The application of a short positive voltage reversal in HIPIMS – Widening the process window and increasing deposition rate

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Frank Papa, founder and president of GP Plasma, LLC. He represents Nano4Energy in the USA and China. He currently manages Gencoa USA and has worked at Hauzer Techno Coating, Crystallume Inc. and Vergason Technology. His background is in sputtering, arc and CVD processes and hardware development.

冯利民, 工程热物理专业; 豪泽技术涂层5年销售经理; 上海新弧源涂层技术有限公司6年总经理; Nano4Energy国内独家代理.
What do we do?

The industrial HiPIMS choice!

The All in ONE

HiPIMS-PS

Features:

- HiPIMS-PS Uni-Polar / Bi-Polar (with Superimposed / Sequential HiPIMS capability)
- DC-PS (for magnetron sputtering, PECVD, Etch...)
- DC-Pulsed-PS Uni-Polar / Bi-Polar (for magnetron sputtering, PECVD, Etch...)
- HiPIMS-Bias / DC-Bias / DC - Pulsed- Bias (synchronization possible)
- Single & Dual magnetron capability
- hiPLUS Option (Positive voltage reversal for boosted productivity)

Not only power supplies!

We do process development, system design, and on site commissioning and training. Contract R&D available in Madrid, Spain (along with great food and wine!)

不仅仅是电源，工艺开发，系统设计，现场调试、培训，合作研发等

西班牙马德里（西班牙美食&红酒）
# What do we do?

## Product Overview:

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>Power</td>
<td>1KW</td>
<td>6KW</td>
<td>10KW</td>
<td>10KW</td>
<td>20KW</td>
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<tr>
<td>Peak Power</td>
<td>0.1MW</td>
<td>0.5MW</td>
<td>1.2MW</td>
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<td>2.4MW</td>
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<td>Voltage</td>
<td>1200V</td>
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<td>1200V</td>
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<tr>
<td>Current max. HiPIMS</td>
<td>100A</td>
<td>500A</td>
<td>1000A</td>
<td>2000A</td>
<td>2000A</td>
<td>1000A</td>
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<tr>
<td>Current DC max.</td>
<td>3A</td>
<td>18A</td>
<td>25A</td>
<td>25A</td>
<td>50A</td>
<td>50A</td>
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<tr>
<td>Frequency max.</td>
<td>40KHz</td>
<td>2KHz</td>
<td>2KHz P&lt;sub&gt;max&lt;/sub&gt; @1KHz</td>
<td>1KHz</td>
<td>1KHz</td>
<td>2KHz P&lt;sub&gt;max&lt;/sub&gt; @1KHz</td>
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<tr>
<td>Time ON</td>
<td>5-1000μs</td>
<td>5-1000μs</td>
<td>5-1000μs</td>
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<td>5-1000μs</td>
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<tr>
<td>ARC Control</td>
<td>&lt; 3μs</td>
<td>&lt; 3μs</td>
<td>&lt; 3μs</td>
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<td>&lt; 3μs</td>
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<tr>
<td>Cooling</td>
<td>Air</td>
<td></td>
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<td>Water &amp; Air</td>
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Custom HiPIMS Power Packs up to 80kW available.
What do we do?

- High peak powers (500-2000 W/cm²)
- Reasonable average power (up to 80kW)
- Low duty factors (0.5-5%)
**HiPIMS with V+**

Active V+

Passive V+

no V+

hiPlus Option

What does it look like?
High density of ions in HiPIMS, so, any effect on plasma and coating properties?

具有高离化率，高离子密度。正脉冲对涂层属性的影响？
HiPIMS with V+  Negative phase  负脉冲周期

Voltage (V)  time (μs)

Floated substrate
- Ion acceleration from the target surface 离子被加速沉积
- Raise of plasma potential (bombardment of low V surfaces) 等离子电位提升
靶电压和基体电压同比例变化 - 可以控制涂层的性能
HiPIMS Carbon: IEDF 沉积碳膜，粒子能量提高
**HiPIMS with V+**

**OES 离化率提高**

![Graph showing intensity vs. wavelength with V+ on and off](image)

