatalysis, gas sensors and SERS at the Applications section of this brochure. Following a high-throughput screening approach can reduce the time required for new materials development from months to just a few days.

Electrocatalysis



Gas sensors

Surface Enhanced Raman Spectroscopy

""With the use of the VSP-P1 NanoPrinter I have been able to implement all my ideas when it comes to decorating biosensors with nanoparticles. I really like that I can choose between a lot of different parameters and get exactly the size and quantity of nanoparticles that I desire but also combine different materials."*

Merlin Palmar - Master's in biomedical engineering at Delft University of Technology, Bioelectronics department

"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

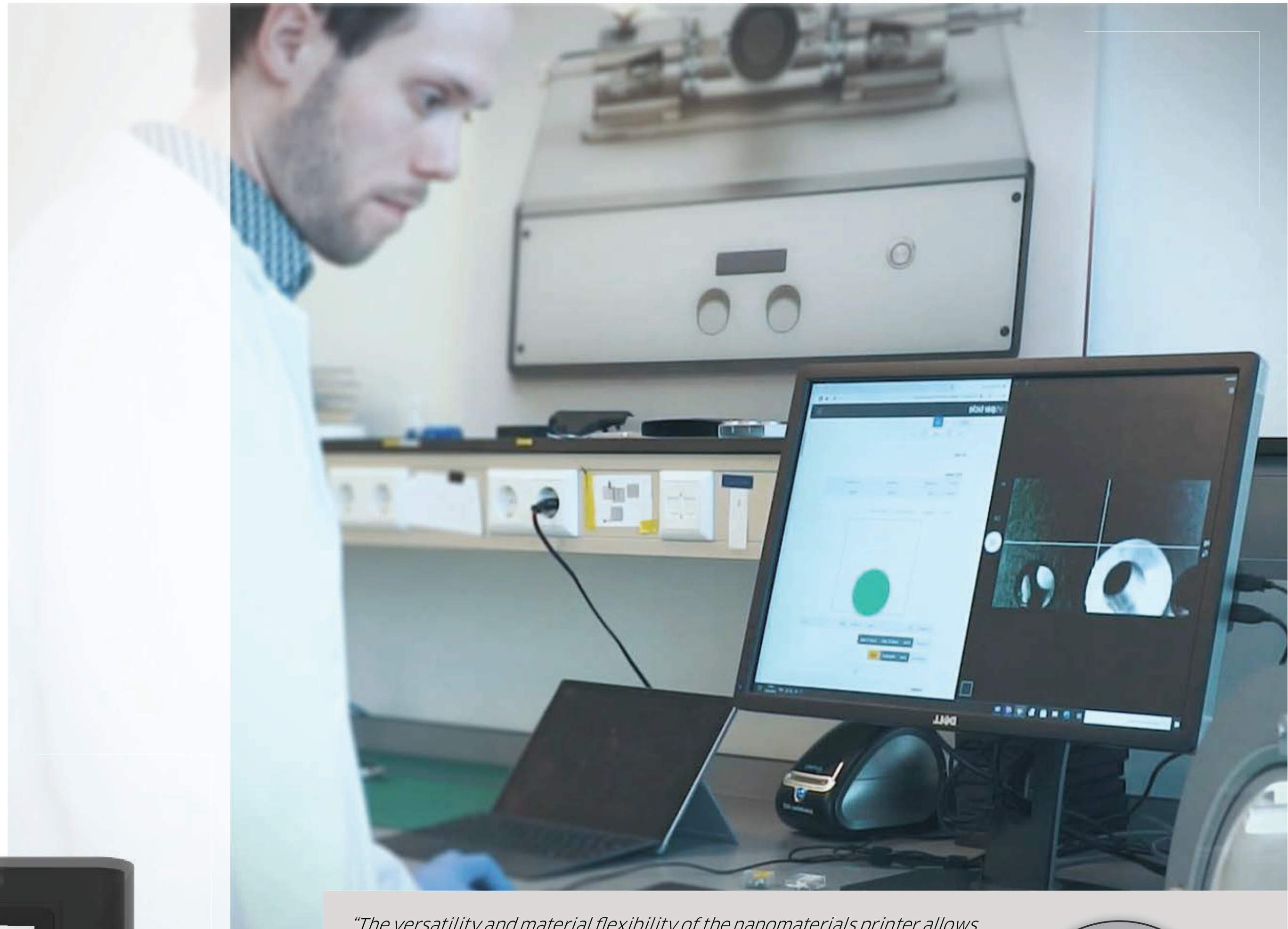
User Interface
Control software

Automated experimentation

Every VSP-P1 system is equipped with an integrated controller and software that allow the user to control all the process parameters. This controller system (VSP-C1) enables the user to control the experimental parameters in two ways. The first way is through the use of the screen that is integrated on the VSP-P1 and the second way is remotely through the use of a computer. The simple and intuitive user interface in both cases allows the adjustment of process parameters as well as the visualisation and logging of data.

Advantages

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



"The versatility and material flexibility of the nanomaterials printer allows us to print a wide range of nanomaterials on finished microelectronics devices. We are now able to decorate gas sensors and deposit on thin membranes and other fragile substrates without putting too much effort in finding a good recipe. Because it's so simple to test something new, we can think of new experiments often and perform them the next day"

