Institution: University of Salford

Unit of Assessment: B13 Electrical and Electronic Engineering, Metallurgy and Materials

Title of case study: Atmospheric Pressure Chemical Vapour Deposition (APCVD)

1. Summary of the impact

Research in atmospheric pressure (thermal) chemical vapour deposition (APCVD) at the University of Salford demonstrates the following impact:

- Developing new concepts in the field of APCVD for application in the environmental, construction, healthcare and biotechnology sectors, resulting in commercially viable processes and products;
- Commercialising the technology via a spin out company; CVD Technologies Ltd., offering an innovative, integrated and client focused approach to exploiting the technology for its wide application;
- Achieving related patents and developing strategic licensing agreements, allowing major international companies to use CVD Technologies Ltd. technology;
- Generating economic and related social benefits, internationally.

2. Underpinning research

The key researchers and positions held at the institution at the time of the research are as follows: Professor David Sheel (from 2000), Dr Heather Yates, (from 1995) and Dr John Hodgkinson (from 2007), School of Computing, Science and Engineering. This case study focuses on research projects relating to atmospheric pressure (thermal) chemical vapour deposition (APCVD) conducted at the University of Salford since 2000, and their advancement and application in new product concepts, the following examples of which underpin the impact described:

- **2008:** University of Salford researchers in the Materials and Physics Research Centre reported, for the first time, the application of volume glow discharge atmospheric pressure (AP) plasmas to initiate CVD thin film growth of titania. By exploring the plasma conditions, the onset of crystalline film growth, critical for many titania properties (optical - for high refractive index and also for photocatalytic properties) was demonstrated. It was also demonstrated that the onset of crystallinity can be initiated around 300C (c.f. thermal typically 450C+) and that a volume plasma is viable (compared to more common “jet” designs), with volume capability compatible with scaling to larger areas, high growth rates and therefore, throughputs.
- **2008/2009:** A new approach to controlling surface nano- and microstructures in Transparent Conducting Oxides (TCOs) was based on the addition of organic additives during the growth process. A range of alcohols were screened and compared to show that surface morphology can be controlled and/or selected to a significant extent. This is significant in a number of application areas. In the Solar Cell area, a patent was filed (with an industrial collaborator) and the technology is being used by CVD Technologies Ltd.
- **2010/2011:** University of Salford researchers developed the application and the interpretation of the structure and optical relationships in the design, building and application of a new and unique instrument developed by CVD Technologies Ltd., which offers the capability to analyse angular and spectral properties of critical Photovoltaic thin films, enabling understanding of the impact on the efficiency of measuring and interpreting light scattering from nano- and micro-textured surfaces, and specifically thin film transparent conducting oxides (TCOs).
- **2010/2012:** High bio-activity is a key property for infection control which must usually be combined with appropriate durability. The research reports on the combination, for the first time, of two CVD processes (flame assisted CVD and thermal CVD – both atmospheric pressure based) which allow the creation of film compositions and structures not previously possible with APCVD. Additionally, the research has observed both passive (dark) and active (photo-) biocidal properties, including visible wavelength light enhancement for the first time, with these systems. The research results from a collaborative project which was part of an International project Nano to Production (N2P) between the UK Health Protection Agency and the University of Salford, EU funded from May 2008 to Nov 2012 involving a range of European industrial and academic partners**.**

