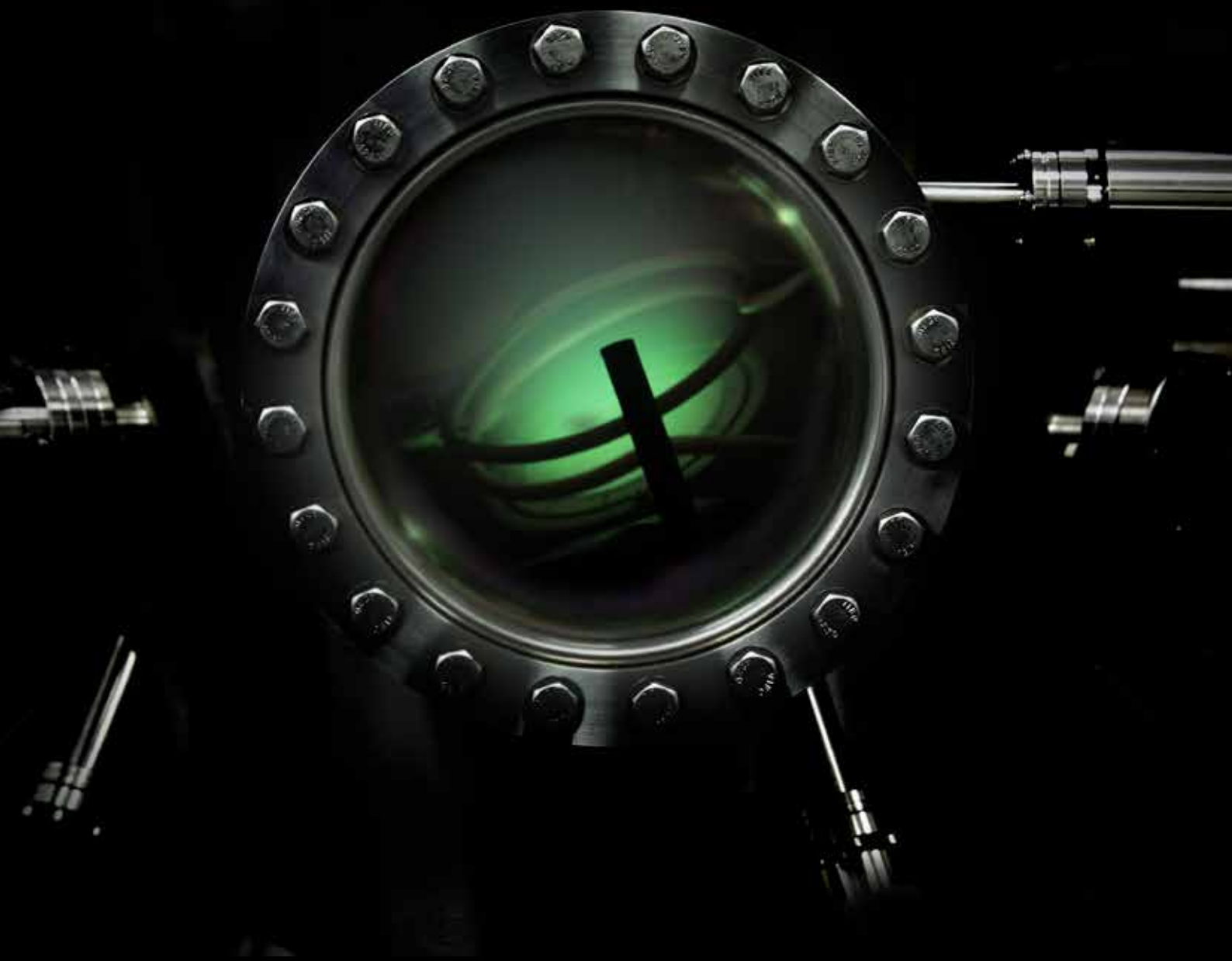
Sheffield Hallam University | Materials and Engineering Research Institute

High power impulse magnetron sputtering (HIPIMS) *for surface pre-treatment and coating deposition*



HIPIMS Technology

High power impulse magnetron sputtering (HIPIMS) is a revolutionary magnetron sputtering technology used for surface pre-treatment and coating deposition.

HIPIMS uses several MWs of power in short pulses in a gas discharge allowing it to access high peak power densities on the sputtering target (up to 3000 Wcm^{-2}) resulting in the production of highly ionised gas-metal plasma.