PhD Candidate Joost van Ginkel - Department of Microelectronics TUDelft

Getting started
VSP-P1

Preparation

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. 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.

"..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."

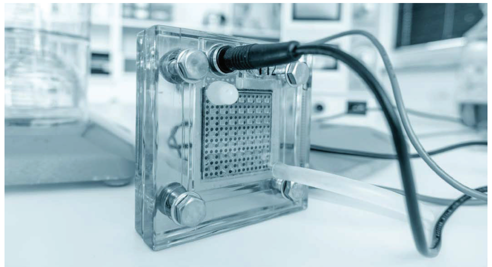
PhD candidate Iris ten Have - Bert Weckhuysen Group, Utrecht

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.

Application Example - Electrocatalysis

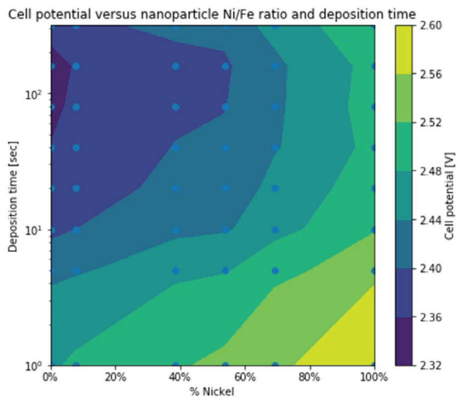
Many of today's best performing electrocatalysts are expensive noble metal-based materials. In order to make electrochemical processes scalable and commercially viable, the noble metal contents of such electrocatalysts must be significantly lowered or replaced by cheaper base-metal alternatives.



High-throughput screening of Ni/Fe electrocatalysts

Using two VSP-G1 Nanoparticle Generator systems connected to the VSP-P1 NanoPrinter, the possibilities in terms of material composition expand even more. A great example to illustrate this, is the collaboration with Avantium for the high-throughput screening of different electrocatalysts.

An array of 8 x 8 dots was printed (with the VSP-P1) directly on the high-throughput setup, using a different ratio of Fe/Ni and different layer thickness for each dot. Then the performance of each of those 64 catalysts for the OER was tested simultaneously significantly reducing the required screening time.



Contour plot showing cell potential variation with nickel/iron generator power ratio and deposition time.

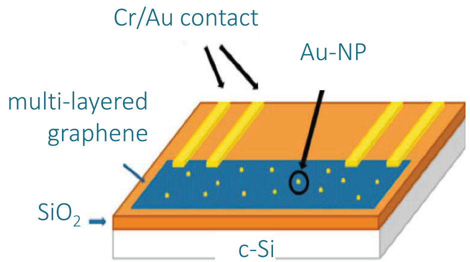
Becker, R., Weber, K., Pfeiffer, T.V., Kranendonk, J.V. and Schouten, K.J., 2020. A Scalable High-Throughput Deposition and Screening Setup Relevant to Industrial Electrocatalysis. Catalysts, 10(10), p.1165.

