Advanced Coating Systems
SWISS QUALITY

Diamond-Like Carbon (DLC) Coatings
by PLATIT PVD Coating Plants

Jan Procházka

Workshop "Integrita"
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Outline

1. Why DLC Coatings
2. Deposition Methods
   - Me-C:H
   - a-C:H:Si
   - ta-C
3. Applications
   - Example DLC^2: combustion engine components
   - Example DLC^3: milling of Al alloys

1. Why DLC Coatings

Diamond. Good for …?

Knowing the excellent hardness and chemical inertness to some materials, engineers have long been eyeing diamond for many industrial applications, e.g.:

- machining / extrusion of aluminium alloys
- machining / moulding of plastic
- machining of composite materials (printed circuit boards, carbon fibre reinforced plastics)

However, natural diamond is extremely expensive and only available as bulk material. Man-made diamond crystals cost around 1 USD/mm^3. Still, crystals are not useful when we would only need a thin film of this material.

1. Why DLC Coatings

Diamond: stable or not?

At room temperature (both in vacuum and under atmospheric pressure), diamond is stable. However, it is thermodynamic-ally unstable. The higher the temperature, the faster the conversion into graphite (activation energy, Arrhenius law).

By using non-equilibrium plasma, we are able to help the conversion into the respective thermodynamically stable allotrope - or into the other one. Process window problem!

1. Why DLC Coatings

Diamond: and its mechanical properties?

Diamond is the hardest material known. However, its elastic modulus and coefficient of thermal expansion are too different from the usual engineering materials.

For a coating, this is a problem!

If the coated item is put under a thermal or mechanical stress, the coating may peel, rendering the coated item useless.

In real life, we'd often prefer a coating which has some of the properties of diamond but some of graphite (e.g. low coefficient of friction).

1. Why DLC Coatings

DLC = Diamond-Like Carbon …

… is the coating industry's answer to address these problems.*)
Instead of pure diamond, we deposit a coating which is:

- easier to produce industrially (or, can be produced at all using the methods known so far)
- with its mechanical properties, it fits better the material underneath and/or the intended purpose

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*) Yes, CVD *(chemical vapour deposition)* diamond coatings are being job-coated too, but their field of application is pretty limited due to the constraints of the method.

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2. Deposition Methods

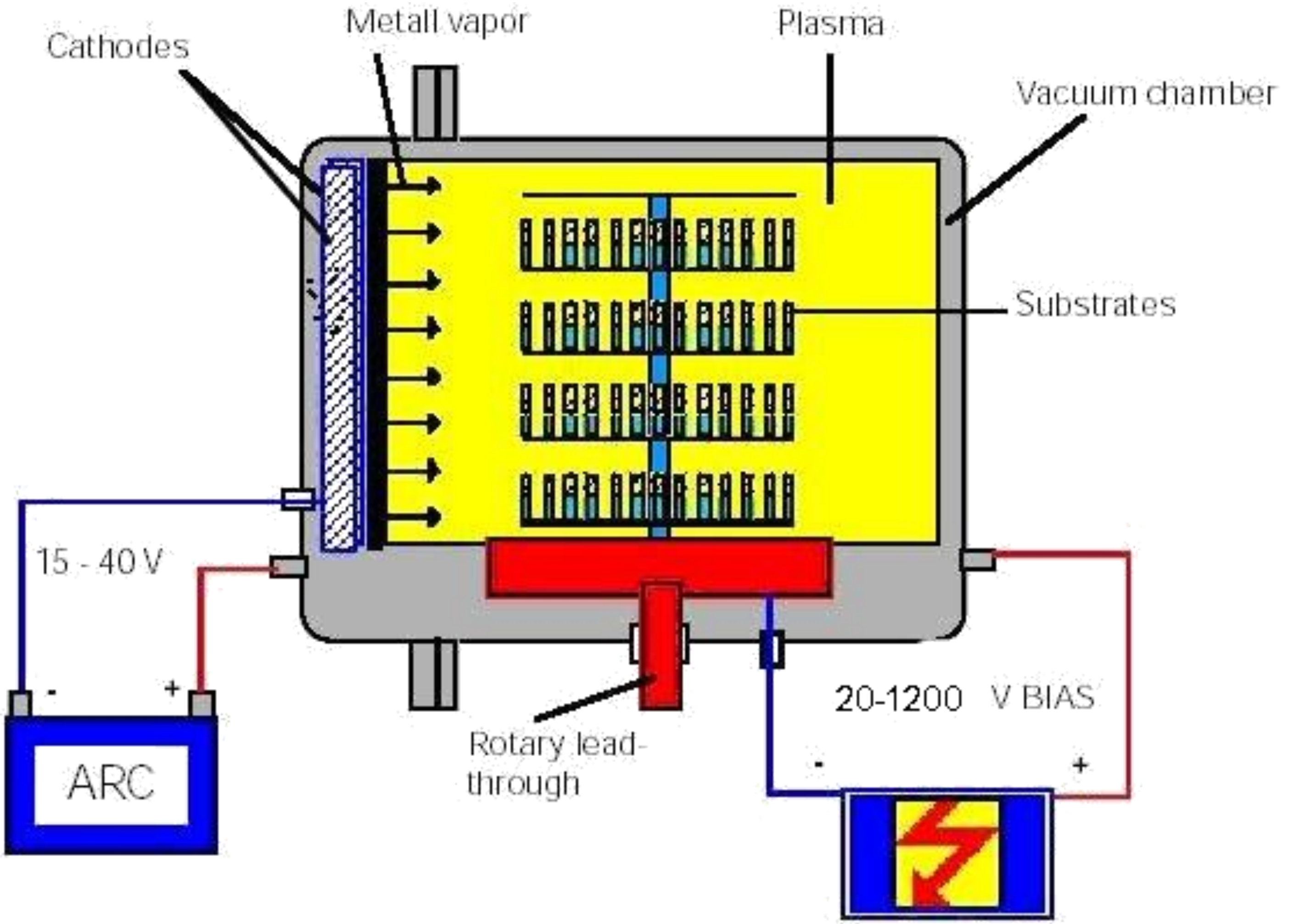
At PLATIT, we have three "generations" of DLC coatings:

1. Metal and hydrogen doped (Me-C:H)
2. Silicon and hydrogen doped (a-C:H:Si)
3. sp^3 amorphous carbon (ta-C)

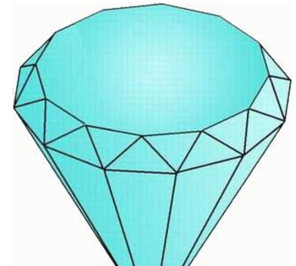
Higher generation = higher hardness but (unfortunately) higher initial cost of coating plant too.

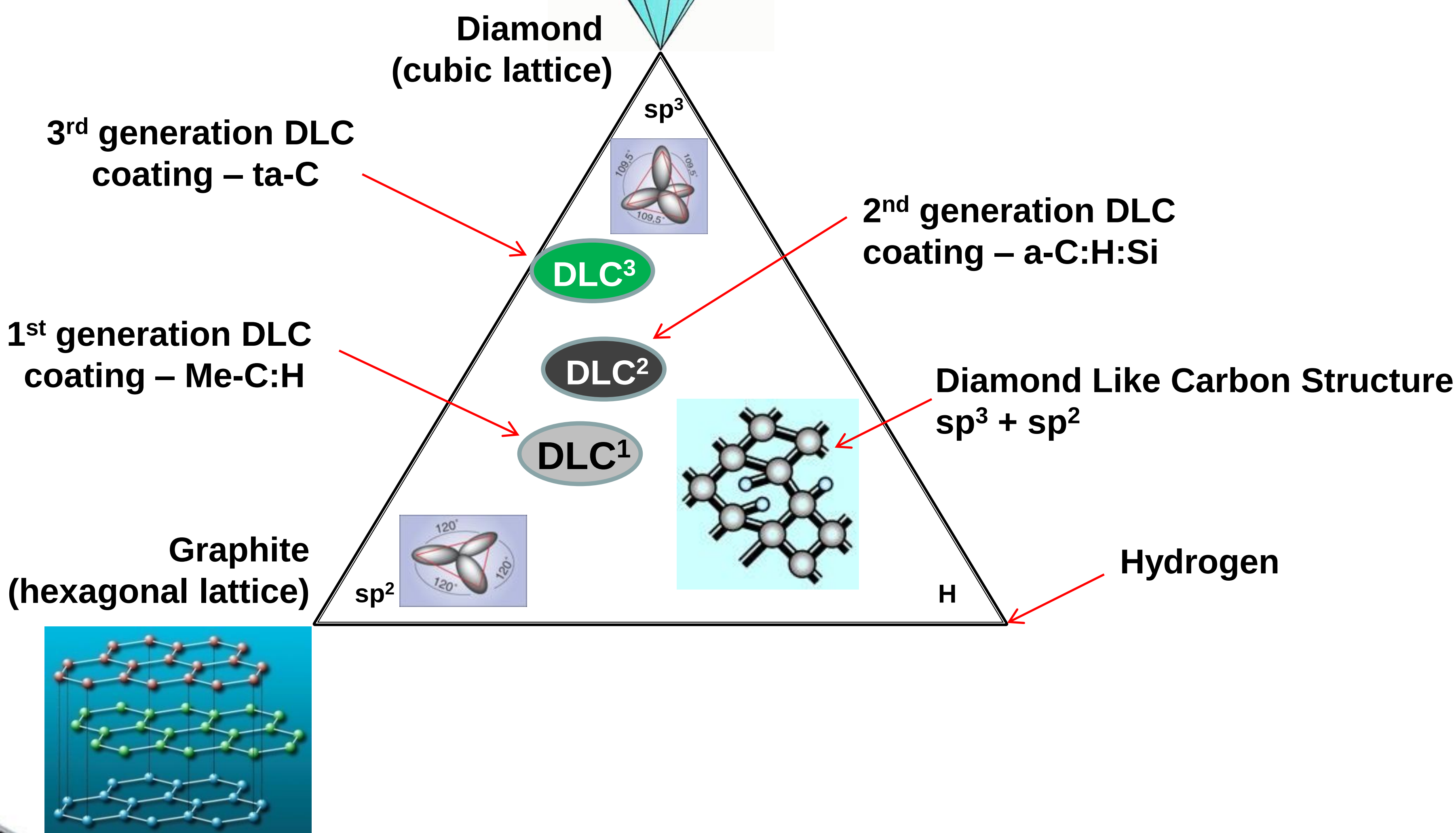
2. Deposition Methods

We need a vacuum-arc PVD machine:

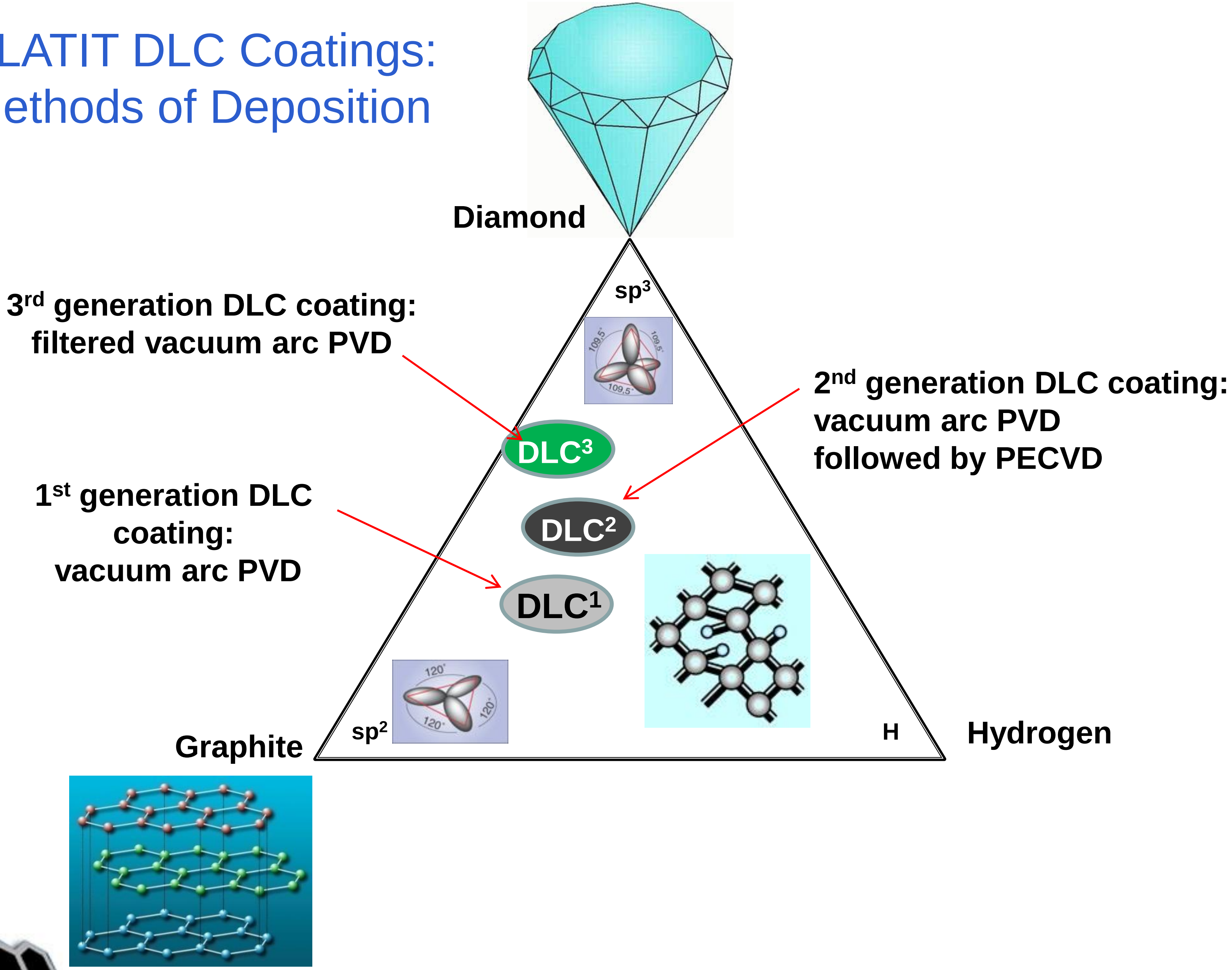


PLATIT DLC Coatings: Chemical Composition





PLATIT DLC Coatings: Methods of Deposition



2. Deposition Methods

1. **Metal and hydrogen doped (Me-C:H)**

Produced in a standard (=any) PLATIT vacuum arc PVD machine. While the arc is being operated, relatively large quantities of acetylene (e.g., 200 sccm) are introduced into the chamber. The acetylene "polymerizes" in the plasma and is deposited along with the metal from the arc cathode.

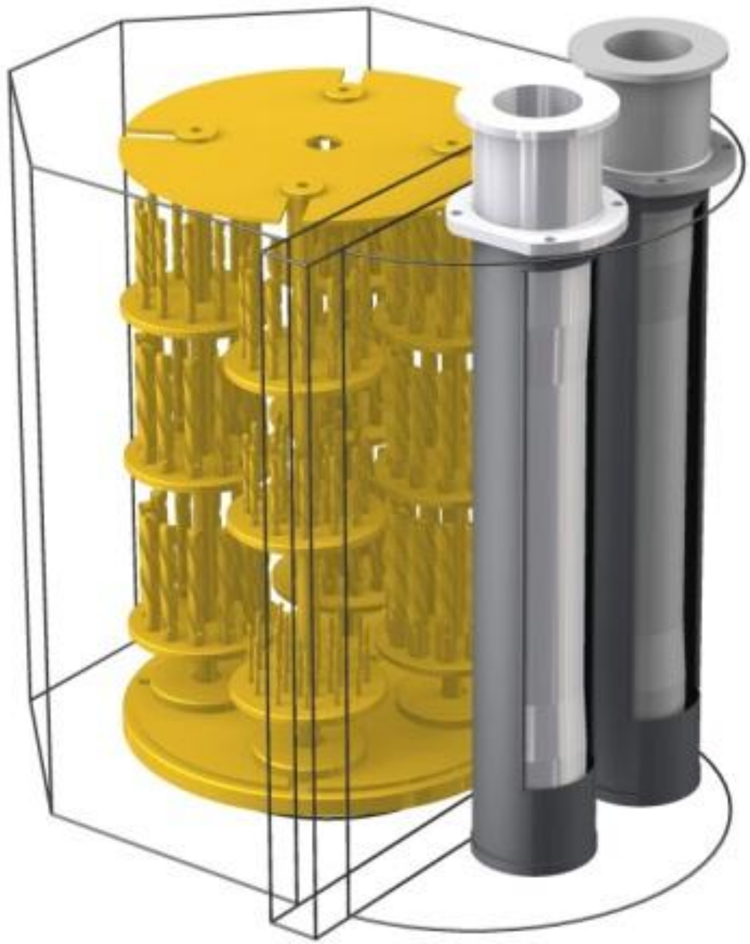
Titanium, chromium or zirconium doped Me-C:H can be produced with this method. The coating has ca. 15 GPa hardness and COF ≈ 0.15 against steel.

