Institution: University of the West of Scotland

Unit of Assessment: 13

Title of case study: Advanced plasma source for electron-beam deposition of high performance optical filters.

1. Summary of the impact (indicative maximum 100 words)

An advanced plasma source based on novel engineering has been developed and proven in conjunction with Thin Film Solutions Ltd (TFSL). This source is retrofittable to existing electron-beam deposition systems and significantly improves the properties of thin films and advanced optical filters. TFSL has produced commercial products based on this source and has achieved sales to date of £2.3 million (letter from CEO of TFSL provided) as the new technology has been widely adopted in the optical filter industry.

2. Underpinning research (indicative maximum 500 words)

Prof Frank Placido has researched advanced optical filters for the last twenty years, leading the development of both advanced materials and process techniques. He pioneered the production of so-called rugate filters for laser notch filters from 1993 to 2002 using a simple reactive sputtering technique, but with very careful control of the reactive gases, oxygen and nitrogen. This allowed the production of narrow band reflection filters based on aluminium oxynitride films, having a periodic variation of refractive index with thickness. This led to the award of the John Logie Baird prize for Innovation in 1999 and was the catalyst for the subsequent development of the Thin Film Centre at UWS. An award of £1.2 million from the Scottish Funding Council allowed the purchase and development of an advanced sputtering system, an electron-beam system and characterisation tools. This allowed continuing development of expertise in materials and plasma-assist processes to improve thin film properties for advanced optical filters as required by the multi-billion pound filter industry.

Electron-beam evaporation was, and still is, very widely used in industry, but optical filters made by this method suffer from a number of problems because of the relatively low energy of the adatoms arriving at the substrate. In particular, evaporated films have a rather porous nano-structure that makes them susceptible to the ingress of water vapour. This leads to refractive index changes and general deterioration in performance of such filters with time, necessitating expensive encapsulation. These optical filters also tend to have unacceptable levels of absorption due to the difficulty in ensuring stoichiometry of the metal oxides used as high and low index materials. Traditionally, high-temperature deposition and/or subsequent annealing of the films were used to improve the density of evaporated films, but with limited success and considerable extra time and cost. Our research led naturally to the investigation of plasma-assisted techniques where the growing film is bombarded with argon ions and oxygen during deposition to improve densification and stoichiometry. In fact, many research groups and companies have tried to develop ion guns and plasma sources for this type of application, but the production of a stable, wide-area source that can operate reliably at e-beam deposition pressures for the many hours of a deposition run has proved a difficult nut to crack, particularly in a form that can readily be retro-fitted to existing e-beam chambers.

Our research initially developed a compact design of plasma source using an inductively-heated LaB6 cathode and novel ion extraction, producing high ion densities at the optimum energies for thin film enhancement. This has progressed by several innovative steps, such as implementing a hollow cathode effect in the electron emitter, removing the need for inductive heating during operation, thereby leading to considerable savings in operational costs. The latest models use modified magnetics with the aim of allowing operation at higher chamber pressures.

3. References to the research (indicative maximum of six references)

Key outputs from this research include many conference presentations and papers, some of which are listed below.

Journal Publications:-
1. F. Placido and D. Gibson, "High Ion Current Density Plasma Source for Ion Assisted Deposition of Optical Thin Films" Chinese Optics Letters 8, (2010)
2. J.B. Oliver, P. Kupinski, A.L. Rigatti, A.W. Schmid, J.C. Lambropoulos, S. Papernov, A. Kozlov, J. Spaulding, D. Gibson, F. Placido, "Large-aperture plasma-assisted deposition of Inertial Confinement Fusion laser coatings", Applied Optics, 50, pp19-26, (2011)
3. O. Duyar, F. Placido, H.Z. Durusoy, "Optimization of TiO_2 films prepared by reactive electron beam evaporation of Ti_3O_5" J. Phys. D: Appl. Phys. 41, pp 095307-13, (2008)
4. M. H. Asghar, M. Shoaib, F. Placido, S. Naseem, , "Wide bandpass optical filters with TiO_2 and Ta_2O_5", Cen. Eur. J. Phys. 6, pp853-863, (2008)

Conference Publications:-
1. F. Placido, D.Gibson, E, Waddell and D. Child, "High Ion Current Density Plasma Source for Ion Assisted Deposition Over Extended Areas, SVC 55th Technical Conference, Santa Clara, USA (2012)
2. F. Placido, D. Gibson, E. Waddell, E. Crossan, "Characterisation of Optical Thin Films obtained by Plasma Ion Assisted Deposition" , Advances in Thin-Film Coatings for Optical Applications III, Proc of SPIE 6286, 628602-1,628602-6, (2006)

Funding:-
A £300,000 industrial-scale, electron beam deposition system was purchased in 2006 through funding from Scottish Enterprise and Satis Ltd.
Thin Film Solutions Ltd (TFSL) have contributed equipment (parts, power supplies) as required over the last 9 years and are the industrial partner in an ongoing iCASE PhD studentship (£80,000).

4. Details of the impact (indicative maximum 750 words)

TFSL has seen a rapid growth in business through the proven performance of this retrofittable plasma source. According to the CEO of Thin Film Solutions Ltd, total sales value to date (June 2013) of advanced plasma sources is £2.3 million over a four year period.
Industrial and academic users exist in most of the developed world including Japan, China, USA, Europe and UK.

The addition of this new technology, with appropriate training, has allowed companies to achieve very significant improvements in the performance of optical filters produced on existing electron-beam deposition equipment.
Encapsulation of e-beam optical filters is no longer necessary, as the films are dense and do not change with changes in humidity.
Room temperature deposition is now possible, allowing a wider variety of substrates to be coated, including polymers.
Optical filters produced using plasma-assist can now show much lower absorption losses, improving the performance of laser mirrors.
Very large area substrates (1 m diameter) can now be uniformly coated with high performance optical filters, as multiple plasma sources with very uniform coverage can be fitted into large chambers.

5. Sources to corroborate the impact (indicative maximum of 10 references)

A letter confirming the above claims has been supplied by the CEO, Thin Film Solutions Ltd, 76 John St, Helensburgh, Argyll & Bute G84 9LY, Scotland, UK
Reference 2 above gives user confirmation of the performance of the plasma sources in a very demanding application, the production of large area, low loss, laser mirrors for application in inertial confinement fusion.