# “New vacuum coating technologies for metal strips and foils”

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## 1. Introduction

Metal strips and foils with special surface functions are of growing interest. One aspect is related to very thin substrate materials for light-weight applications and to reduce the amount of needed resources. Another aspect is the requirement for more and more complex layer systems with special and high-quality properties. The overall requirement is the call for low cost coating technologies onto large areas.

Vacuum coating technologies have the potential to fulfill these demands for a lot of applications. The main motivations to use PVD and CVD processes are:

- large variety of layer materials available for deposition (metals, alloys, compounds, …),
- very precise coatings possible,
- outstanding environmental compatibility of processes, because they are running in closed chambers,
- promising research and development results as well as first industrial applications.

Additional demands for the new processes are:

- adapted in-situ pre-treatment processes are necessary,
- high-rate deposition results often in porous and columnar layer structure which is for many applications not useful; to enhance the layer properties plasma assistance of the coating processes is required,
- condensation, plasma and other heat sources during the deposition process result in high thermal load of the metal strips and foils, therefore an active substrate cooling in vacuum during coating has to be applied in some cases.

## 2. Vacuum in-line pre-treatment by hollow cathode arc sputter etching

Fraunhofer FEP has developed a powerful in-line pre-treatment process based on hollow cathode arc sputter etching. Figure 1 shows the schematic layout of the arrangement. With this process ferror-magnetic and non-magnetic metallic strips and foils with arbitrary thickness can be treated. For a large width some hollow cathodes can be arranged side by side (e.g. for 1 m width about 5 hollow cathodes). The strip itself is biased but electrically on earth. For arc suppression the bias voltage is pulsed powered in the frequency range of 20 … 50 kHz. The dynamic etching rate is in the range of 5 nm m/s depending on the strip material and the oxide thickness at the surface. For higher removal some hollow cathode arrangements can be installed in the strip moving direction.

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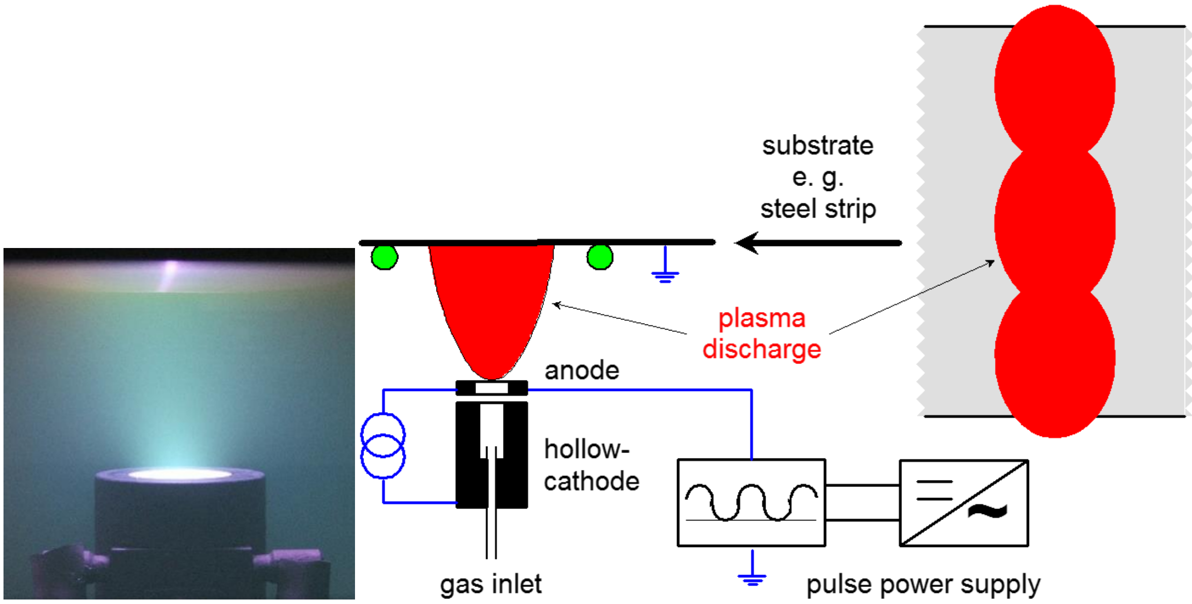