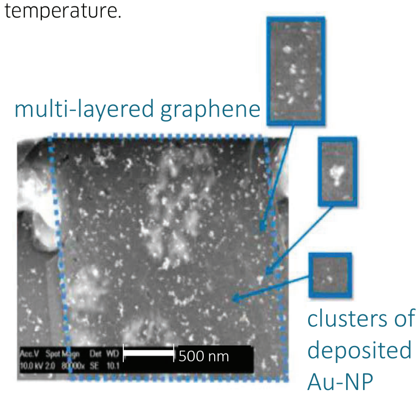
Application Example - Gas Sensors

Functionalisation of multi-layer graphene sensors

Deposition of a sparse, nanoporous layer is also possible with the VSP-P1. In a recently published work, Au nanoparticles were deposited on a multi-layered graphene (MLG) sensor. The Au nanoparticles homogeneously covered 7 % of the device area.

This functionalisation effectively reversed the gas-sensing behavior of the MLG leading to a saturating MLG-based sensor operating at room temperature.



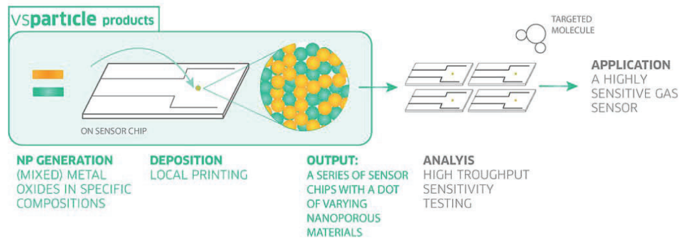


Functionilisation of multi-layered graphene sensors with Au nanoparticles using the VSP-P1. L. Morelli, F. Ricciardella, M. Koole, S. Persijn, S. Vollebregt, Proceedings 2020, 56, 1

Metal Oxide (MOx) Gas Sensors

Current metal oxide (Mox) gas sensors are able to detect a wide range of gases, however selectivity to the individual molecular level is poor. To improve selectivity, extensive screening of different material combinations is essential.

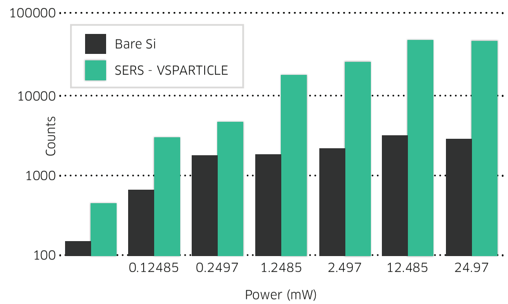
With the VSP-P1 it is possible to locally print mixed metal oxide layers in specific compositions. The whole process is automated and reproducible, allowing the fast screening of many different compositions.



Application Example - SERS development

SERS optimization

Surface-Enhanced Raman Spectroscopy (SERS) is a highly-sensitive detection technique which can contribute greatly to the development of chemical and biological sensing applications in many different fields. Due to Localized Surface Plasmon Resonance (LSPR), SERS substrates provide orders of magnitude electromagnetic enhancement in Raman signal, overcoming the traditional problem of Raman Spectroscopy – its inherent weakness. This is achieved by using nanostructured surfaces, typically with metals such as gold, silver or copper. Size, shape and distribution of particles of the nanostructure surface can significantly affect the SERS substrate's enhancement effect.

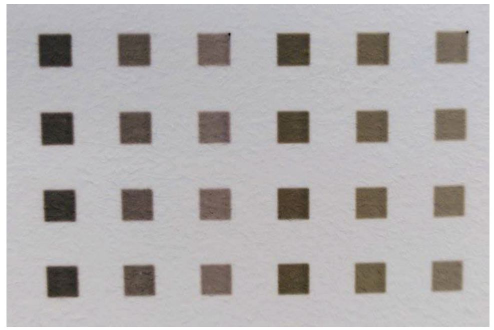


Difference between bare Si substrate and Au SERS substrates prepared by VSPARTICLE's VSP-P1 Nanoprinter. The results are a courtesy of the group of prof. Ventsislav K Valev from University of Bath.