2. Deposition Methods

1. Metal and hydrogen doped (Me-C:H)

Example of a "standard arc PVD ma

PLATIT π111



- two rotary arc cathodes (e.g., T protected by "shutters" again coated when not in use
- carousel with four satellites for rotation

2. Deposition Methods

1. **Metal and hydrogen doped (Me-C:H)**

The usual batch time (important for the economy of the coating business) is between 4 and 6 hours. A cleaning batch may be necessary afterwards, meaning that the machine might be unavailable for production for another 4 hours.

2. Deposition Methods

2. Silicon and hydrogen doped (Si:C:H)

Produced in a DLC[2]-enabled PLATIT vacuum arc PVD machine. At first, a standard arc PVD coating of arbitrary thickness is deposited. Then, a relatively large quantity of acetylene and of a silicon precursor are introduced into the chamber, while the substrate bias is around 400 V with medium-frequency pulsing. In the glow discharge produced in this way, the DLC coating is produced via plasma-enhanced chemical vapour deposition.

The coating has ca. 25 GPa hardness and COF ≈ 0.10 against steel (dry).

2. Deposition Methods

2. <u>Silicon and hydrogen doped (Si:C:H)</u>

The coating machine must have a medium-frequency pulsed bias power supply (which costs twice as much). Proper measures must be taken that the medium-frequency bias voltage can reach all items to be coated. Because glow discharge is used, we must know the peculiarities of it. By proper arrangement of the items coated, we must preserve the plasma sheath, avoid forming hollow cathodes and effects of unwanted magnetic field.

A typical coating batch will require 6-8 hrs. A cleaning batch afterwards is almost a must (another 4 hrs).

2. Deposition Methods

2. <u>Silicon and hydrogen doped (Si:C:H)</u>

Example of a DLC^2 enabled machine:

PLATIT π311

- three rotary arc cathodes in the doors + one in the middle (but not used for DLC^2)
- carousel with seven satellites for planetary rotation
- medium frequency pulsed bias

π^{311}: 3•LARC® + 1•CERC®

2. Deposition Methods

3. **sp³, amorphous carbon (ta-C)**

Produced in a filtered vacuum arc PLATIT PVD machine. At first, a thin filtered-arc PVD coating is deposited using a metallic cathode. Then, the ta-C coating is deposited with a graphite filtered-arc cathode.

The coating has ca. 50 GPa hardness and COF ≈ 0.10 against steel (dry). More important, this coating is "non-stick" for low-alloyed aluminium alloys. Such alloys are usually difficult to machine because of build-up on the cutting edge.

2. Deposition Methods

3. <u>sp^3, amorphous carbon (ta-C)</u>

The coating machine must have at least one filtered cathode (graphite). Keeping the temperature low within the coating process might pose a challenge for some items. The batch times may be as short as 3.5 hrs in a good case. If the heat cannot be removed fast enough, the coating rate must be reduced, resulting in very long batch times (12 hrs+).

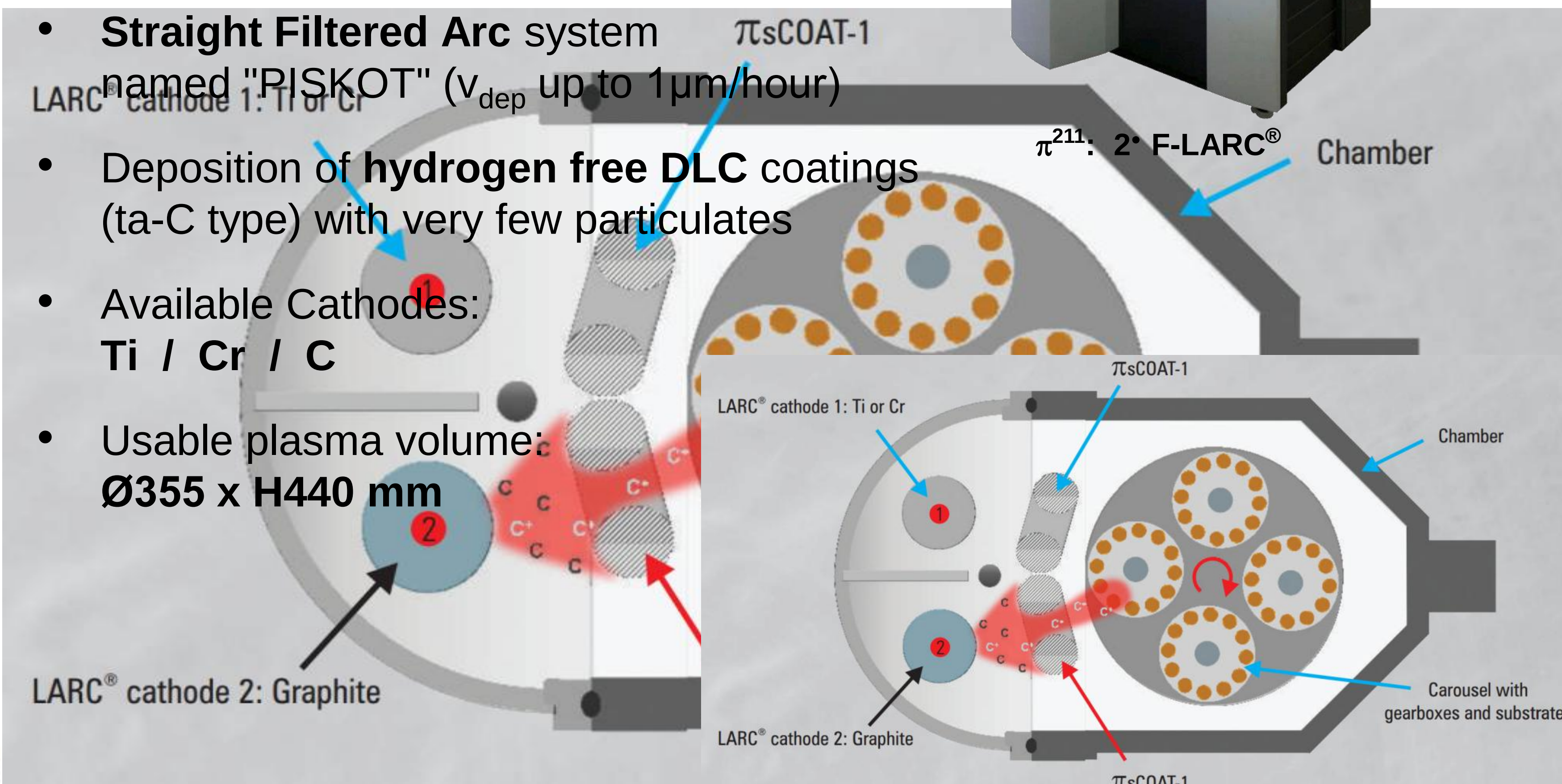
The ta-C is electrically almost an insulator, so a cleaning batch (3.5 hrs) is necessary, preferably after each DLC^3 batch.