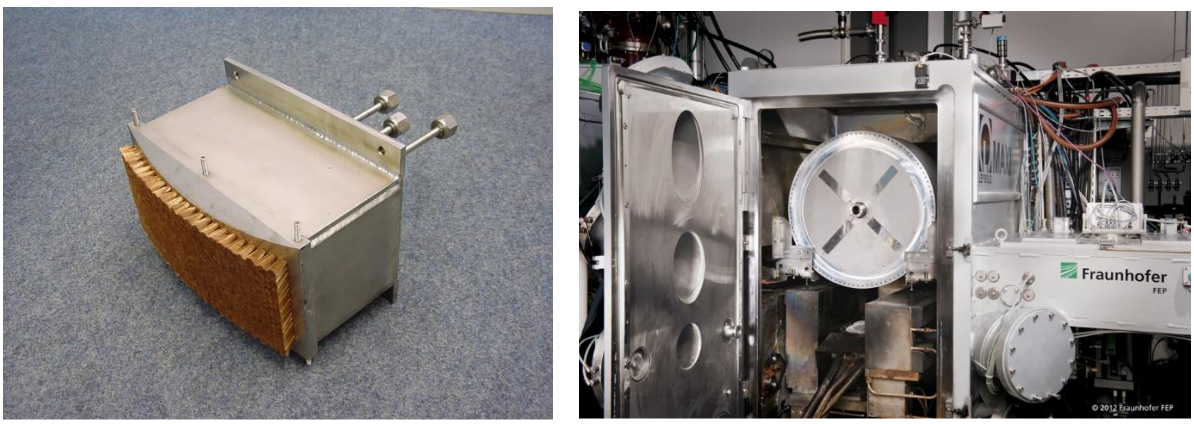

**Figure 1:** Schematic layout of vacuum in-line pre-treatment by hollow cathode arc sputter etching

## 3. Substrate cooling in vacuum

Fraunhofer FEP has developed two cooling processes useful for active cooling of metal strips and foils during deposition (see figure 2):

a) *Brush cooling:* Idea is the realization of a large number of effective working contact points for heat transportation by brush arrangement. Heat transmission coefficients of up to 150 W/m²K were reached with a static brush cooling device.

b) *Gas cooling drum*: Idea is the realization of gas filled contact area for heat transportation between strip and cooling drum, meanwhile the requirements on the pressure for vacuum coating (1 x $10^{-4}$ mbar) were fulfilled. Heat transmission coefficients of up to 600 W/m²K were reached with a gas cooling drum. There are further potential for increasing of cooling effect.




a) b)

**Figure 2:** a) Brush cooling device, b) Gas cooling drum installed in FEP’s in-line vacuum coating equipment for sheets and metal strips/foils “MAXI”

## 4. PECVD process for metal strips and foils

Fraunhofer FEP has developed a special plasma-enhanced chemical vapor deposition process (PECVD) for strip like electric conductive substrates (see figure 3).

The principle based on a magnetron discharge burning on the metal strip, which acts as cathode. The metal strip is at ground potential. At the opposite side is an encapsulated anode. For arc suppression the power is pulsed in the frequency range of 20 … 50 kHz.

By using of different precursor gases different layers can be deposited at high rates:

- *a-C:H*: precursor $C_2H_2$, deposition rate 110 nm/s, hardness 40 GPa,
- *a-C:H:Si:O*: precursor HMDSO, rate 50 nm/s, hardness 13 GPa,
- a-Si:H: precursor $SiH_4$, rate 3 nm/s (not optimized)