The sensing capabilities of the ligand-free printed nanoparticles and the nano-porous morphology of the printed layers from the VSP-P1 have proven to be very effective for developing SERS substrates for different analytes. Additionally, because of the easy and automated sample preparation, further optimization of the substrates is achieved within months. Due to the nature of the technology, there is no need to change the nanoparticle synthesis and deposition process when a different substrate is used.

At the same time, deposition of varying patterns of nanostructured porous structures with different layer thicknesses is possible.

This approach has also recently been applied in literature for the development of Cu SERS substrates that significantly enhanced the Raman signal of Rhodamine B, after low-temperature thermal treatment (S. Aghajani, 2020). The same authors have also selectively deposited 3D printed gold nanostructured layers and show that it is possible to tune their optical behaviour and optimize response for specific bio-analytes through a low temperature thermal treatment (S. Aghajani, 2021)



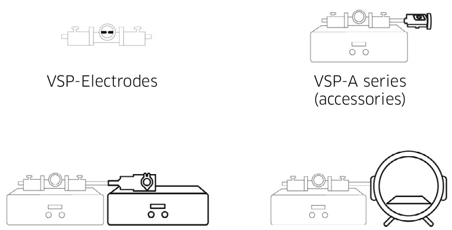
Multiple samples with different particle size and layer thickness printed as one batch

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.

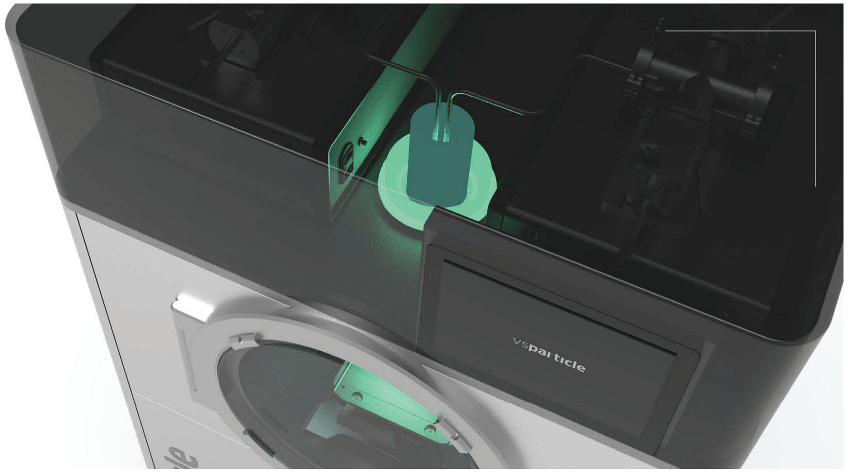
Modular system

Easily connect the VSP-G1 to VSP deposition modules



"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."

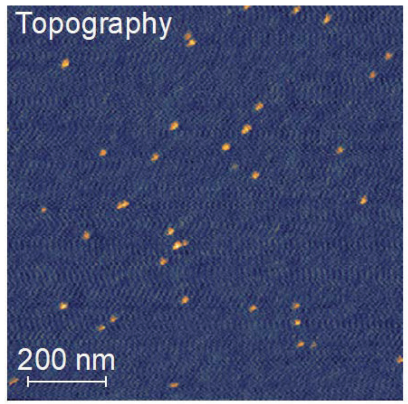
Dr. Charlotte Vogt - Assistant professor at Technion - Israel Institute of Technology



Printing Size-Selected Nanoparticles
Example modularity VSP-G1 + S1 + P1

VSPARTICLE's modular approach regarding the product portfolio drastically increases even more the available setup options for the researchers. An elegant example on how well VSPARTICLE's technology can be combined to prepare highly specialized materials is showcased through the printing of size-selected nanparticles. Herein, the VSP-G1 Nanoparticle Generator, the VSP-S1 Size Selector and the VSP-P1 NanoPrinter are all connected in series to precisely print 3 nm Pt particles.

