HIGHTECH IN PVD-COATING

COMPANY

PVT designs and manufactures vacuum coating systems and develops coating processes for the most complex thin film applications in the field of cutting tools, dies and molds, wear parts and components as well as other products made of steel, metal, carbide, ceramic and glass.

PVT – PEOPLE WITH VISION AND TECHNOLOGY

Ion and plasma-assisted vacuum coating technologies to deposit metallurgical coatings and thin films to enhance the product's life and properties – these technologies are the exclusive subjects PVT Plasma und Vakuum Technik GmbH is dealing with and working on in a globally leading position since the company started in 1985.

In its headquarter in Bensheim, close to Frankfurt, Germany, PVT is developing such technologies for enhancing products, protecting the environment and saving valuable resources for more than 35 years.
In 2002 PVT moved to its own facilities, where on 15.000m² the office building with two workshops host the various departments to develop coatings and coating processes, to provide coating service and to design and manufacture industrial coating systems "Made in Germany".

In order to maintain and expand their own leading position in the global competition our strong worldwide customer base relies on the expertise we accumulated over more than 35 years of operation:

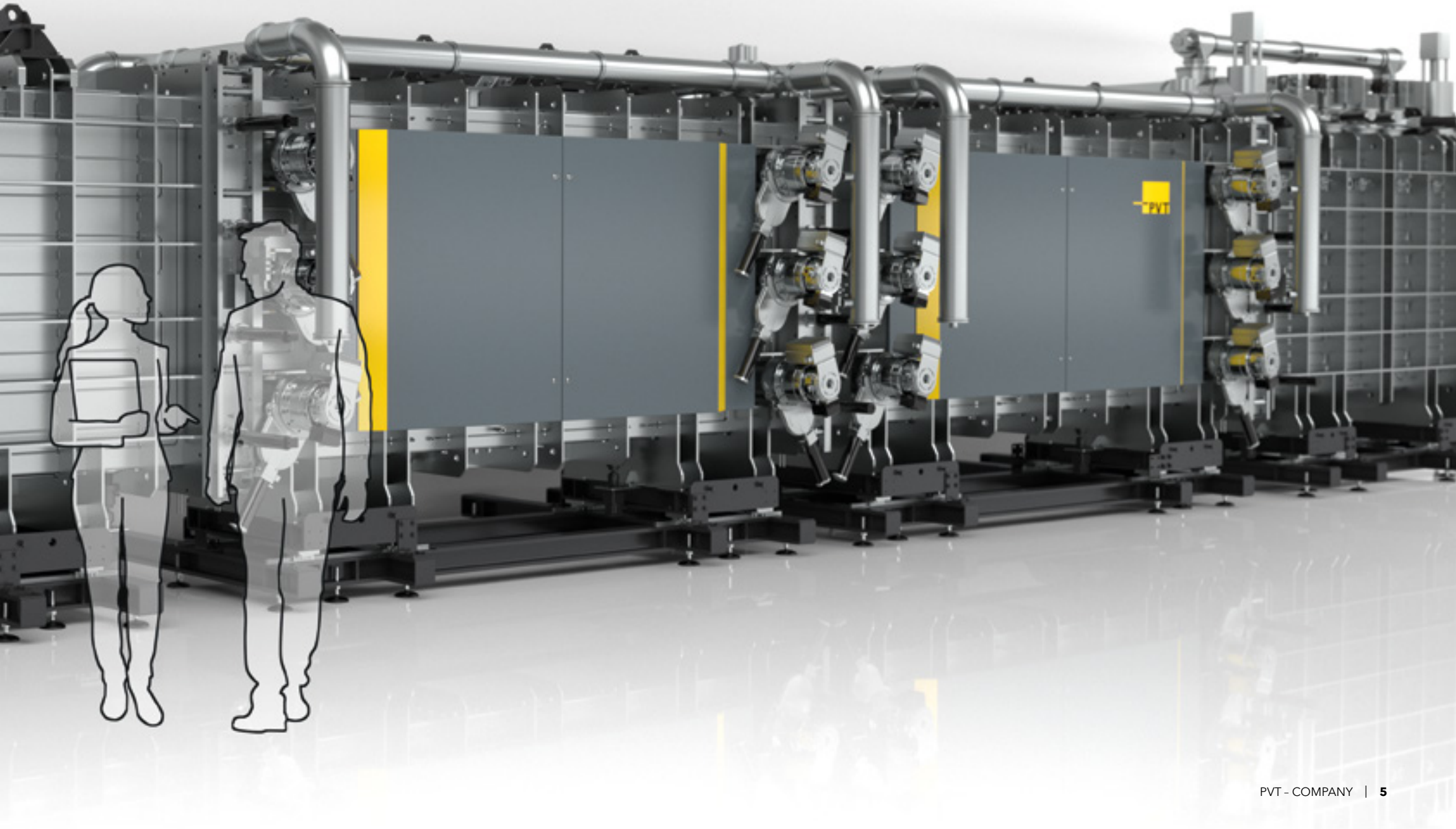
- PVT's equipment design and manufacturing
- PVT's coating service
- PVT's ongoing development programs concerning coatings, coating processes and coating systems

SCOPE OF BUSINESS

- **Development of ion- and plasma-assisted vacuum coating processes** (PVD – Physical vapor deposition and PECVD – Plasma-enhanced Chemical Vapor Deposition)
- **Development of high performance coatings** in the range of 5 nm up to 100 µm thickness
- **Design and manufacture of vacuum coating equipment** (Batch-type and continuous in-line-systems)
- **Configuration, supply and installation of complete turn-key coating centers**

HISTORY

1985	Registration of PVT – Plasma und Vakuum Technik GmbH
1991	Change of ownership
1998	First activities in China
2002	Headquarter moved to own facility in Bensheim
2004	1st Coating center established in China (Harbin)
2006	Representative Office established in Beijing, China
2010	Several more coating centers established in China
2015	R&D center established in Harbin
2020	Registration of PVT India
2021	PVT Shanghai established


PVT

PVD
(PHYSICAL VAPOR DEPOSITION)

- **PVD describes a variety of vacuum deposition methods to deposit thin films and coatings.** These methods are characterized by processes in which material is transferred from the solid phase into the vapor phase and then back to thin solid films.

- **Arc evaporation** or **magnetron sputtering** are used to transfer the coating material from the solid phase into the vapor phase for deposition. **PECVD** is a third method where gases are fed into the vacuum chamber from which the coatings are synthesized.