The technology delivers improved coating adhesion and quality, such as high density and low surface roughness, and enables coating of complicated shapes or cavities that are traditionally difficult to coat.

There are wide ranging applications where HIPIMS technology can be used to improve coating adhesion and quality, including

- applying coatings to biomedical implants such as hip joints
- high temperature applications such as turbine blades
- low friction applications such as piston rings in the automotive industry
- applying coatings to cutting tools that are used to machine difficult materials
- cryogenic materials applications
- semiconductor wafer metallisation.

This brochure showcases a number of specialist applications developed at the HIPIMS Technology Centre at Sheffield Hallam University.

HIPIMS at Sheffield Hallam University

We have been developing our HIPIMS facility and expertise for over a decade to remain at the leading edge of this technology.

We have come a long way from our first optical emission spectroscopy of the plasma, generated from a lab-sized magnetron revealing the metal ionisation in 2001.

Along the way, we have worked with partners from industry to create a bespoke HIPIMS power supply which allows large industrial-size cathodes to be energised, and developed a dedicated HIPIMS bias power supply.

These developments gave industry a complete solution for the required HIPIMS hardware.

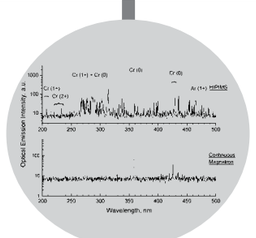
We have granted commercial licenses to a number of industrial companies worldwide, both for surface pre-treatment as well as know-how and recipes for coatings production using HIPIMS.

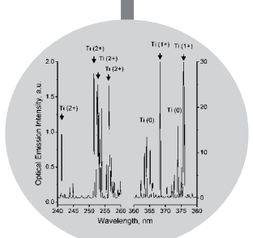
Through our research and development work, we will continue to push the boundaries of the HIPIMS technology and applications for commercial use.

January 2001
First OES of HIPIMS on lab size magnetron

December 2003
First industrially viable HIPIMS power supply developed in collaboration with AC (now HUETTINGER)

January 2004
First HIPIMS on industrial size (500×88 mm) CemeCon cathode.





February 2004
February 2004. HIPIMS on large (600×200 mm) HAUZER cathode.

December 2006
December 2006. First HIPIMS dedicated Bias power supply. Patented by Sheffield Hallam University, Hauzer, Huettinger.

April 2011
AP Ehiasarian et al, Patent ZL200780012990.9 in China, granted 10.04.2011.

From fundamental research *to application*

Outputs from our fundamental research include

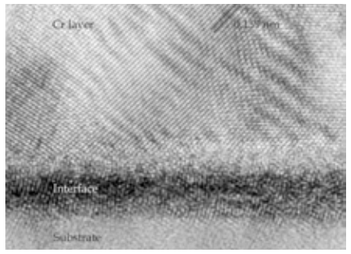
- definition of the power law in the voltage-current characteristics for HIPIMS discharge
- correlating plasma ionisation to the target power density
- revealing the relation between strength of the confining magnetic field and the deposition rate of HIPIMS

Using ultra-fast camera imaging, studies at the University found dynamic formation and restructuring of 'plasma regions' in the discharge due to plasma instabilities in HIPIMS.

In collaboration with the University of Bochum, Germany, these instabilities were shown to be the main reason for plasma ejection from the intended path, and particle transport away from the target.

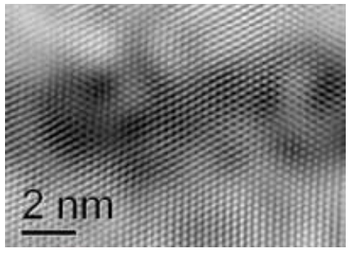
One of the first successful applications of HIPIMS at Sheffield Hallam on a large scale was surface pre-treatment to enhance coating adhesion.