Nanoparticles were generated in the VSP-G1, size-selected by the VSP-S1 and then impacted on the desired substrate (Si coupon) using the VSP-P1. This setup is ideal for applications for which a sparse layer consisting of a very specific nanoparticle size is important.



Courtesy of the Inorganic Chemistry and Catalysis Group, Utrecht University

Technical specs

Gas inlet/outlet	6 mm tubes (with Swagelok connectors)
Dimensions of the apparatus	147 x 90 x 70 cm
Weight of the apparatus	Approx. 220 kg
Power	120 – 240 V AC *a power plug based on your country of residence will be provided*
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/h (material dependent)
Primary Particle Size	1 – 20 nm
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 15 cm
Layer thickness	From sparse agglomerates (100 nm) up to a few microns
Layer morphology	Nano porous
Spot size	100 µm up to 1 cm
Position Accuracy	10 µm

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, Cu electrodes and the user interface to control the experimental parameters). The user is responsible for providing the gas supply and power (standard power connection).

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

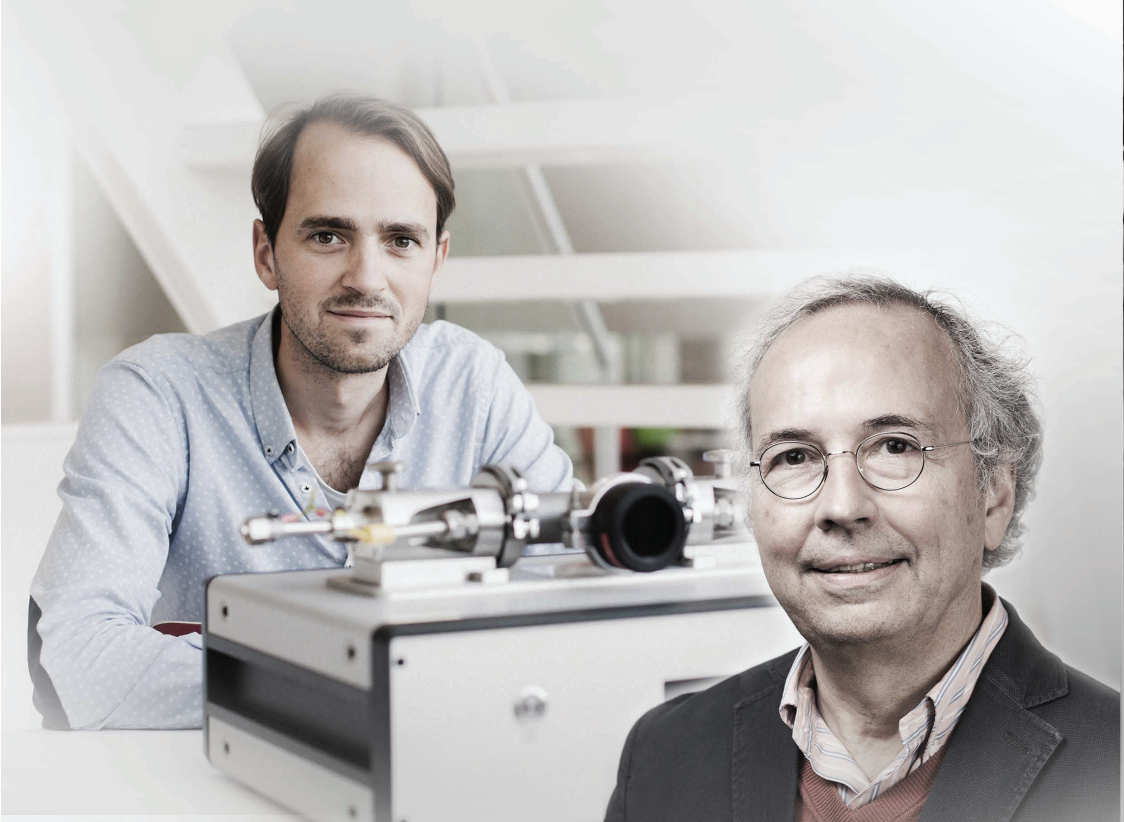
Spark Ablation: Building Blocks for Nanotechnology

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

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

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