2. Deposition Methods - π^{211} DLC³ Coating Plant

Most Important Features

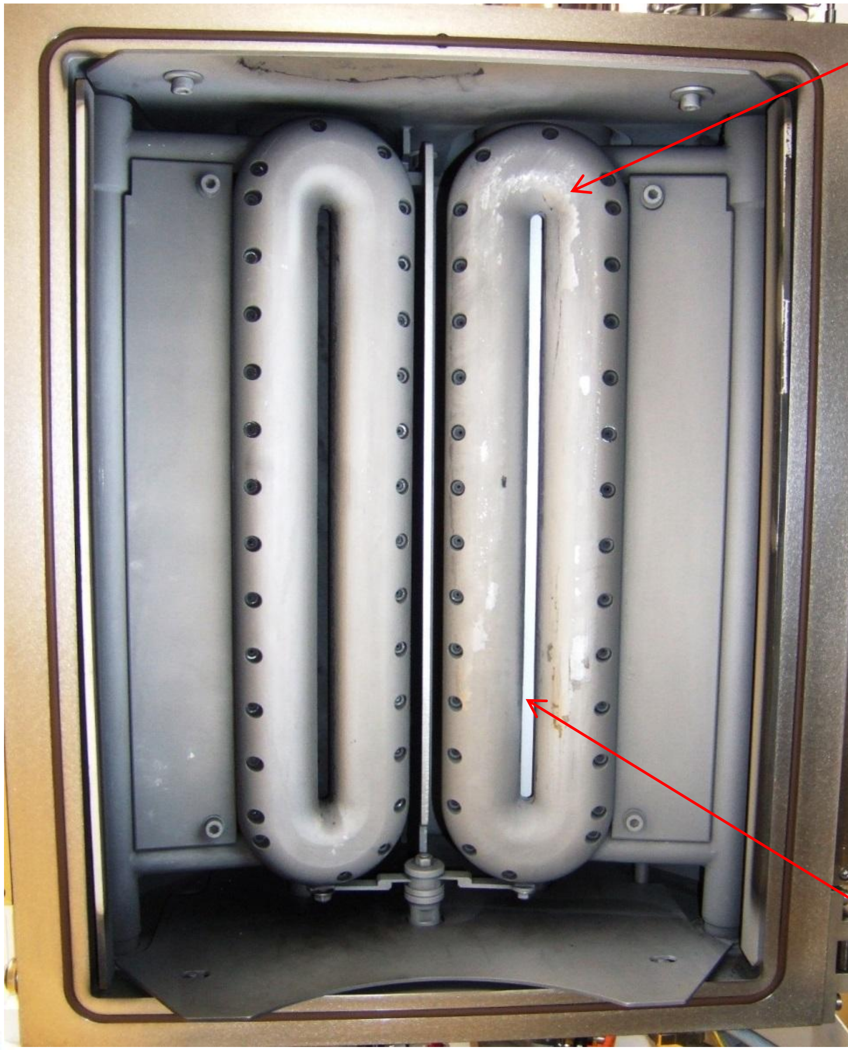
- **Arc PVD** technology with 2 Cathodes (Lateral, Rotating, Arc = LARC)
- **Straight Filtered Arc** system named "PISKOT" (v_{dep} up to 1µm/hour)
- Deposition of **hydrogen free DLC** coatings (ta-C type) with very few particulates
- Available Cathodes:
  Ti / Cr / C
- Usable plasma volume:
  Ø355 x H440 mm

π^{211}: 2• F-LARC®



2. Deposition Methods - π^{211} DLC³ Coating Plant

View of the chamber door



Separator - "PISKOT"

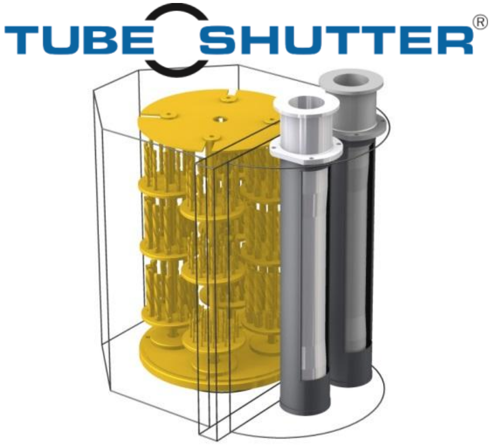
Name derived from the Czech word "piškot" = "ladyfinger", "biscuit"

Target (=cathode) surface behind the slit. Anodes are placed in the chamber.