- The complete PVD-process starts with loading the pre-cleaned (by aqueous solutions) parts (substrates) into the pre-heated vacuum chamber. Thereafter a fully automatic process runs through the following steps:

- Pump down
- Pre-heating to the required coating temperature
- Sputter-etching, aka ion-etching or sputter-cleaning
- Metall-ion-etching
- Deposition
- Cool down
- Venting and unloading

PVT is considered as one of the early pioneers of hard coatings by PVD-processes, in particular using the arc evaporation with large area planar evaporators.

INNOVATIVE COATING TECHNOLOGIES

PVT Plasma und Vakuum Technik GmbH has its focus on the development of ion and plasma-assisted vacuum coating technologies: PVD (Physical Vapor Deposition), by Arc-Evaporation and Magnetron-Sputtering as well as PECVD (Plasma Enhanced Chemical Vapor Deposition).

However, should customer applications require, also combinations of different processes might be used, such as Electroplating combined with PVD, Electrostatic Powder Coating combined with PVD, Plasma-nitriding combined with PVD and Arc evaporation combined with Magnetron sputtering.

Such process combinations will only be applied as long as the advantages for the customers prevail concerning the lifetime and the longevity of the coated parts, taking into account the total cost.

ARC-EVAPORATION

During arc evaporation the magnetically guided arcs are run in a controlled manner over the coating material (target), being e.g. Ti, AlTi, AlCr, TiSi etc. The arcs cause a nearly 100% ionization of the evaporated material.

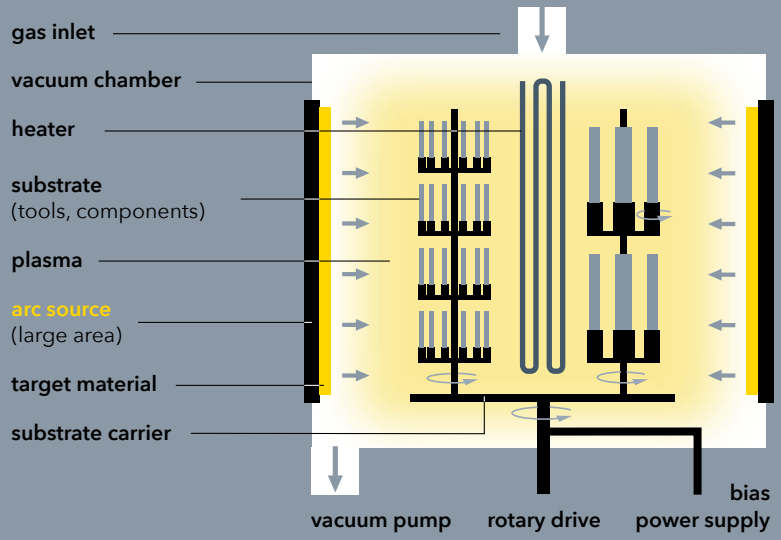
The ionized metal vapor recombines with the reactive gases, such as 2 Ti + N_2 (nitrogen) > 2 TiN (Titanium-nitride). Due to the high intrinsic energies and the extremely good throwing power of the arc-evaporation process very well adherent coatings can be uniformly deposited, even on complex-shaped, 3-dimensional substrates (parts and tools), while single, double and triple rotation of the parts support the uniform deposition.

Depending on the application different process are used, such as arc evaporation with constant dc power or pulsed dc power at different power levels whereas the substrates are electrically biased either with constant dc, pulsed dc or bipolar pulsed dc bias-power.

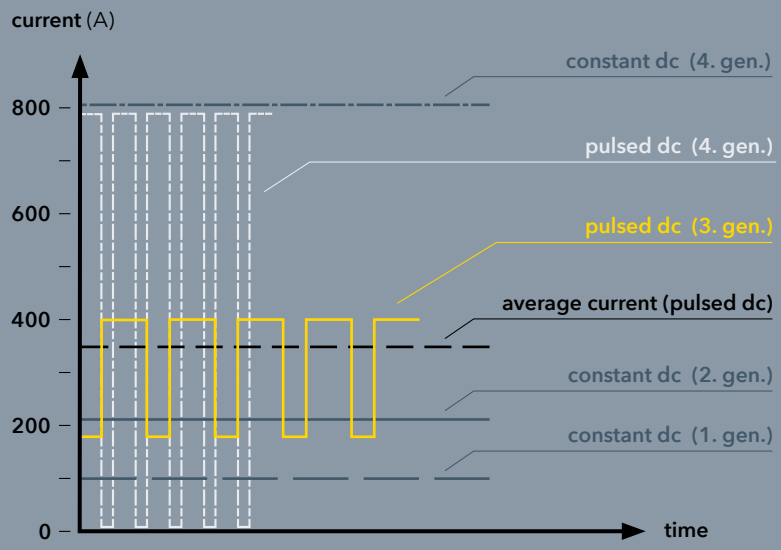
The processes are designed that the arcs are uniformly run over the targets to control and minimize the number and size of the micro-droplets and to maximize the target utilization.

PDA (Plasma Diffused Arc) and HiParc (High Power Pulsed Arc) are two processes developed by PVT to maximize the target utilization, to minimize the size of the micro-droplets and to increase productivity.

