The role of HiPIMS and Discharges with a Positive Voltage Reversal on Coating Properties in Industrial Applications such as Hard Coatings and DLC

Frank Papa\textsuperscript{1,2}, Dr. Iván Fernández Martínez\textsuperscript{2}, Ambiorn Wennberg\textsuperscript{2}, Gerhard Eichenhofer\textsuperscript{3}

\textsuperscript{1}Gencoa USA, Medina, Ohio USA  
\textsuperscript{2}Nano4energy , Madrid Spain  
\textsuperscript{3}Hip-V, Stocksund, Sweden  
\textsuperscript{4}4A-Plasma, Holzgerlingen, Germany
Jose Antonio Santiago
Jon Molina
Miguel Monclus

Iván Fernández Martínez
Ambiorrn Wennberg

Raquel González-Arrabal

Juan C. Sanchez-Lopez
Cristina T. Rojas
J.Miguel García

Victor Bellido-González

Tomás Kozác
Jiri Capek
Petr Zeman
HiPIMs with V+

High density of ions in HiPIMS, so.....

.........any effect on plasma and coating properties?
HiPIMS with V+ 

A new ion extraction mechanism: acceleration from target surface.

Raise of plasma potential (bombardment of low V surfaces)
HiPIMS V+
Floating Potential

\[ I_{\text{peak}} \sim 200\text{A} \quad +450\text{V} \]

\[ V_{\text{floating}} = -25\text{V} \]

\[ E_i = E_0 + Qe (V_{\text{plasma}} - V_{\text{surface}}) \]
HiPIMS with V+ H-free DLC

6kW Hip-V 1200V – 500A.
Cr, WC and Graphite targets
40x10 cm² rectangular magnetrons.
Pure Ar atmosphere.
Deposition on Silicon + HSS coupons
High energy ions are generated in the switching electric field.
Nanomechanical properties: H/E t-a:C

More energetic ions $\rightarrow$ higher sp$^3$ hybridization

Hardness = 36GPa
Young’s Modulus = 248GPa

Triboindenter TI950 from Hysitron equipped with a diamond Berkovich indenter.
Raman shift – Carbon Coatings

A.C. Ferrari, Chapter 2 in “Tribology of Diamond-Like Carbon films”
Getting close to t-a:C by filtered-arc

Reference commercial ta-C by Filtered Arc (60% sp3)

sp³ ratio proportional to:
- G peak shift to higher wavenumbers
- D peak reduction

Raman excitation wavelength Argon 522nm (Green)
Double HiPIMS: Cr-doped DLC

Nanoindentation tests: Air, diamond Berkovich tip, Hysitron Xsol Stage and Tip

Temperature (°C)

Hardness (GPa)

Stable up to 400°C

‘Hard’ DLC

‘Hard’ Cr-DLC (optimum %Cr)

‘Soft’ Cr-DLC (excess of %Cr)

‘Soft’ Cr-DLC (Carbon with low sp3)
Cr-DLC: Wear vs Temperature in Air

Lowest wear rate for Double HIPIIMS Cr:DLC! < $0.5 \times 10^{-15}$ m$^3$/Nm at 200°C

Low amount of Cr is sufficient to delay graphitization.
COF for Cr-DLC

As deposited

COF for Cr-DLC as low as 0.02 at 200°C
(as compared to 0.08 for standard 30GPa DLC)

Pin-on-disk conditions: Air, Al2O3 ball, 5N, 10cm/s
Examples of ‘Hard’ DLC Coated Parts
Implementation on Industrial Tool

xPro4C
DLC - Coating System
HiPIMS with V$^+$ TaN CFUBM

<table>
<thead>
<tr>
<th>Dep. rate [µm/hr]</th>
<th>0.51</th>
<th>0.42</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hardness [GPa]</td>
<td>21</td>
<td>17</td>
</tr>
<tr>
<td>POSITIVE</td>
<td>YES</td>
<td>NO</td>
</tr>
</tbody>
</table>

25% increase of deposition rate (ion incorporation into the film)
CrN/ZrN in Industrial System
CrN/ZrN in Industrial System

3-fold rotation
2 x magnetrons
5kW average each
-60V bias
650 mm diameter x
650 mm height
CrN/ZrN in Industrial System

1µm/hr!! for CrN and ZrN

23-25 GPa
250 °C
Summary

- HIPIIMS with Positive Voltage Reversal can be used to control the degree of metal/gas ionization as well as ion energy
- 25% increase in deposition rate as compared to standard HIPIIMS
- Self “Ion Assisted” deposition for coatings on insulating substrates
- Successfully implemented on several Industrial platforms
Thank you for your attention !!

Visit us in booth #310 Genco