2. Deposition Methods - π^{211} DLC³ Coating Plant

Less Important Features

- **Footprint** and chamber size same as in π111
- **Fully reconfigurable** into the π111 for standard coatings with standard LARC cathodes
- Robust coating adhesion through **LGD®** etching technology
- Shutters → **target cleaning**



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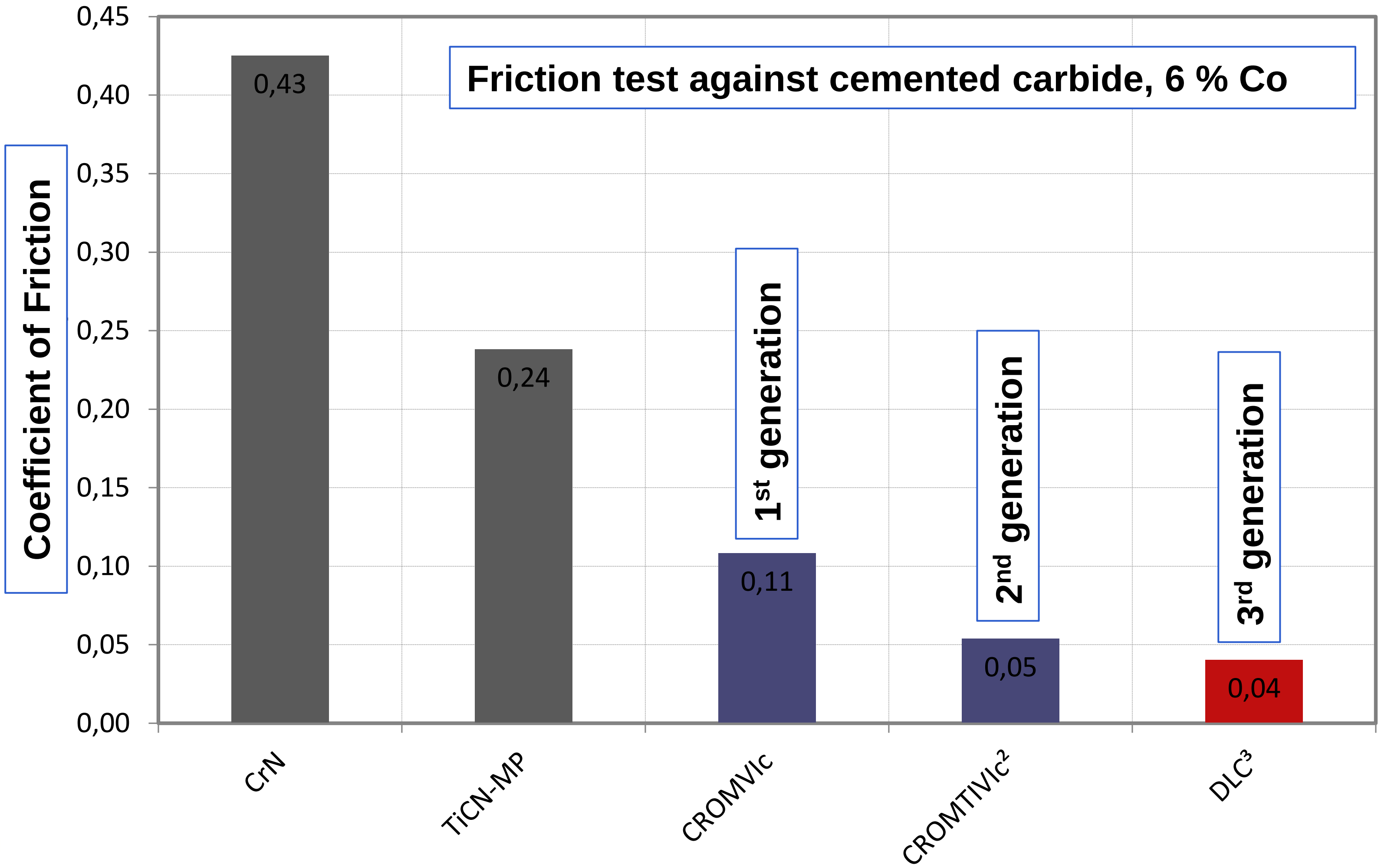
3. Applications

This is intended to demonstrate the potential of DLC coatings.



