Design and fabrication of a coating research machine to explore the nanometer scale coating of glass tubes for Concentrating Solar Power (CSP) systems

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Abstract
This paper presents the design and fabrication of a precision designed CSP receiver tube coating machine for research purposes, designed to deposit and examine the properties of novel anti-reflection (AR) coatings possessing a thickness in the nanometre range. The manufacturing process chain and in line thickness control technique are also described.

1. Introduction and Background

Over two hundred large CSP plants are operational or under construction, with many additional and smaller systems also in existence. Concentrating Solar Power (CSP) uses large area solar collectors to concentrate direct sunlight (Direct Normal Insolation - DNI) to a focal line. The thermal energy is absorbed along the focal line within a receiver tube and transported by a heat transfer fluid (HTF) to either a thermal energy storage tank or an appropriate application (steam for electrical power generation, thermal energy for heating and cooling, and water desalination) [1-3]. Two European based companies that are producing 4m long evacuated receiver tubes, PTR70 and HEMS11 are Schott and Archimede respectively [4-5].

The deposition of thin film coating on glass and metal tubes using sol-gel solutions has been done by various companies. Industrial deposition techniques employed vary from spray coating, dip coating, flow coating and capillary coating. One technique employed successfully on receiver glass tubes is the dip-coating technique [6-7]. The tube is lowered into a tank filled with a silica based sol-gel solution. The withdraw speed determines the thickness of the film deposited. Vertical deposition can lead to variation in the film thickness therefore, the tube can be angled during withdraw in order to improve the thickness uniformity. Coating thicknesses obtained with this technique are of the order of 100nm, the thickness targeted for AR coatings. Finally, the AR coating is cured in an oven at temperatures above 400°C [6]. The process is repeated if a protective layer or a hydrophobic layer is necessary.

2. Coating research machine

The tubes are made of borosilicate glass with relatively low thermal expansion and a refractive index of 1.472 (@ 589 nm). The tube transformation temperature is 525°C which is higher than the temperature required to cure the sol-gel solution. Its resistance to a heat shock is in the region of 175°C which limits cooling rate and process cycle time. The coating machine prototype is designed to coat up to 1.5m long glass tubes with 100mm diameter and 3mm wall thickness. In order to facilitate the process development, a first stage machine was built for 300mm long glass tubes with a circular cross-section of 85mm and 2.5mm wall thickness (Figure 1).

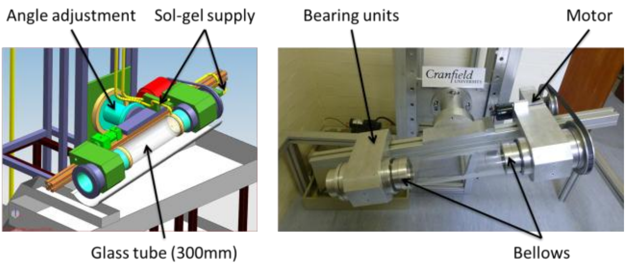

Figure 1: Coating research machine – schematic and as-built

The precision design principles behind the philosophy of the machine and an outline of the key features of the mechanical design are described below. The glass tube is held in position between two aluminium bellows that are held by two bearing units. One can translate to enable loading and unloading of the tube as well as account for manufacturing tolerances on glass length. Two Teflon O-rings per bearing unit are used to compensate for the tube diameter tolerance. The sol-gel is delivered by two nozzles on inside and outside of tube using a combined pump and gravity fed recycling system. This minimise the amount of sol-gel required for processing several tubes. The whole assembly can be angled from horizontal to vertical position in order to adjust process parameters such as sol-gel travel speed versus tube rotation speed that have significant effects in dip coating techniques reported [7]. A Design of Experiments is used to determine what parameters are significant in controlling the film thicknesses. This flexibility is also an important characteristic of the machine, bearing in mind the on-going development of the sol-gel materials which includes significant variation in viscosity and wettability. The sol-gel drying and curing requirements are been tested using a large oven that can reach temperatures in excess of 450°C. The motor torque and other mechanical elements of this coating machine have been specified to enable scaling up to 1.5m capacity. The full assembly can be raised and the support beam will be extended to accommodate longer tubes. The two bellows are interchangeable to accommodate for significant variations in tube diameter as-received from the external supplier larger than the O–ring material compressibility. A built-in drying and curing capability is been considered to increase the daily manufacturing process through-put especially for these longer tubes. The design of final machine for scaling up to 4m long glass tubes is yet to be finalised. The focus is on obtaining an adequate process through-put with high manufacturing flexibility for different sol-gel solutions and deposition rates. Therefore, a manufacturing process simulation using WITNESS software is currently been developed to take into account each process step. We will outline the findings and present an optimised manufacturing process chain using the 4m machine concept.

3. In line measurement technique

The film thicknesses obtained have been measured below 200nm using a direct measurement technique such as a stylus profilometre on 300mm tubes. However, this requires the specific masking of a region of the glass tube. A focus ion beam figuring (FIB) sectioning was employed but this requires sectioning of the glass tube. These techniques are limited for continuous manufacturing process quality inspection, especially on 1.5m long glass tubes. An in-line measurement approach (Figure 2) has been implemented using a controlled wavelength light source and a photodiode [8].

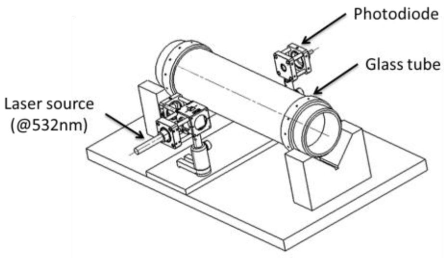

Figure 2: In line measurement technique

Different transmittance values depending of number of coating layers and coating thicknesses will be detected by measuring response (A/W) of photodiode signal at 532nm wavelength. By comparing these values to calibrated transmittance of targeted AR coating, the deposition process can be controlled and fluctuations can be detected.

4. Conclusions

It is expected that the machine will first be used to develop novel and highly cost-competitive thin film coatings for optical surfaces on solar thermal power plant components, competing with existing but costly technology that uses large evacuated PVD chambers.

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