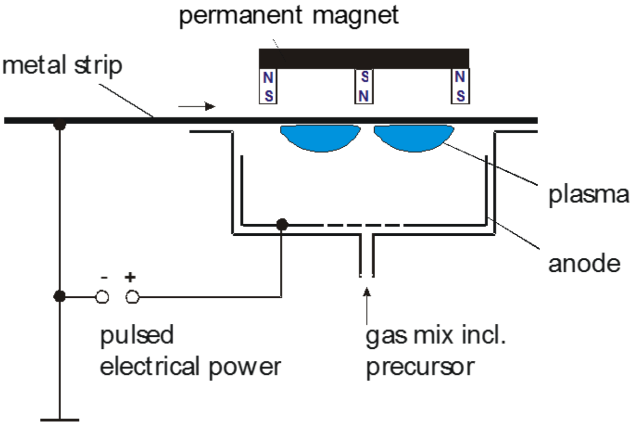



**Figure 3:** Schematic layout of a special PECVD process for metallic strips and foils

## 5. Plasma activated high-rate electron beam deposition

Fraunhofer FEP has developed two special plasma-enhanced electron beam deposition processes (SAD and HAD), well adapted to high-rate deposition on large areas (see figure 4).

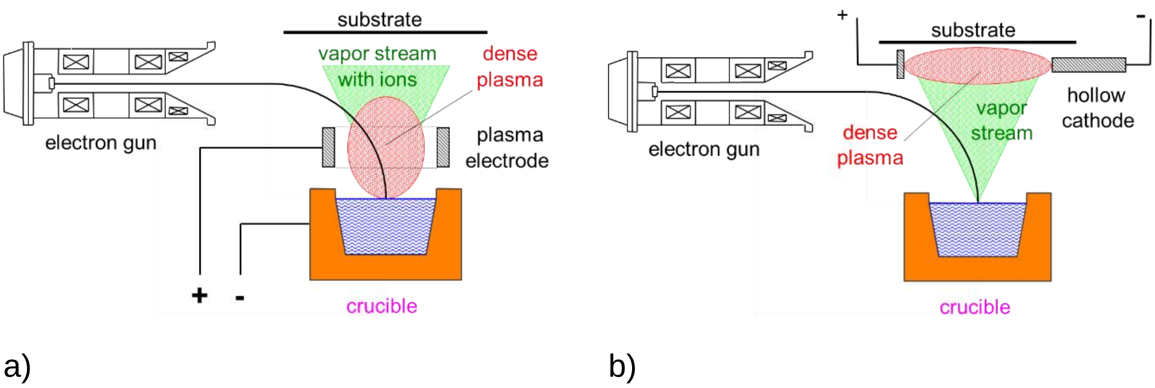


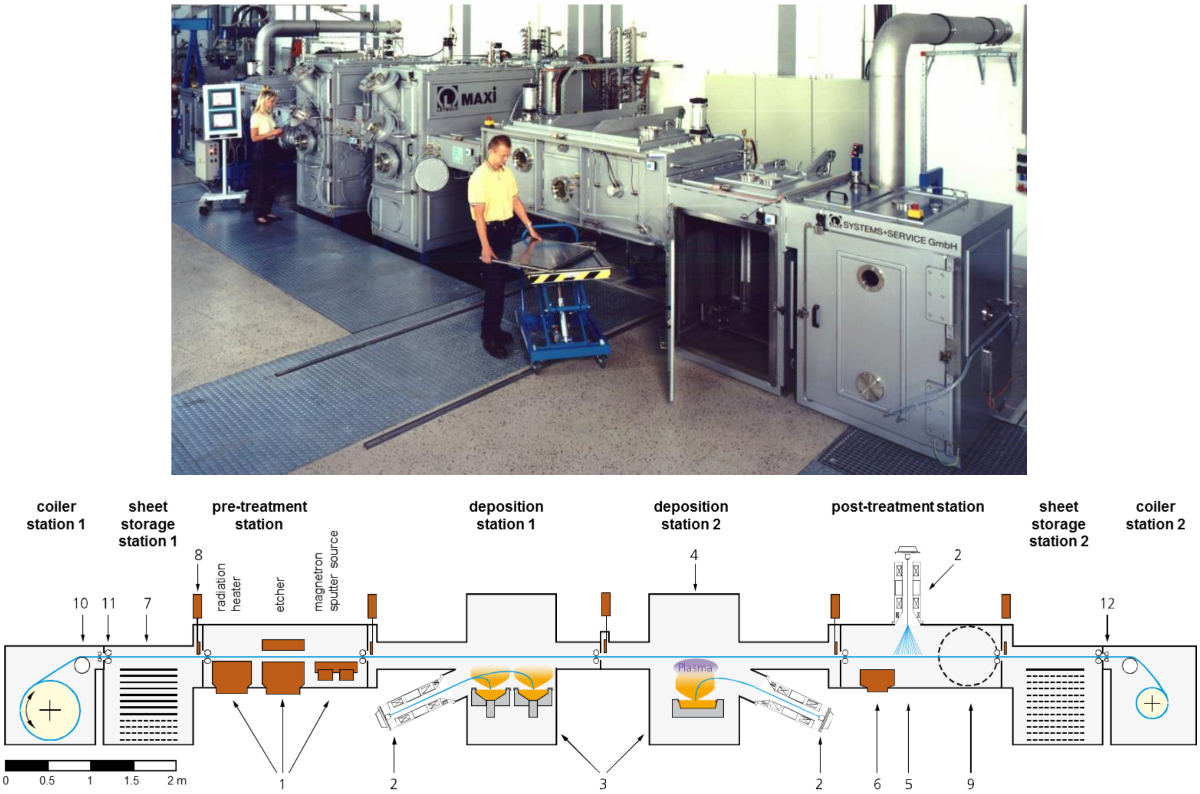

**Figure 4:** Schematic layout of
a) Spotless arc Activated Deposition (SAD) process and
b) Hollow cathode arc Activated Deposition (HAD) process

## 6. Applications for plasma activated high-rate electron beam deposition

FEP has used the plasma activated high-rate electron beam deposition for different applications:

- Titanium based photo-catalytic and hard coatings (anatase $TiO_2$, TiN, TiC)
- Silicon oxide layers for different applications like:
  - transparent abrasion protection,
  - corrosion resistance,
  - electrical isolating properties and
  - optical functions.
- Zirconium oxide coatings for fuel cells
- Mo back contact layers for photo voltaic application
- decorative colored coatings

For most of the R&D work we use our in-line vacuum coating equipment for sheets and metal strips/foils “MAXI” (see figure 5).




**general**
**(flexible technological equipment - example)**
1...various pre-treatment processes, e.g. heating, etching, deposition of interfacial layers
2...high power electron beam gun
3...various crucibles to evaporate different materials (metals, alloys or compounds)