3. Applications: DLC^2

Valve lifter with CROMVIc$^{2®}$

Tappets with Fi-VIc$^{2®}$

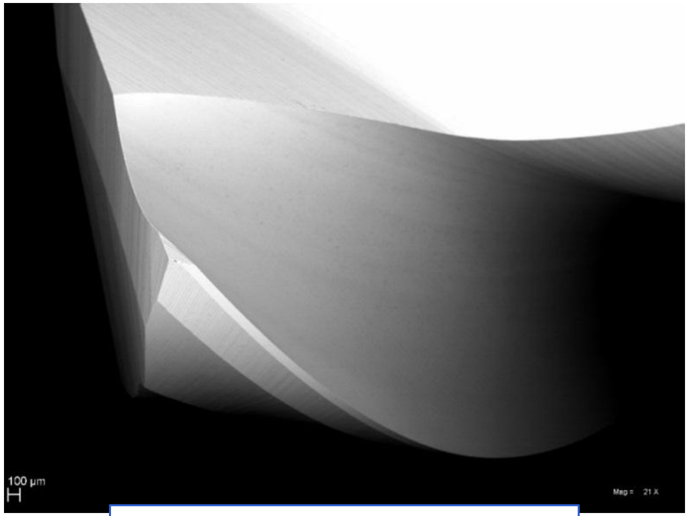
Camshaft
with CROMVIc$^{2®}$

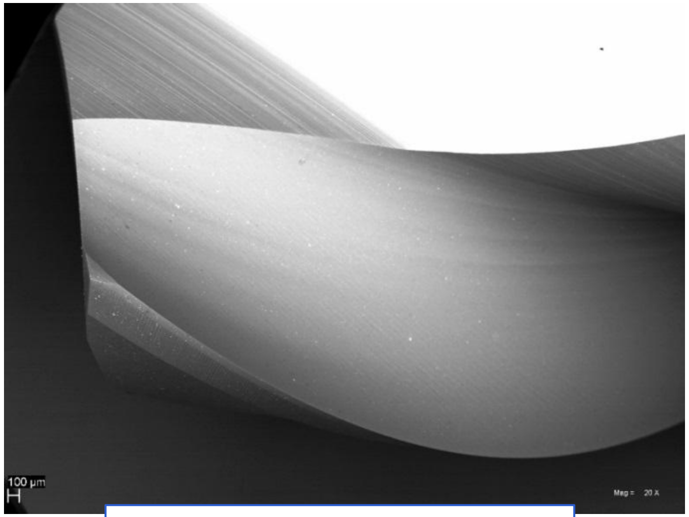
Piston pin
with CROMVIc$^{2®}$

Racing valves.
Shanks coated with Fi-VIc$^{2®}$

3. Applications: DLC^3

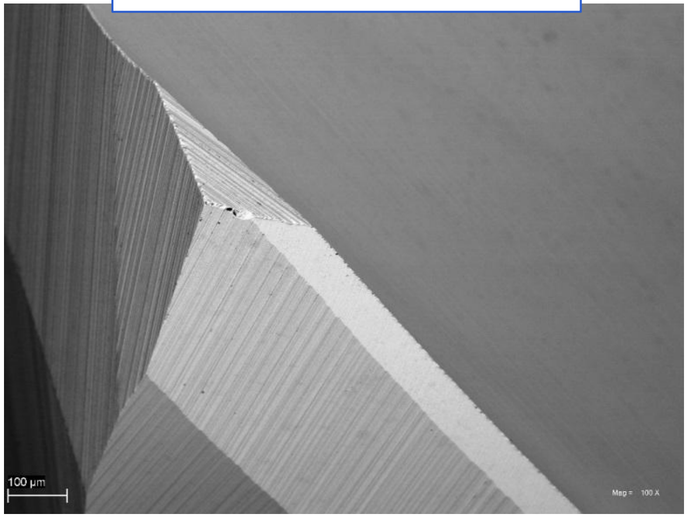
Coating end mills (SEM images)

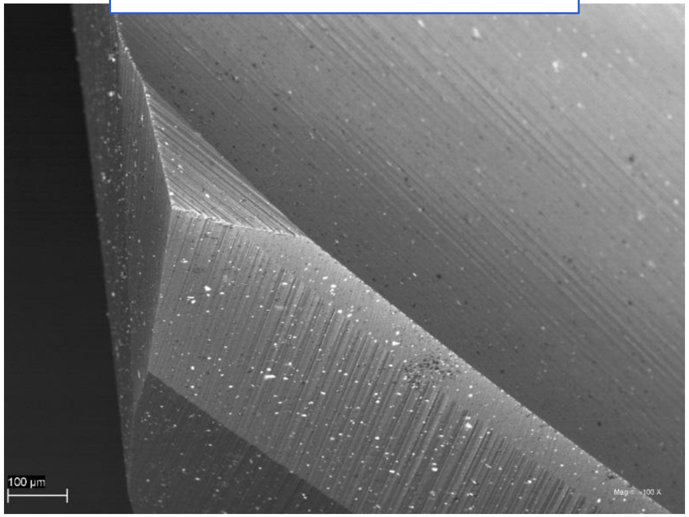




NEW

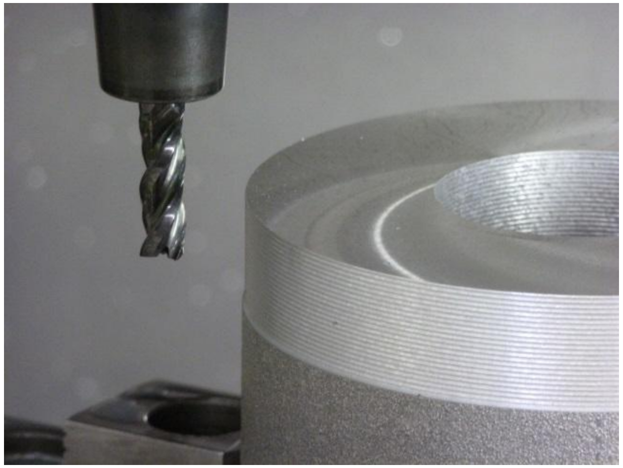
COATED





3. Application: Milling of Al Alloys - DLC³

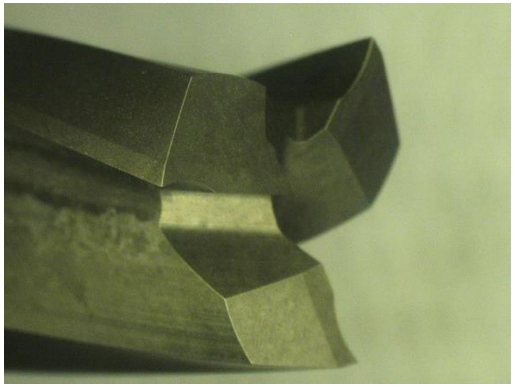
Machine:	**DMC 64V**



Material:	**AlMg4.5Mn (soft)**
Cut Settings:	**v_c = 250 m/min** **f_z = 0.16 mm** **a_p = 5 mm** **Dry Cut**