- **V+ ON**
- **No V+**

**Integrating (a.u.)**

**Wavelength (nm)**

450 480

10

20
Pure C-DLC 纯碳膜，硬度提升

Negative Bias at substrate = -40V
DLC coating on Glass 玻璃上沉积 DLC

Hardness in the range of 20GPa for 400nm thick DLC layer

Patent applied with Gencoa Ltd.
Pure C-DLC 纯碳膜，硬度提升

Hardness = 33GPa

Negative Bias at substrate = -150V
Hardware used for experiments 试验用器材

6kW HIPIMS PS unit
Constant Average Power 3kW
120us – 500Hz
$I_{\text{peak}}$ : 220 – 500A peak

Planar rectangular magnetron (400x100mm²)
Ti, Al targets
N,O reactive gas

With HIPIMS option (optical and electrical)
HIPIMS V+ TiN coatings: feedback control

反应溅射TiN，不同靶中毒控制下的对比

SetPoint

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<th>45%</th>
<th>35%</th>
<th>25%</th>
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<tbody>
<tr>
<td>Ti (400mm2)</td>
<td>Ar + Nitrogen</td>
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<td>RT deposition</td>
<td>Floating potential</td>
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<td>Constant Average Power</td>
<td>3kW</td>
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<td>120us – 500Hz</td>
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<tr>
<td>$I_{peak}$</td>
<td>220 – 500A peak</td>
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<table>
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<tr>
<td>Hardness [GPa]</td>
<td>22.0</td>
<td>22.5</td>
<td>17.5</td>
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<tr>
<td>Dep. Rate [µm/hr]</td>
<td>3.7</td>
<td>3.7</td>
<td>3.5</td>
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</table>
TiN Planar rectangular magnetron (400x100mm)

<table>
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<tr>
<th>Hardness [GPa]</th>
<th>22.0</th>
<th>13</th>
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</thead>
<tbody>
<tr>
<td>Positive V reversal</td>
<td>YES</td>
<td>NO</td>
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</table>
Morphology: SEM

光滑致密涂层 Smooth TiN coating

TiNx

Ti bonding
Morphology: XRD

晶体形貌改变 Change in morphology with HiPIMS v+
Higher deposition rate at same magnetron poisoning condition!

室温下反应溅射TiN

对比不同靶中毒条件下的沉积速率，有和没有V+
Dep. rate $[\mu m/hr]$: 0.51, 0.42
Hardness $[GPa]$: 21, 17
POSITIVE: YES, NO

4kW, 75 $\mu$s, 325Hz, $I_{\text{peak}} = 450A$, $V_{\text{peak}} = 950V$

Magnetron in fully poisoned mode. 溅射靶中毒情况下
Similar at% composition  不同靶中毒条件下具有类似情况
Metal Ion Etching

金属离子蚀刻，提高结合力

Epitaxial Ti/Cr (RT)

Metal etched + implanted

M2 HSS

Critical loads above 100N!! – 1 micron thick DLC layer
Advantages / Improvements of HiPIMS V+

- Discharging the target - reduces Arcing.
- Higher deposition rates for metals and reactive processes
- Ion assistance for coatings on insulating substrates
Advantages / Improvements of HiPIMS V+

➢ Can be used for energetic deposition – wider process window

更广泛的工艺窗口，控制沉积能量

➢ And for substrate pre-treatment!! (metal and oxygen ion etching!)

涂层前蚀刻！（金属及氧化物离子蚀刻）

➢ Low temperature deposition

低温沉积
• Power supplies are built by Viesca (founded in 2004) in Madrid Spain.

• Viesca’s developed high power pulsed power supplies for trains – up to 1MW average power, 0.5 GW peak power!

• Need to guarantee service and parts for power supplies for 30 years after purchase!

• 24 direct employees + subcontractors

• In house development and testing

• Started to produce for Nano4Energy in 2008
3 generations...

Gen 3 - 2016

Gen 1 - 2008

Gen 2 - 2014
Most companies developed in the following order:

- DC
- Pulsed DC
- HIPIMS
- Low to high power

We went the other way 不走寻常路！

Our Hipims supplies (1 – 20 kW) are a smaller version of Viesca’s high power supplies (100kW-1MW)!
power supply sales and support

Quoted price to your factory

Spare power supply in China

Chinese technical support and Service

Remote Support

Process Development and Contracting

Coating Development and Sampling in Madrid

Coming to China soon!
Ready for Industry!

3 meters tool coating machine

80 kW HIPIMS!
Thank you for your attention !!