3. References to the research

Key outputs

1. J.L. Hodgkinson, H.M.Yates, D.W. Sheel, Low temperature growth of photoactive titania by GD plasma', *Plasma processes and polymers*, 6, 575-582, (2009) DOI **(REF 2)**
2. D.W. Sheel , H.M. Yates , P. Evans , U. Dagkaldiran , A. Gordijn , F. Finger , Z. Remes , M. Vanecek Atmospheric pressure chemical vapour deposition of F doped SnO2 for optimum performance solar cells, *Thin Solid Films* 517 3061–3065 (2009) DOI **(REF 2)**
3. H A. Foster, D W. Sheel , P Evans , P Sheel, S Varghese, S O. Elfakhri, J L.Hodgkinson, H. M.Yates, Antimicrobial activity of dual layer $CuO\text{-}TiO_2$ coatings prepared by CVD against hospital related pathogens, *Chem. Vap. Deposition* 18, 140–146 (2012) DOI **(REF 2)**
4. K.Sanderson K , D.W.Sheel, J Van Deelen, W Dewald, A Roose, K Jager, Characterisation of TCO layers, ICCG 9, Breda 2012, *International Commission on Glass* (ICG)

Key grants

5. **2012:** Process Line Implementation for Applied Surface Nano Technologies (PLIANT), EC (Framework), £352,871.00, Principal Investigator: H Yates (50%). Co-Investigator: D Sheel (50%).
6. **2011:** Electrical and picosecond optical control of transistor-type plasmonic antenna switches EPSRC, £159,456.00. Principal Investigator: D Sheel (100%)
7. February 2011: Wolfson Labs Refurbishment Scheme 2010 Royal Society, £250,000.00. Principal Investigator: D Sheel (85%). Co-Investigators: H Yates (10%), R Pilkington (5%)
8. **2008:** A study of methods to produce MAX phases in thin films at temperatures below 900 C, EPSRC, £272,501.26. Principal Investigator: D Sheel (100%)
9. **2008:** UK Health Protection Agency and the University of Salford: Flexible production technologies and equipment based on atmospheric pressure plasma processing for 3D nano structured surfaces - N2P, EC (Framework), £474,682.00. Investigator: D Sheel (100%)

4. Details of the impact

Developing new concepts in the field of APCVD for application in the environmental, construction, healthcare and biotechnology sectors, including:

- Low E window coatings and Solar Control coatings for energy efficiency;
- “Self” Clean photo-catalytic coating;
- Anti-reflection coatings;
- TCOs and Interface Layers for photovoltaic thin film cells;
- Bacteriocidal coatings for infection transfer suppression.

- The EU funded collaborative project (N2P Nano to Production) has a range of European industrial and academic partners and involved (in the Biocidal surfaces part of the project) the UK Health Protection Agency and the University of Salford. The project is focused on flame assisted CVD and thermal CVD – both atmospheric pressure based, passive (dark) and active (photo-) biocidal properties, including visible wavelength light enhancement. Salford and CVD Technologies are collaborating in developing these systems in applications in hospital and healthcare settings and incorporating the technology into a patent application.
- A primary focus of our work is in the field of thin-film Photovoltaics (i.e. the modules which generate electricity from the sun). APCVD is widely used for Low E windows (which reduce heat losses through the glazing). A second significant area (and more recent) is in “self – clean” windows. These windows are photo-catalytically active and destroy organics under sunlight via photo-oxidation. Both applications are exploited by CVD Technologies Ltd. A recent focus of our research work has been in exploring lower temperature routes to APCVD using AP plasma activation (e.g. coating steels or even plastics).

Commercialising the technology via a spin out company of the University; CVD Technologies Ltd., which offers an innovative, integrated and client focused approach to exploiting the technology for its wide application:

- Impact results directly from the supporting structure offering full research and development and a complete vertically-integrated service, directly from theory through product and process feasibility, prototyping and design and commissioning of the full production process. Clients benefit from direct access to research in APCVD, meeting their requirements from concept to application. A portfolio of translational knowledge has been developed through close understanding of client needs and alignment of product development, which in turn, informs future research across many application areas.