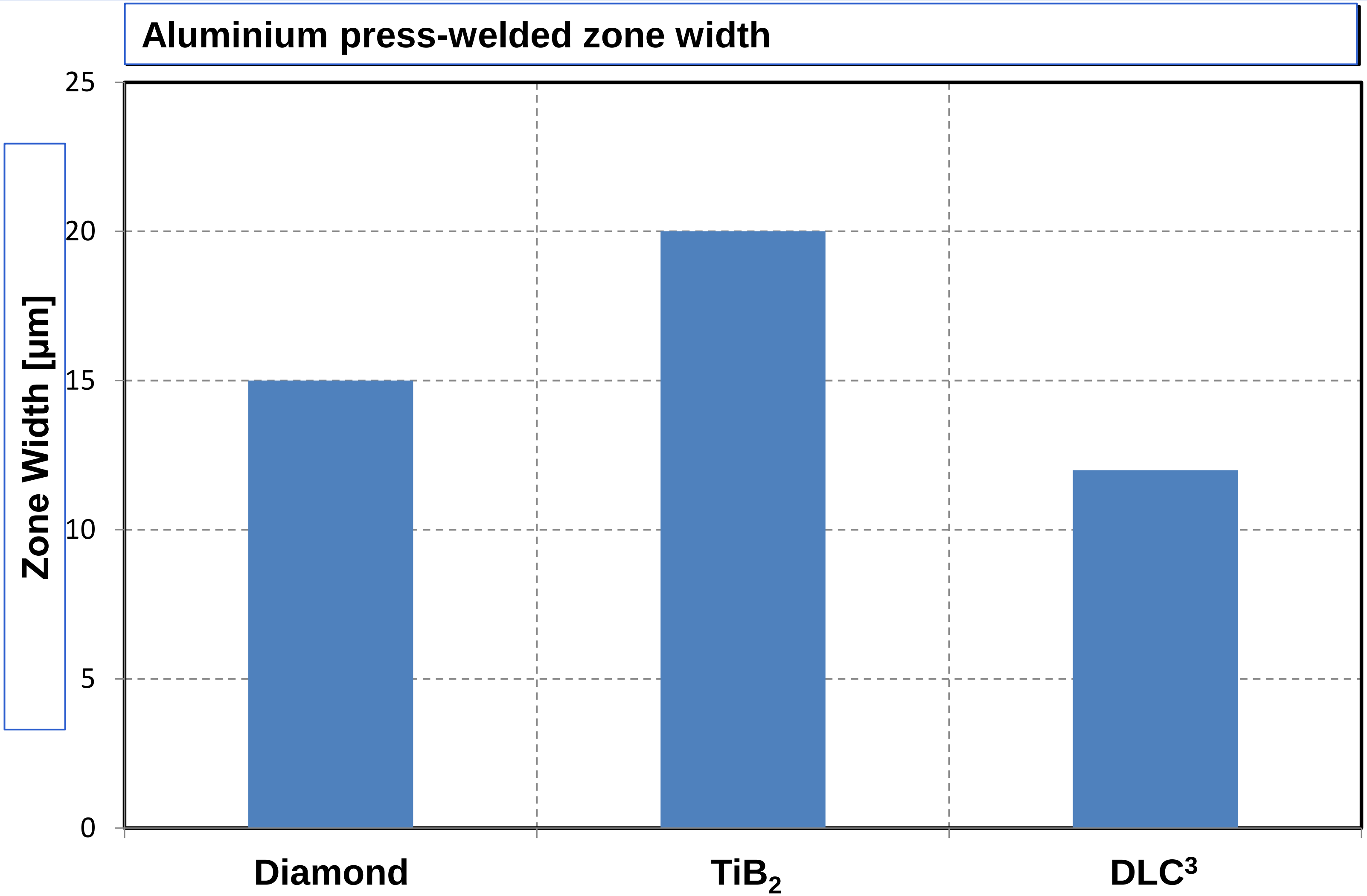
3. Application: Milling of Al Alloys - DLC³

Material:	**AlMg4.5Mn (soft)**
Cut Settings:	**CVD Diamant (CemeCon)** **TiB_2 (CemeCon)** **ta-C (GFE Schmalkalden)** **nACro³ (GFE Schmalkalden)**
Tool:	**Carbide end mill ø8 × 25** **Z = 3**



3. Application: Milling of Al Alloys - DLC^3

AlMg4.5Mn (soft)



Summary

Comparison of the most important features of PLATIT's DLC-coatings

	1st generation	2nd generation	3rd generation
Name	**DLC[1] (CBC) - X-VIc®**	**DLC[2] - X-VIc2®**	**DLC[3] - X-VIc3®**
Availability	Basis coating + DLC[1]	Recommended as top coating Basis coating + DLC[2]	Basis coating + DLC[3] for non-carbide Also without basis coating for carbide
Most common coatings	cVIc1®	VIc2®, cVIc2®, CROMVIc2®, CROMTIVIc2®, nACVIc2®	VIc3®, cVIc3®, CROMVIc3®
Coating process	PVD	PVD+PECVD	PVD, filtered ARC
Deposition temperature	200 - 500°C	200 - 500°C	< 200°C
Composition	a-C:H:Me - Metal doped DLC	a-C:H:Si - Silicon doped metal free DLC	ta-C - Hydrogen-free DLC
Heat resistance	< 400°C	< 450°C	< 450°C
Internal stress	medium	lower due to Si	high
Typical thickness	up to 3 μm	up to 3 μm	up to 1 μm
Electrical conductivity	good	none	none
Hardness	< 20 GPa	< 25 GPa	> 50 GPa
Roughness	Ra~0.1μm - Rz~coating thickness	Ra~0.03μm - Rz~coating thickness	Ra~0.02μm - Rz~coating thickness
Friction coefficient to steel	μ~0.15	μ~0.1	μ~0.1
Wear resistance	Wear through after a short time	Wear through after a long time	Wear through after an extra long time
Main application goal	Improvement of tool's run-in behavior Lubrication by forming transfer films	Reducing friction for machine components, molds and dies	Cutting light metals, composites and graphite

Tributes

Materials for this presentation:

- **Dr. Tibor Cselle**, PLATIT AG
- **Dr.-Ing. Heiko Frank**, GFE Schmalkalden

✶✶✶ GAME OVER ✶✶✶

Thank you for your attention!

Jan Procházka