ARC-EVAPORATION – BASIC PRINCIPLE



CURRENT OVER TIME – CONSTANT DC / PULSED DC



THE ARC: STANDARD, PDA, HiParc, PDA+HiParc

Standard arc – 1st generation

PDA III – much higher plasma density; more diffused

HiParc – Pulsed arc; much higher power level

HiParc + PDA III – very high power level; 3rd generation

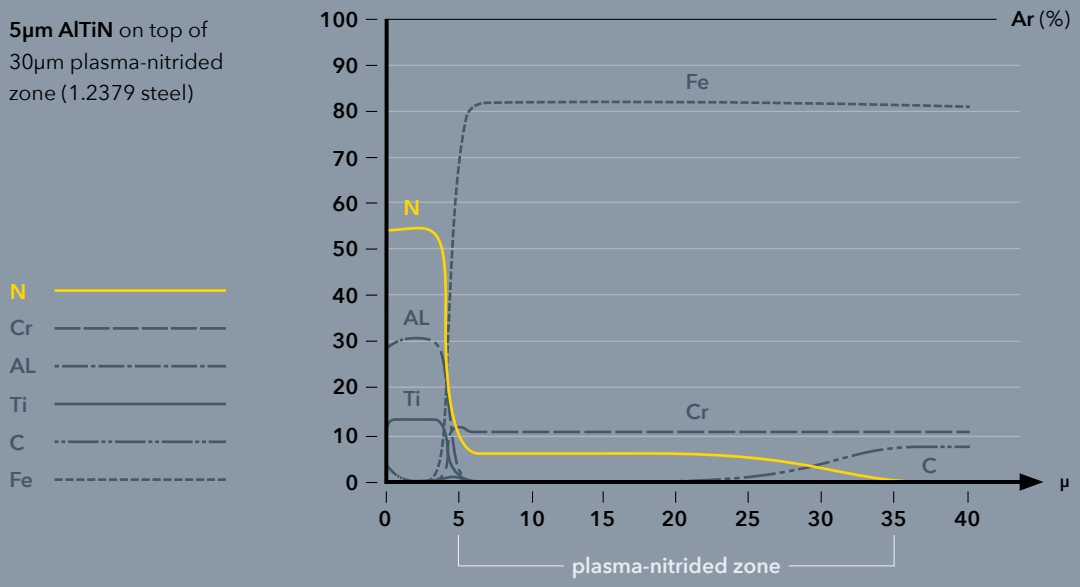
HYBRID PP

Hybrid PP is a combination of processes which fortifies the surfaces in an excellent cost/performance ratio to bear the highest loads and to decrease wear and tear.

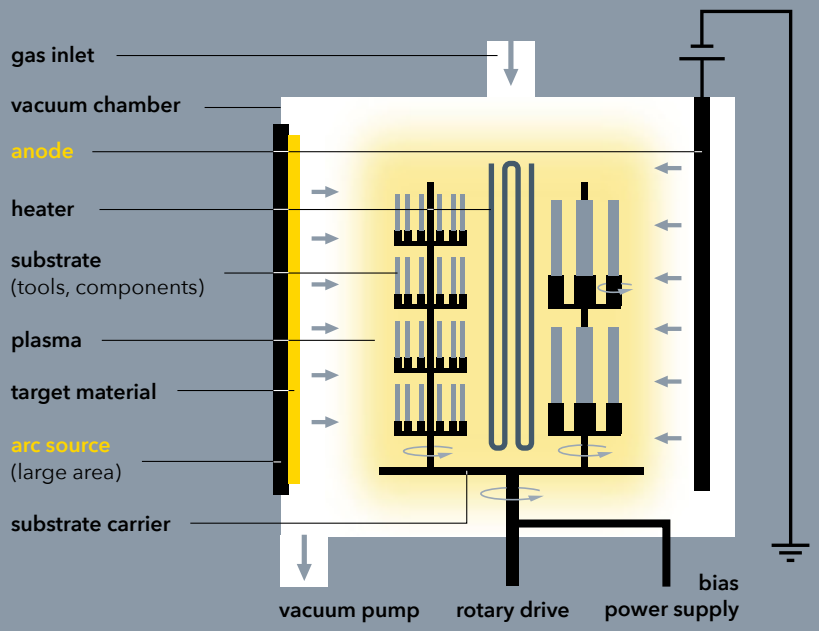
Pulse-Plasma-Nitriding and PVD-coating by ARC-evaporation – the combination of these processes create hard nitrided sub-surface regions and on top hard coatings. The combination of these processes extend the lifetime of components and dies & molds significantly.
For the Pulse-Plasma-Nitriding a separate anode is used to enhance the plasma, thus creating highly energetic Nitrogen ions which penetrate and migrate into the surface up to 100 µm deep.

GD-OES PROFILE – HYBRID PP

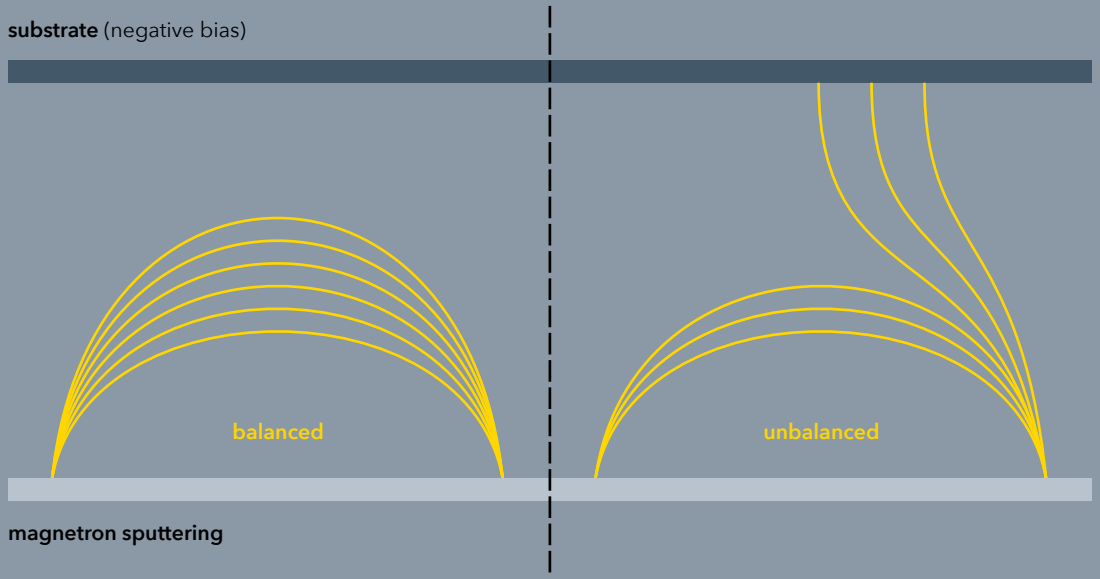
5µm AlTiN on top of 30µm plasma-nitrided zone (1.2379 steel)