4...plasma activated deposition process
5...thermal post-treatment, e.g. electron beam heating
6...XRF-thickness-distribution-measurement-system, optical film thickness measurement system by using acromatic light
7...sheets in frames, stacked
8...valves, to decouple pressure
9...turn-over device for double side coating of sheets
10...strip edge control system
11...sealing roll pairs, to decouple pressure
12...squeeze valve, during coil change

**sheets**

| | |
|---|---|
| maximum size: | 500 mm x 500 mm |
| maximum weight: | 15 kg |
| speed: | 0.001 ... 1.0 m/s |

**strips**

| | |
|---|---|
| maximum width: | 300 mm |
| minimum thickness: | 0.04 mm |
| maximum thickness: | 1.50 mm |
| speed: | 0.001 ... 1.0 m/s |

**Figure 5:** FEP’s in-line vacuum coating equipment for sheets and metal strips/foils “MAXI”

## 7. Summary and outlook

New vacuum coating technologies for metal strips and foils:

- Many new coating technologies are on the way.
- New plasma processes are developed.
- New cooling possibilities are developed and proven.
- Fundamental research has been performed.
- Quality of the deposited layer stacks is promising.
- Estimated deposition cost are reasonable.
- Some unique large scale laboratory equipment are available at FEP
  e.g. our MAXI line closes the gap between laboratory equipment and industrial plants.
- Some new applications are well prepared for upscaling and industrialization.
- Main fields of current and future applications:
  Energy (PV, batteries, fuel cells, mirrors, solar thermal, …) and decorative elements