HIPIMS pre-treatment of the surface allows metal ion implantation whilst maintaining the crystalline character of the substrate material. This promotes local epitaxial growth of the coating over large lateral areas, resulting in excellent adhesion. (AP Ehiasarian et al, EP 02 011 204.1 (2001))



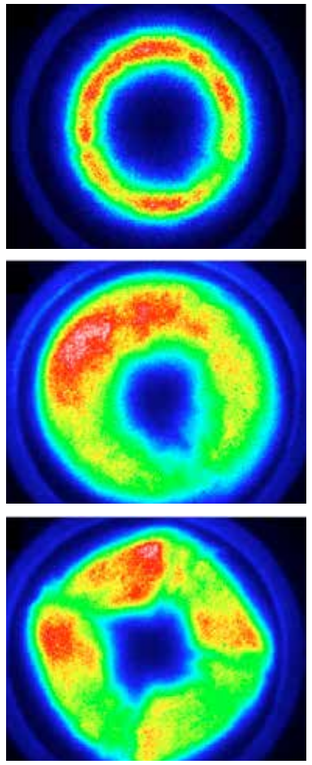
Standard Ar pre-treatment.
Amorphised interface with a more random structure.
Results in poor adhesion.

(Image courtesy of Jeff Th. M. De Hosson, the Department of Applied Physics, Mater Scientific Centre, University of Groningen, The Netherlands.)



HIPIMS pre-treatment.
Crystaline interface with well-defined orientation.
Results in strong adhesion.

(Image courtesy of EC, Innovatial Project. NMP3-CT-2005-515844.)



(Images show plasma instabilities on the surface of a planar circular cathode.)

Coating applications

Coatings using monolithic, nanoscale multilayer and nanocomposite structures deposited by reactive and nonreactive HIPIMS have been developed for a wide range of applications.

Multilayer coatings – CrAlYN/CrN

Nanoscale multilayer structured coatings CrAlYN/CrN have been grown with excellent interlayer segregation and strongly improved density and adhesion. These coatings provide excellent environmental protection and reduced fatigue deficit of aerospace as well as steam turbine blades.

Multilayer PVD coatings – TiAlCN/VCN

Using HIPIMS, a new generation of nanoscale TiAlCN/VCN multilayer PVD coatings have been developed that enable the machining of difficult-to-cut materials, such as titanium and aluminium alloys.

A new structure concept using low shear strength interfaces manipulates the coating wear mechanism which reduces the built-up edge formation during machining.

The images 2-4 show the difference in the built up edge of an end mill after machining an aluminium-silicon alloy. The uncoated end mill (3) shows a built up edge, while the end mill coated with the new TiAlCN/VCN coating (4) has no built up edge.

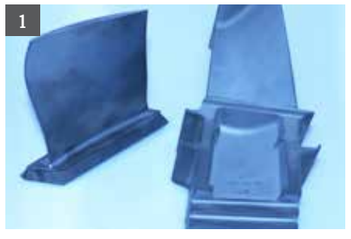
High aspect vias

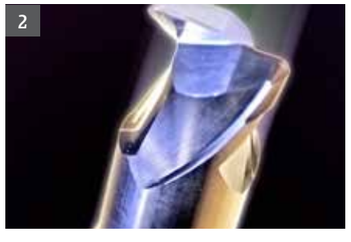
In microelectronics, the drive to miniaturise devices has meant rethinking the way microchips are connected with each other. Rather than the traditional layout of microchips on a board, several microchip wafers are combined into one package and interconnected by microscopic vias that are filled with conducting material.

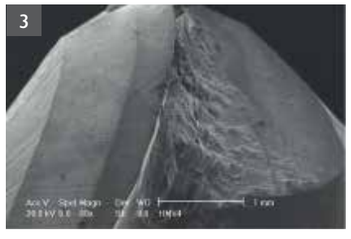
In close cooperation with OC Oerlikon, a company that develops specialist coatings and equipment, a HIPIMS technology has been developed at the University for metalizing high-aspect vias with a depth-to-width ratio of 30:1. This long, yet thin cavity would be extremely difficult to apply a coating to using traditional methods of deposition.

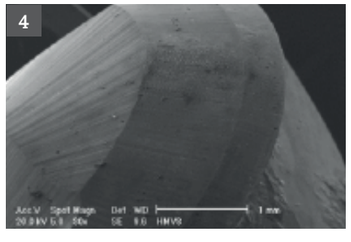
The technology has been up-scaled to a production cycle for through-silicon via (TSV) interconnects on 200 mm wafers, used in the production of 3D integrated circuits.