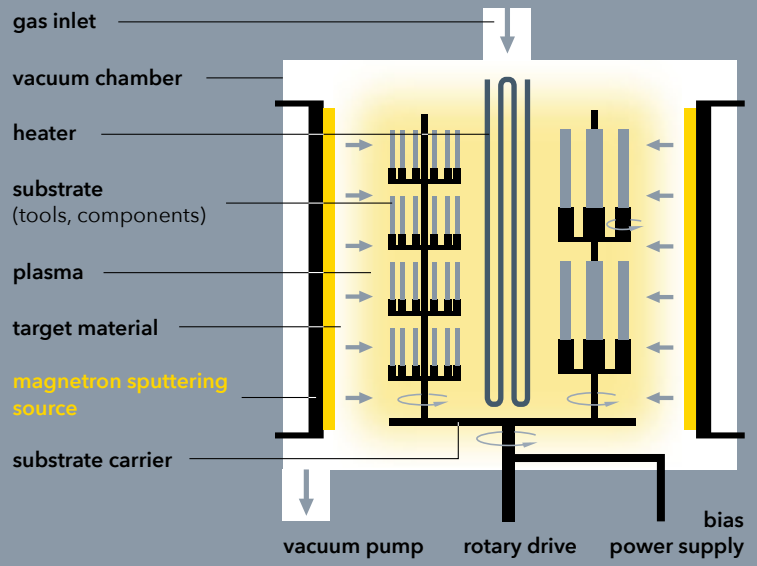
HYBRID PP – BASIC PRINCIPLE



FIELD LINES OF BALANCED AND UN-BALANCED MAGNETRONS



MAGNETRON SPUTTERING – BASIC PRINCIPLE



MAGNETRON SPUTTERING

Magnetron sputtering (aka sputtering) is a process where the transfer of the coating material into the vapor phase is done by an argon ion bombardment of the coating material and releasing this way coating atoms from the target, partially ionizing them and depositing, while recombining with the reactive gases, such as e.g. nitrogen, to the desired coating material on the electrically biased substrates.

Due to the low intrinsic energy of this process and the limited throwing power the distance between the substrate and the magnetron sputtering source is significantly smaller than with arc-evaporation.

While conventional sputtering used highly balanced magnetic fields, i.e. concentrating the field lines and the discharge in front of the targets, un-balanced magnetron sputtering was developed, opening up the field lines, stretching out the plasma and thus releasing ionized particles into the coating room onto the substrates.

PVT found in HiPIMS (High Power Impuls Magnetron Sputtering) a crucial solution to overcome the significant drawback of magnetron sputtering: the low intrinsic energy of the process.

HiPIMS

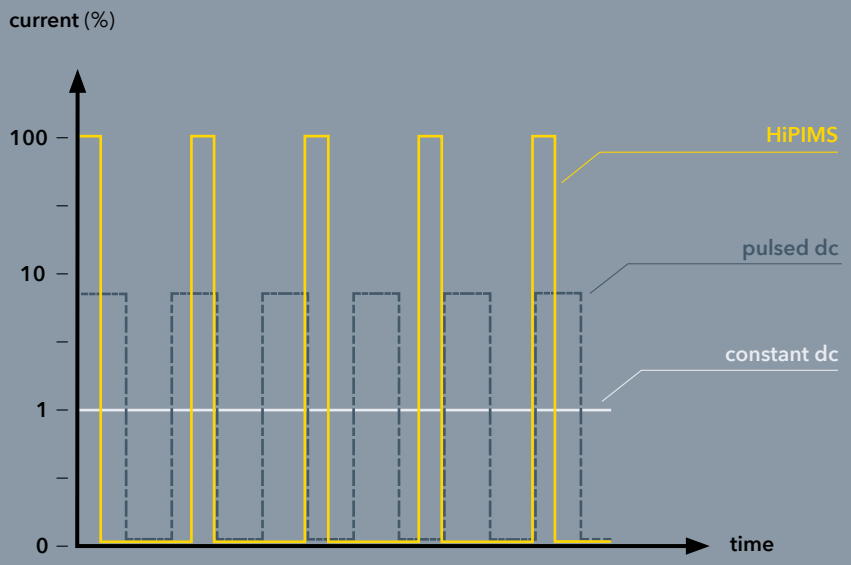
HiPIMS V$^+$ is the ultimate in magnetron sputtering using high pulsed power levels and subsequent positive reverse pulses influencing the coating properties in any desired direction*.

During HiPIMS short power pulses in the range of fractions of microseconds hit the substrates at very low duty cycles (<10%) at several kW per cm^2 creating significant impacts of highly ionized coating material for very dense and smooth coatings.

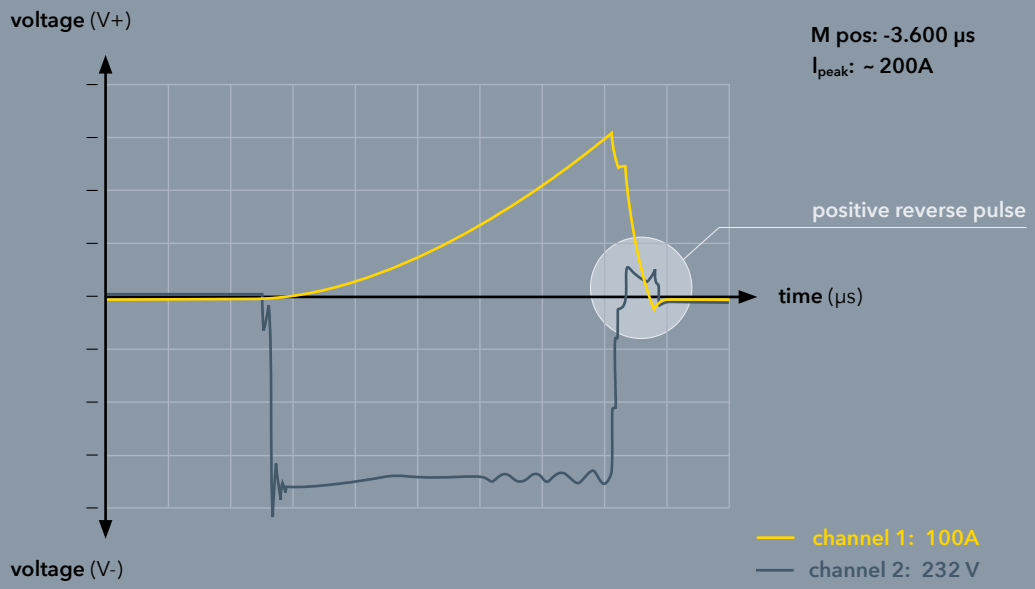
HiPIMS V$^+$ compensates for the low deposition rate by the positive reverse pulse after the high energetic negative pulse, thus increasing the deposition rate and tuning the coating properties.

