Industrial Applications of PVD Coating Technology Today

Jinghong Vacuum Thin Film Co., Ltd
www.jh-vac.com
Outline of content

• Surface engineering technologies in general, relative comparisons
• Examples of coated tools and components used in major industrial segments
  – Cutting tools
  – Metalforming stamping, punching tools
  – Plastic injection molding
  – Automotive sliding engine components
  – Decorative applications
• PVD basics
  – Physics of vapor deposition
  – Tool surface requirements for good coating adhesion
  – Some limitations
• How do you acquire PVD technology for your product?
• Some statistical data on coated tools and components, including SECA information
Surface engineering principle: A hard skin protects metals against all forms of wear
Comparison of surface hardening treatments in metalforming

<table>
<thead>
<tr>
<th>Work material</th>
<th>Surface Treatment</th>
<th>Layer Hardness, HV</th>
<th>Layer Thickness, µm</th>
<th>Process Temperature, °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon steels, alloy steels, stainless steels</td>
<td>Nitriding, Carburizing</td>
<td></td>
<td>125 - 1500</td>
<td>800 - 1100</td>
</tr>
<tr>
<td></td>
<td>Gas (Ion) nitriding</td>
<td></td>
<td>75 - 750</td>
<td>350 - 570</td>
</tr>
<tr>
<td>Tool steels</td>
<td>Hard chrome plating</td>
<td></td>
<td>25 - 250</td>
<td>40 - 70</td>
</tr>
<tr>
<td></td>
<td>Thermal Diffusion carbide coating</td>
<td></td>
<td>5 -10</td>
<td>1000 - 1050</td>
</tr>
<tr>
<td>Tool steels, high speed steels, cemented carbide</td>
<td>Chemical Vapor Deposition (CVD)</td>
<td></td>
<td>5 - 15</td>
<td>900 - 1050</td>
</tr>
<tr>
<td></td>
<td>Physical Vapor Deposition (PVD)</td>
<td></td>
<td>2 - 10</td>
<td>250 - 500</td>
</tr>
</tbody>
</table>

25 µm = 0.001 inch
Hard coatings at the cutting edge of carbide tools: PVD developments predominate the last decade

<table>
<thead>
<tr>
<th>Year</th>
<th>Coatings</th>
</tr>
</thead>
<tbody>
<tr>
<td>1970</td>
<td>CVD TiC</td>
</tr>
<tr>
<td>1975</td>
<td>CVD TiC / TiCN / TiN</td>
</tr>
<tr>
<td>1980</td>
<td>CVD TiC / Al₂O₃ / TiN</td>
</tr>
<tr>
<td></td>
<td>CVD TiC / TiCN / Al₂O₃ / TiN...</td>
</tr>
<tr>
<td></td>
<td>MTCVD TiCN</td>
</tr>
<tr>
<td>1985</td>
<td>PVD TiN</td>
</tr>
<tr>
<td></td>
<td>PVD TiCN</td>
</tr>
<tr>
<td>1990</td>
<td>PVD TiAlN</td>
</tr>
<tr>
<td></td>
<td>CVD Diamond</td>
</tr>
<tr>
<td>1995</td>
<td>PVD TiN / TiAlN / TiN / TiAlN...</td>
</tr>
<tr>
<td></td>
<td>PVD TiB₂</td>
</tr>
<tr>
<td>2000</td>
<td>PVD TiN / TiCN / MoS₂, TiAlN / WC-C</td>
</tr>
<tr>
<td></td>
<td>PVD TiAlN multi-, nano-layers, AlCrN</td>
</tr>
</tbody>
</table>
CVD vs. PVD coated tools

**PVD has certain advantages cf. CVD**
- PVD applies to HSS and carbide, CVD only to carbide tools
- low $T_{dep}$ preserves carbide edge toughness
- compressive residual stress $\sigma_R$ inhibits crack propagation
- applied to sharp cutting edges
- finer grains (smoother), higher microhardness
- non-equil. compositions impossible with CVD
- environmentally cleaner process

**PVD has certain limitations cf. CVD**
- adhesion to substrate *sometimes* marginal, relative to diffusion bonding in CVD
- thickness limited due to residual stress – typical 4 µm PVD cf. 12 µm CVD coatings
- multilayer coatings more common in CVD, including alumina (not yet economic by PVD).
In metal cutting coating properties alter the heat generation and heat transfer between chip and tool.