P. Eh. Hovsepian et al, "PVD Coated Substrate" - GB0508485.0, EP 1874981, granted 14.02.2009.

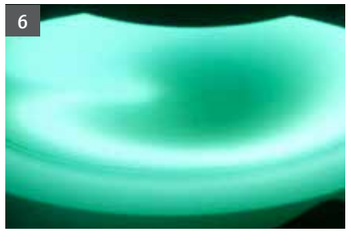

1


2


3


4


5


6

This page Left to right:

1. NP gas turbine buckets coated with CrAlYN/CrN nanoscale multilayer coating EC, Innovatial Project,NMP3-CT-2005-515844. Patent numbers GB2450950B and EP2017366B1

2. Coated end mill

3. The formation of a built up edge on a non-coated end mill

4. The cutting edge of a coated end mill, free of a built up edge

5 and 6. HIPIMS discharge in operation

Performance-enhancing rare-earth coatings

HIPIMS was successfully employed at Sheffield Hallam in a joint project with the Space Science Technology Department of Rutherford Appleton Laboratory (RAL), based in the UK.

The project required first time flight-worthy, highly crystalline, dense and highly adherent rare-earth coatings to enhance the performance of cryocoolers used in space satellites.

The new coatings that were developed now allow Stirling cycle cryocoolers to reach record low temperatures of 9.3K. This feature makes them the first choice for forthcoming missions such as EChO, a space-based observatory to characterise the physics and chemistry of exoplanet atmospheres.

Industrial photovoltaic cell coatings

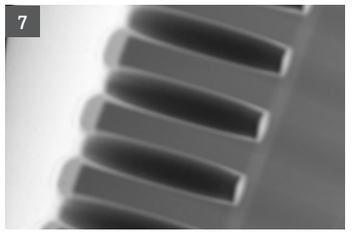
HIPIMS technology is finding new applications in the deposition of Cu(InGa)Se2 in industrial photovoltaic cell coaters. A 3% (absolute) improvement in efficiency over conventional sputtering has been achieved using HIPIMS, in cooperation with Day Star, USA.

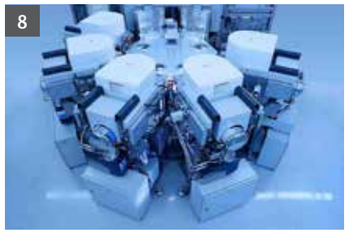
The research continues through an Engineering and Physical Sciences Research Council (EPSRC) funded project where Sheffield Hallam is working closely with Fraunhofer IST and Von Ardenne Anlagen Technik in Germany. The project is also supported by Pilkington and Gencoa.

Inductively coupled impulse sputtering (ICIS)

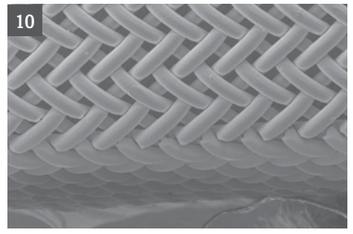
ICIS is the latest development in the field of highly ionised plasma generation at Sheffield Hallam University. (AP Ehiasarian et al, 'RF-Glow Discharge Sputtering', UK appl. GB 2469666 A. 27.10.2010)

ICIS is a magnetron free operation using high impulse power. The absence of a magnetron using electrons and a magnetic field to deposit plasma means that now both magnetic and non-conducting materials can be sputtered with a high degree of material ionisation. Even deposition on sidewalls and good bottom coverage has been demonstrated for high aspect ratio structures.


7


8

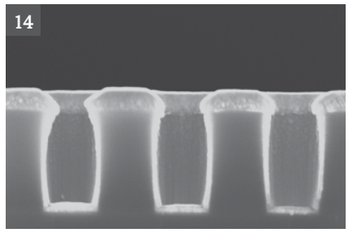

9


10


11


12


13


14


15

This page Left to right:

7. TEM Cross section of vias showing excellent bottom coverage

8. Oerlikon Clusterline 200, producing the 200mm silicon wafers with an aspect ratio of 30:1. Commercialised 2010

9. RAL Stirling cycle cryocooler array

10. HIPIMS coated cooling mesh. The mesh was bent to 180° without any coating spallation, demonstrating the excellent adhesion due to the HIPIMS pre-treatment