* developed by and applied in cooperation with Nano4Energy, Madrid, Spain

POWERS OF CONSTANT DC , PULSED DC AND HiPIMS

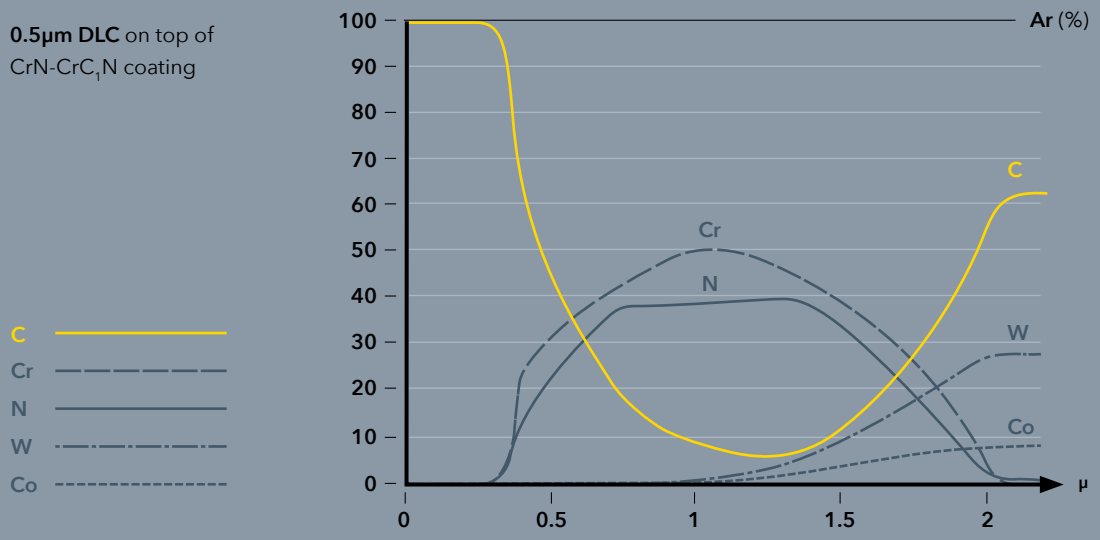


HiPIMS V$^+$ PULSE

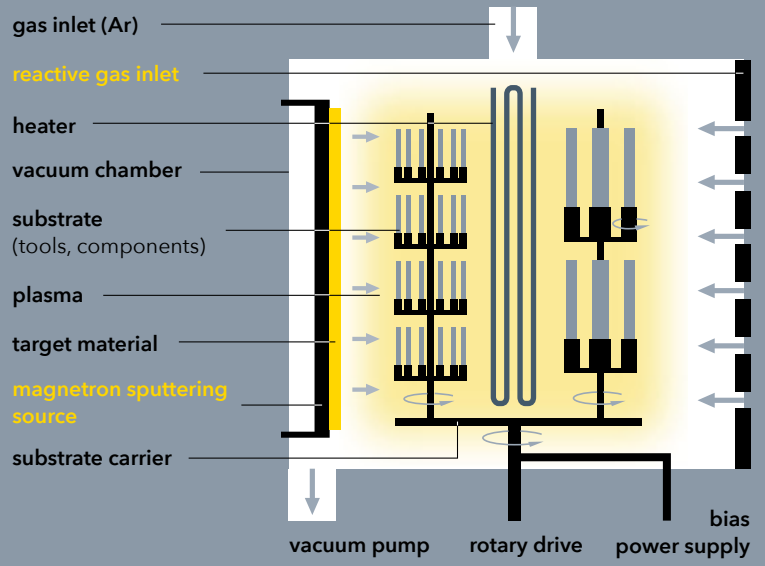


GD-OES PROFILE – PE-CVD DLC

0.5µm DLC on top of CrN-CrC_1N coating



PE-CVD – BASIC PRINCIPLE



PE-CVD

PE-CVD is a process with excellent throwing power, where the plasma is dissociating the reactive gases, fully surrounding all of the substrates.

When using a PE-CVD-process (Plasma-Enhanced CVD), as with CVD (Chemical Vapor Deposition), only gases are used to deposit a coating in the presence of a plasma. For PECVD the deposition temperatures are considerably lower (100–600 °C) compared to the classical CVD with temperatures in the range of 1000 °C and higher.

The plasma is used to enhance the reaction as well as the dissociation of the reactive gases, such as e.g. C_2H_2 or CH_4 during the deposition of DLC (Diamond Like Carbon) coatings. Also combinations of processes are used, such as

- magnetron sputtering + PECVD
- arc evaporation + PECVD

To deposit well adherent DLC-coatings adhesive layers have to be deposited prior to forming DLC. Cr (Chromium), deposited by arc evaporation or HiPIMS, is an excellent candidate to improve the adhesion of DLC.

HIGHLIGHTS OF ALL COATING SYSTEMS MADE BY PVT

Most advanced technology
- Arc-evaporation systems based on HiParc- and PDA-technology
- Magnetron-sputtering systems based on HiPIMS V+ technology in combination with DC-pulsed magnetron sputtering
- Increased deposition rate
- Highest target utilisation

Short process time
- Increased heating capabilities
- Efficient cleaning and etching cycles

Improved coating properties
- Advanced interface formation
- Extremely clean process environment

Improved part handling and fixturing
- Safest most manoeuvrable transport carts
- Easy to load and use carts with high load capabilities

Improved software design
- Extreme ease of use
- Highly reproducible runs
- High level of flexibility for custom tailored coating solutions
- Remote control and diagnostics

Improved thermal management
- Intensive water cooling
- Double walled construction

Most reliable components
- Brand name components
- Clever integration

SYSTEMS

We offer – tailored to the customer's application – a large portfolio of standardized or completely customized systems using arc-evaporation, magnetron-sputtering or PECVD technologies.

OUR COATING SYSTEMS

All of our systems are fully automated and integrated, fully controllable via remote and are built from materials and components of highest quality delivered by world-leading suppliers. Due to the high level of standardization we guarantee a maximum spare parts availability.

These systems ensure highest productivity and efficiency due to highest industrial standards and excellent reliability in 3-shift operation combined with simple operation and easy maintenance.