- The supporting structure facilitates companies with product ideas which may benefit from APCVD technology including feasibility evaluation and the capacity to accelerate the process and improve quality and value in the development of products and processes, enabling clients to exploit APCVD technology within their own markets. The successful business strategy of CVD Technologies supports design, cost and supply of Industrial scale APCVD equipment, or to license the technology for exploitation.
- With a leading international reputation and the development of strategic industrial partnerships to promote APCVD in a range of markets, clients access bespoke technology solutions. CVD Technologies has secured a share of number of major turnkey APCVD coating line orders in China to the value of over $10million**.**
- Over 90% of contracts derive from outside the UK with the signing of several strategic licensing agreements allowing major international companies such as Stewart Engineering of USA, Akzo-Nobel, and Sisecam of Turkey to utilise tailored APCVD technology.
- CVD Technologies Ltd. employs industrially experienced staff who provide the ‘scale up’ expertise to link the University research work with a route to exploitation through the development of a range of Industrial R&D, prototype and full scale production equipment and system designs and offers a technology licensing model supported by equipment design and supply.
    - The first license was signed with Akzo-Nobel (later Nuon) to develop an in-line reel-to-reel APCVD system.
    - A key milestone was the signing of a licence to jointly develop a Float Glass coating system with Stewart Engineers Inc (USA), launched in 2008. A major engineering exercise (being 4 metres wide and required to operate at up to 700C and run 24 hrs a day, the system cost (turnkey) is between $7and 20 million (depending on required capabilities). CVD Technologies Ltd. is a partner in the turnkey system project. The first system was installed in China in 2009/10 and generated approaching $1million income for CVD Technologies Ltd. with a margin of around 50%.
    - CVD Technologies Ltd. has since worked on three further Float lines in China with Stewart Engineers and are currently working on two in Turkey and a sixth in Russia
- In parallel with this work, the company has developed processes for use in the Photovoltaic industry and has signed licences in this area. A recent initiative has been the development of an instrument to allow for in-line monitoring of APCVD coatings as they are manufactured.

<u>Successfully submitting related patents and developing strategic licensing agreements, allowing major international companies to use CVD Technologies Ltd. Technology:</u>

- EP1525336 A2 - Flame assisted CVD of metals (2005)
- DE 102008 017 076 - TCOs for PV application (2008)
- US 20110086235 - Process for achieving improved coatings in Float Bath environment (2011)
- PCT/EP2011/061551- Biocidal coatings by flame and plasma coating CVD (2011)
- UK Patent Application 1215996.8 – Fast pulses to volume glow discharge atmospheric pressure (AP) plasmas (2012)

<u>Generating economic and social benefits, internationally</u>:

- The leverage provided by the relationship between APCVD research and development, application and uptake, through a range of production processes through its commercial arm, generates commercial impacts for the UK economy and for international partners and economies:
    - CVD Technologies Ltd. has averaged c.£200K profits over each of the last 3 years, which has allowed reinvestment in the local economy, employing 9 staff and bringing related income and specialist skills to the North West of England, ensuring the sustainability of the research and its commercial application
    - Over 90% of CVD Technologies Ltd. business is focused outside UK - in Europe and the Far East, generating economic benefits and skills development internationally.

5. Sources to corroborate the impact

a) CEO, Stewart Engineers Inc, USA for corroboration of jointly developing a Float Glass coating system.
b) Head of Chemistry, UCL, London for corroboration of collaboration on Self Clean Photocatalytic coatings.
c) Former Technical Director now Special Projects Manager, Sisecam , (Turkey's largest Glass company), Turkey, for corroboration of utilising tailored APCVD technology.
d) Head of Coatings Group (retired), Fraunhofer, IWS, Dresden, for corroboration of projects related to biocidal coatings, Transparent Conducting Oxides and atmospheric pressure flame and plasma technologies.
e) Former Tech Manager Helianthos/Nuon BV, now Director at Helmholtz Centre, Berlin for corroboration of license signed with Akzo-Nobel (later Nuon) to develop an in-line reel-to-reel APCVD system.
f) Sheel has membership of the CEC 'expert list' for evaluation of large project proposals and is Founder Board membership of EJIPAC (European Japanese Initiative in Photocatalysis Applications and Commercialisation).