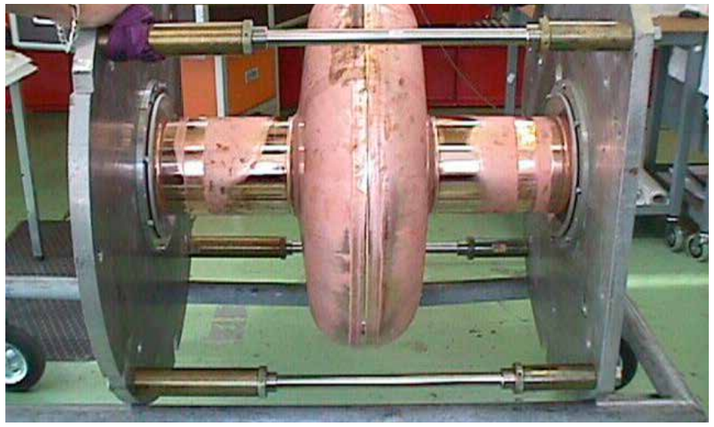
11. CuInGaSe – PVD solar panels

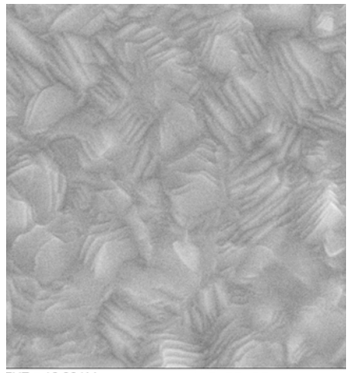
12. PVD facility at Day Star USA for pilot production of CuInGaSe panels

13. HIPIMS of copper on 1500mm tall rotatable cathode

14. SEM cross section of ICIS sputtered nickel on silicon wafer vias

15. ICIS source in operation





This page clockwise:
Copper super-accelerating cavity
Morphology of HIPIMS-deposited superconductive coating for cavities
Large Hadron Collider at CERN, Geneva

Superconducting films
In collaboration with CERN – the European laboratory for particle physics – we're developing a plasma informed HIPIMS technology for the deposition of low temperature superconducting films on the inner walls of the particle accelerator.

The particle accelerator lies in 17 miles of tunnel beneath Geneva and forms part of the Large Hadron Collider, which aims to push the boundaries of understanding relating to particle physics and high-energy physics.

In order to collect collision data for two opposing particle beams, the inner walls of the accelerator need to have zero resistance to achieve maximum acceleration of the particles.

The superconducting films developed have improved electrical resistance and expulsion of magnetic fields, making them ideal for coating the particle accelerator tunnel.

Areas of *expertise*

As a leading institution in the development of HIPIMS, we have wide-ranging expertise, including

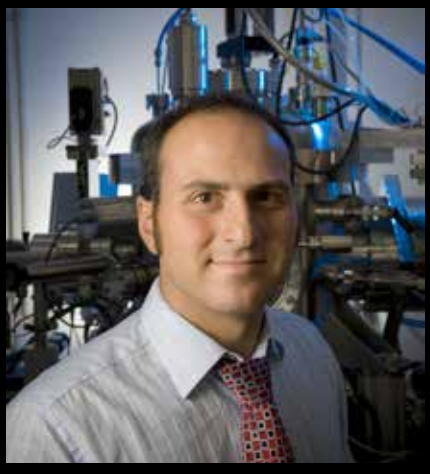
- the development of HIPIMS-based technologies for deposition of application tailored PVD coatings
- plasma characterisation
- the development of plasma sources for new processes, such as inductively coupled impulse sputtering (ICIS)
- characterisation of microstructure and mechanical properties
- tribological and high temperature oxidation studies
- corrosion performance of PVD thin films

Services
We offer organisations HIPIMS services including

- basic research on highly ionised plasmas used for coating deposition and surface modification
- contract research to provide HIPIMS based surface engineering solutions to industry
- postgraduate training
- HIPIMS training courses – fundamentals and application

Partnerships
We work very closely with partner organisations in industry to further develop our HIPIMS expertise and technology, including Hauzer, IonBond, Huettinger and many others.

We have also created the joint Sheffield Hallam University and Fraunhofer IST HIPIMS Research Centre – the only one of its kind in the UK. This broadens our expertise and provides critical mass for undertaking large research and development projects in new areas of industry.



For research, technical and business information contact

Professor Arutiun P Ehiasarian
HIPIMS Technology Centre
Materials and Engineering Research Centre
Sheffield Hallam University
Howard Street
Sheffield
S1 1WB, UK
Email a.ehiasarian@shu.ac.uk
Phone +44 (0)114 225 3646

www.shu.ac.uk/hipims