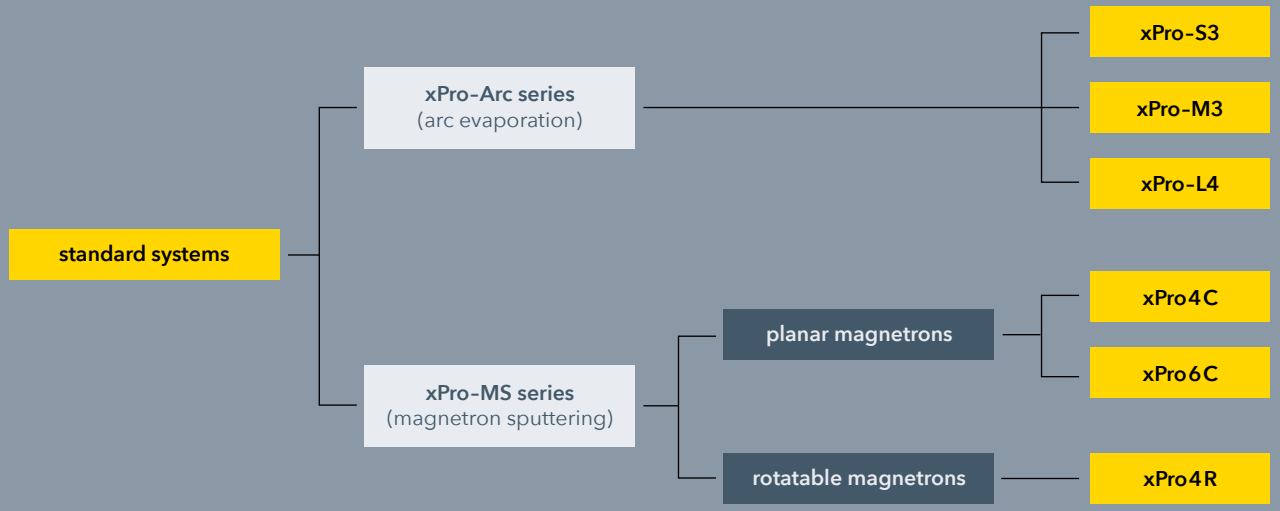
STANDARD BATCH-TYPE SYSTEMS

All of our standard systems, named xPro (= extended productivity), are characterized by:

- Robust system designed for the rigorous production environment using sophisticated vacuum coating technologies.
- Rugged construction marked by an extremely advanced highly refined design.
- Extreme reliability based on intelligent straightforward design and construction.
- The broadest spectrum of coatings and coating technology available in a single system at the lowest possible cost.
- Fully automatic, computer controlled, closed loop process control providing process repeatability, reliability and a user-friendly environment.
- The coating industry's broadest capabilities on the smallest footprint.

Our portfolio of standard coating systems can be differentiated by the technology used (arc evaporation or magnetron sputtering) and the number of large area sources.

OVERVIEW STANDARD SYSTEMS



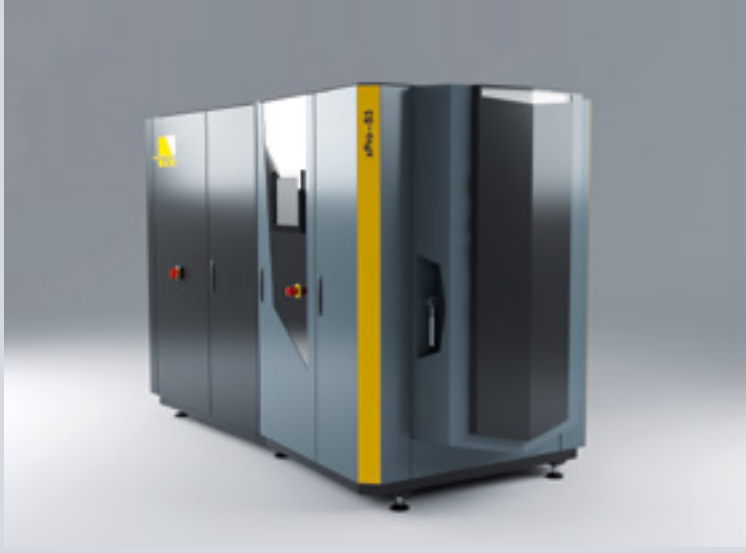
xPro–ARC SERIES

The systems are specifically designed for the deposition of high performance metallurgical coatings, such as AlCrSiN, AlTiSiN, AlCrN, AlTiN, CrN, TiC,N, TiN and many others. Such coatings are evaporated by arc onto a variety of cutting tools, dies and moulds, components and consumer products for wear and erosion corrosion protection as well as tribological purposes. All coatings are nanostructured, whether single- or multi-layered.

The PDA- and HiParc-technologies as an integral part of these systems enable faster deposition rates, shorter cycle times and significantly improved target utilisation to operate at highest output.

We offer three standardized systems to be chosen from depending on the anticipated throughput.

The xPro–ARC series are the most advanced industrial arc-evaporation systems, which include the PDA- and HiParc-technologies.



SPECIFICATIONS xPro–ARC SERIES (ARC EVAPORATION)

xPro-ARC system	**size of vacuum chamber** (L x W x H) in mm	**coating volume** (Ø x H) in mm	**large area arc evaporators** number
xPro-S3	680 x 650 x 1150	350 x 720	3
xPro-M3	860 x 860 x 1150	520 x 720	3
xPro-L4	1000 x 1000 x 1150	710 x 720	4

xPro-MS SERIES

The systems are designed to deposit coatings in HiPIMS, HiPIMS V+ and DC-pulsed magnetron sputtering mode onto a variety of components and consumer products but also cutting tools, dies and moulds.

All 3 process modes allow an accurate control of both, the flux and energy of the ion species bombarding the substrate - this is the crucial mechanism to produce coatings with optimum properties such as crystallinity, smoothness, highest density or low internal stress.

All single – or multi-layerd coatings are nanostructured for highly advantageous tribological purposes, i.e. extremely low cof (coefficient of friction) and high wear resistance.

The systems xPro4C and xPro6C are equipped with planar magnetron sputtering sources and are specifically designed for the deposition of high performance DLC coatings, such as a-C, a-C:H, ta-C and a-C:Me and many others.
Besides the DLC coatings, in these systems also high performance metallurgical coatings, such as AlCrSiN, AlTiSiN, AlCrN, AlTiN, CrN, TiC,N, TiN and many others can be deposited with extremely smooth surface structures.

Both systems, the **xPro4C** and the **xPro6C**, are the ideal systems for industrial coatings due to their high performance and reliability. However, due to their extreme flexibility and their economic sizes they are also excellent research tools.