Variables affecting heat generation:
- Work material – fracture energy, strain-hardening coefficient, thermal conductivity
- Friction coefficient at tool/chip contact surfaces, contact length dictated by cutting edge geometry
- Coating thermal conductivity
- Metal cutting parameters (speed, feed, depth of cut)
Cutting tools are ~2x harder than the workpiece materials; the coating is significantly harder than the tool substrate.

![Strength and Ductility of Steels Diagram]

- **HARDENED ALLOY STEELS**
- **NON-HARDENED ALLOY STEELS**
- **PLAIN CARBON STEELS**

- **HRc**
  - ~90+ PVD coating
  - ~85 Carbide tool
  - ~70 HSS tool

- **Elongation, %**
- **Hardness, HB**
- **Higher Cutting Force**
- **Longer chips**
Coatings benefit tools and components

- Metal cutting
- Punching/Stamping
- Plastic forming molds
PVD coatings are thin!

1 \mu m = \frac{1}{1000} \text{ mm}

Human hair: 50 – 100 \mu m

PVD layers: 1 – 10 \mu m

multi-layered coating
The three phases of coating formation

Vaporization
- Working gas inflow
- Source materials (target, cathode, ingot, etc.)
- Energy

Particle transport in the plasma
- Reactive gas inflow
- Electrons
- Ions (+/-)
- Atoms
- Molecules
- Radicals

Condensation
- Base material (substrate)
- Bias
Typical features of PVD coating technology

**The Process**

- High vacuum, plasma-activated coating deposition
- Coating temperature between 450 and 1030 °F
- Line of sight process (areas can be masked)
- Requires clean, contaminant free surfaces

**The Result**

- Micro/nano-grained, hard, lubricant coating
- Residual compressive stress
- No edge effects – with proper edge prep
- Polished surfaces can be coated
- No heat treatment necessary after coating
- Limited coatability of holes and slots
Critical factors for coated cutting/forming tool performance

- Good tool design, e.g., cutting edge micro-geometry
- Suitable tool substrate material selection
- Proper heat treatment (HSS) / carbide grade choice
- Correct surface preparation
- Appropriate coating for the application
- Selection of a quality coating process
- Optimize the machining/forming parameters
- Machine trial with coated tool on the job
Importance of surface preparation: factors that affect coating adhesion

- Contamination-free surfaces: grease, oxide layers, polishing residues must be removed; no Zn, Cd and low temp. braze metals
- No overheating during surface grinding: avoid deep grind marks and high surface roughness
- Edge prep is important: sharp edge should be de-burred, correctly honed
- EDM’ed surfaces must be post- treated to remove white layer
- No surface cobalt depletion on carbide substrates
- No cobalt capping on carbide substrates
PVD technology acquisition options

Tool company, major end user

1. Toll coating service with one or several toll coaters

2. Investment in coating plant

3. Partnership on in-house coating plant
Typical 3-day coating service from SECA companies
Estimates of realized and potential PVD coating global market for cutting tools

Assume PVD value = 10% of $1.1B tool sales = $1100M; total PVD coated penetration of the global cutting tool market is ~25%, cf. 33% CVD coated, 32% uncoated.
PVD coating USA statistics help SECA members plan their business

Market Capacity:
PVD value if all produced cutting tools were PVD coated (others are CVD coated or uncoated)

US cutting tools 2003 total consumption = $2.53B; assume PVD value is 10%

Market Potential:
PVD value of tools for which PVD coating makes sense

Realizable market potential is 56% of current market volume

Market Volume:
PVD value of coated tools (including OEMs)

This calculation gives total market penetration of 58%.

Company Market Share:
PVD GSR cutting tools

Inferred from SECA statistics

SECA member company can calculate its market share from SECA statistics