SPECIFICATIONS xPro-MS SERIES (MAGNETRON SPUTTERING)

xPro-MS system	**size of vacuum chamber** (L x W x H) in mm	**coating volume** (Ø x H) in mm	**magnetron sputter sources** number	**magnetron sputter sources** type
xPro4C	680 x 650 x 1150	350 x 720	4	planar
xPro6C	1000 x 1000 x 1300	710 x 800	6	planar
xPro4R	940 x 1150 x 1165	570 x 800	4	rotatable

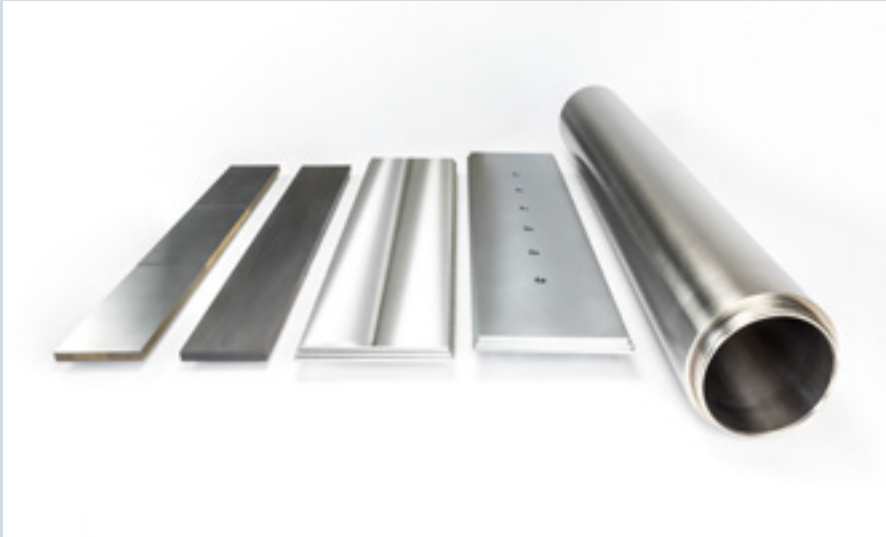
The system xPro4R is equipped with rotatable magnetron sputtering sources (Rotatables) and is specifically designed for the deposition of high performance super-smooth, high density, hard coatings such as AlTi-, AlCr-based, Si-, B-doped metal-nitrides and -carbon-nitrides.
The use of Rotatables supports higher deposition rates for improved economics, reduces the target poisoning and shows the longest lifetime of the target material without target changes at extreme target utilization.
One of the most important advantages of Rotatables is the constant sputter conditions during the lifetime of the targets compared to planar targets which require constant adjustments of the deposition conditions due to the erosion groove.

Furthermore Rotatables can be used at significantly higher energy levels compared to planar magnetrons, thus positively influencing the economics of the process and properties of the coatings.

LARGE AREA TARGETS

ADVANTAGES OF THE PVT LARGE AREA TARGETS

- **lowest target cost/coating run**
- **longest target life time cycles**
- **highest uniformity**
- **quick target change**
- **widest range of materials available**



Currently planar targets up to 1.25 m length and 200 mm width and tubular targets up to 1.0 m length and 150 mm in diameter are in use in our systems. Any other sizes are possible depending on the customer's application.

PVT uses exclusively large area targets for their arc evaporation and magnetron sputtering processes.

CUSTOMIZED SYSTEMS

- Arc-evaporation based coating system for broaches up to 3.0 m length
- Arc-evaporation based coating system for automotive rims
- Arc-evaporation based system for bandsaw coating with coil diameter up to 1.5 m.
- Inline coatings system with up to 8 magnetron sputtering sources
- etc.

Besides our portfolio of standard systems we design and build for our customers tailored systems and coating solutions depending on their requirements and applications.

SELECTION OF OUR DLC COATINGS

	hardness (GPa)	**max. service temp.** (°C)	**coefficient of friction**	**color**
ta-C	≤ 35	< 500	0.15	black
a-C:H	15	350	0.05 - 0.1	black
M-DLC	20	400	0.1 - 0.15	black

Many other customized coatings are available.

COATINGS AND APPLICATIONS

PVT offers a wide variety of high-performance coatings whose specifications are tailored to the customers application:

- Wear resistant coatings
  with high hardness improve significantly the lifetime time of cutting tools, dies and moulds

- Erosion resistant coatings
  for operations under harsh environments. For example, hard coatings extend the life of aircraft turbine blades, which are prone to erosion due to suction of dust and ice crystals during operation

- Tribological coatings
  with low coefficient of friction reduce abrasive and adhesive wear of mating surfaces in motion, i.e. in rolling and sliding contacts.

- Bio-compatible coatings
  are used to extend the life time of medical prostheses and to improve their ingrowth behavior.

- Conductive and non-conductive coatings
  are used to increase respectively decrease the conductivity of electrical parts or to generate electrical insulation.

The information age, our daily life and routines as well as the global society would not be possible without the high technologies, which are largely based on thin film technology. Just one sector of thin film technology is the PVD-based generation of hard- and tribological coatings.

SELECTION OF OUR HARD COATINGS

	hardness (GPa)	**max. service temp.** (°C)	**coefficient of friction**	**color**
Ti-based				
TiN	25	600	0.5 - 0.6	goldyellow
TiCN	30	< 500	0.5	rosegold
Cr-based				
CrN	20	750	0.4 - 0.5	silvergrey
AlTi-based				
AlTiN	33	900	0.5 - 0.6	black-blue
AlTiN+	35	900	0.5	black-blue
AlCr-based				
AlCrN	36	1,100	0.4 - 0.6	light anthracite
Si-doped				
Si+	38	>1,100	0.4	dark copper
Customized coatings, Si- and B-doped				
AlCrB	data on request			
AlCrBTiSiN	data on request			

Many other customized coatings are available.

RESEARCH

PVT is dedicated to R&D in PVD coatings for more than 3 decades.

EXAMPLES OF PAST INTERNAL R&D PROGRAMS

Project: High power for arc evaporation with highest efficiency
- Reduction of process time
- Improvement of target utilization

Project: HiPIMS V+
- Optimization of coating properties like smoothness, density, stress, hardness young's modulus, etc.)

Project Rotatables
- Tubular sputtering targets to merge high quality coatings with high productivity, optimized deposition conditions and improved economics

Project Inline
- Combination of maximum throughput with highest coating quality for planar substrates

RESEARCH AND DEVELOPMENT

Our R&D-projects are aiming at

- Calculation, Design and planning of new customized solutions
- Continuous improvement of coating performance
- Continuous improvement productivity
- Adaptation of process technology for new applications
- Continuous improvement of automation

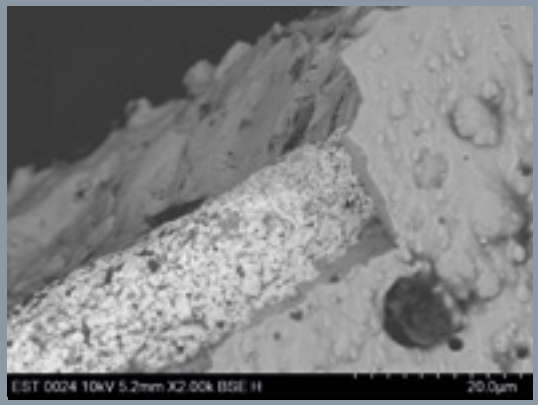
Results from our R&D efforts are immediately transferred to our coating service centers and new equipment design and manufacturing to maximize the benefit of our worldwide customers.

ANALYTICS

Our laboratories are equipped with a wide variety of analytical tools and measuring systems:

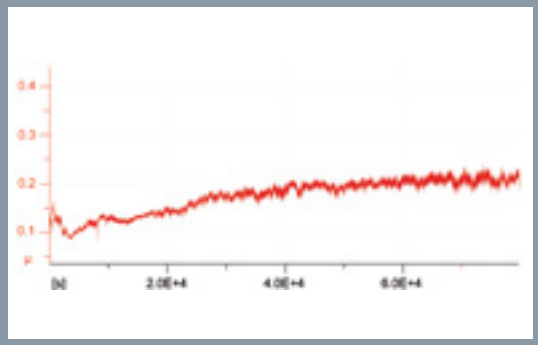
- SEM (Scanning Electron Microscope) to visualize the structure of the coatings
- EDX for composition characterization of the coatings surface material
- GDOES (Glow Discharge Optical Emission Spectroscopy) to characterize the composition of the coatings bulk-material
- Metallurgical microscopes for examining cross sections and calottes
- Overview microscopes for visual inspection of incoming and outgoing costumer tools or large-scale components
- Full digital microscopes for 3D-measures of complex surfaces
- Profilometer for determining the surface roughness
- Cutting-edge measurement device to characterize the roundness of cutting edges
- Hardness-tester to determine adhesion according to Rockwell test
- Tribometer for measuring friction and wear
- Other test methods for more intensive characterization in cooperation with partners and institutes, i.e. Nanoindentation, Crystallographic phase identification, scratch test for adhesion quantification and Raman spectroscopy

Our outstanding and consistent quality is guaranteed by ongoing quality control measures in our in-house testing and analytic laboratories.

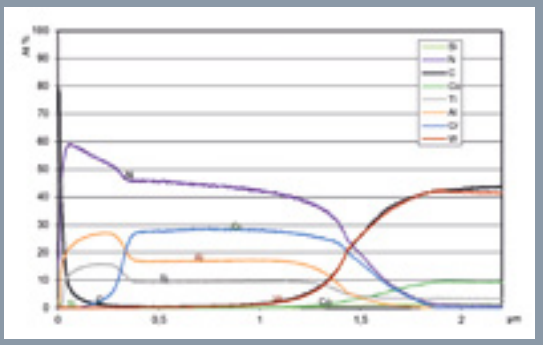


Picture taken with **SEM-system**

Edge of cutting tool taken with **3D-microscope**



Measurement of coefficient of friction done by **tribometer**



Composition measurement done by **GDOES-system**


PVT
xPro – S3
xPro 4 C

SERVICES

PVT is your supplier for turnkey solutions – with most advanced technologies and experience for decades.

SERVICES

We offer our customers complete engineering of turn-key-solutions for the entire production process – from incoming inspection, pre-treatment, cleaning, coating, post-treatment and quality control.

We support the right selection of proper pre- and post-treatment as well as cleaning and stripping processes (dry and wet blasting, tribo-finishing, water-based cleaning, etc.). PVT supplies complete automated cleaning lines, which are designed to efficiently handle the parts flow to the coating systems.
QC equipment can be supplied to investigate film thickness, mono- or multilayer coating structures, adhesion, roughness and hardness and to guarantee highest quality levels.

Depending on the customer's requirements we also design the complete layout of the workshops, including all utilities, such as power, water, gases, exhausts and lighting.

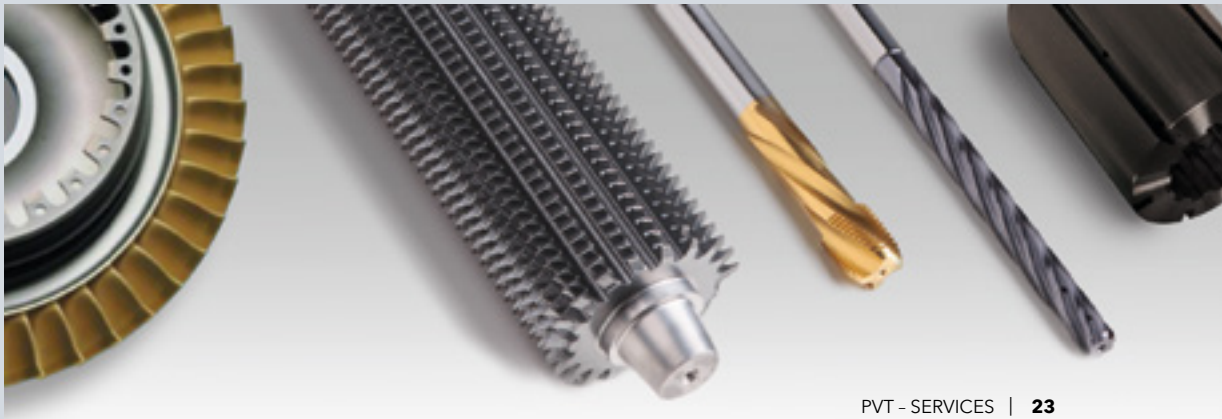
After installation customers will be trained intensively in the handling and maintenance of all equipment.

We assist our customers in upgrading their existing systems by
- selection of the right process – or even a change to a new or different process
- retrofit of existing components like sources, pumps etc.
- update of control – software and related hardware
- rebuild of complete systems

PVT offers different retrofit packages consisting of arc evaporator or magnetron sputtering sources, heater elements, rotary feedthroughs, temperature sensors, etc..
High system uptime is achieved by simplicity in design and best engineering tried and tested for years. The return of investment is guaranteed within a short period of time.

OUR SERVICES

- **Facility layout – Turn-key coatings centers**
- **After-Sales training and support**
- **Upgrade and retrofit of existing systems**
- **Job coating services**



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