Sculptured thin films as luminescent solar concentrators

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Background. It is now widely accepted that our reliance upon fossil fuels is unsustainable on account of the growing concerns over the climatic changes resulting from combustion, the rising environmental costs and decreasing efficiencies of extraction, transportation and storage, and fast depletion of limited reserves. Yet demand for energy looks set to double within the next 50 years. Accordingly, the need to develop more environmentally–friendly, sustainable energy supplies — such as provided by the conversion of sunlight to electricity which occurs in photovoltaic (PV) cells — is most pressing. In principle, solar energy could solve our planet's energy crisis: the supply of energy from the Sun to the Earth is estimated to be 10, 000 times greater than our current global energy consumption [1]. However, harnessing this resource in an efficient and cost–effective manner has proved to be an enormous challenge. Conventional PV cells, based on silicon semiconductors, are simply too inefficient and too expensive [2].

The work proposed here is motivated by the potential improvement in efficiency in harvesting solar energy demonstrated by recent advances in PV technology based on luminescent solar concentrators (LSCs) [3,4]. LSCs are essentially flat-plate waveguides impregnated with fluorescent dyes (or quantum dots). Sunlight absorbed and re-emitted by the fluorescent dyes (or quantum dots) is guided by total internal reflection to PV cells coupled to the edges of the concentrator. The improvement in efficiency arises from the large geometric gains in collector-to-device area ratios and the corresponding low cost of PV devices. Materials which possess an engineered nanostructure optimized for maximum trapping efficiency and guidance of light to the PV device are attractive candidates for LSC applications [5].

The proposed work concerns the implementation of sculptured thin films (STFs) as LSCs. An STF consists of an array of parallel nanowires which can be grown on a substrate using vapour deposition techniques [6]. By careful control of the fabrication process, the nanowire morphology as well as the porosity and optical properties of the STF can be tailored to order. The greater degree of morphology control afforded, higher mechanical stability and compatibility with existing large-scale thin film deposition manufacturing techniques make STFs especially attractive candidates as LSCs in commercially viable devices.

Aims. The aim of this study is to develop guidelines for fabricating efficient LSCs using STFs by: (i) developing detailed numerical models describing electromagnetic absorption and emission by dye-impregnated (or quantum-dot impregnated) STFs; and thereby (ii) determining optimized design parameters (nanowire morphology, porosity and thickness, optical constants, spatial distributions of absorbers/emitters) for STFs as LSCs.

Methods. Practical device configurations of finite extent and spacing and real material properties will be investigated. Since analytic models are not likely to be adequate for such a study, a numerical approach based upon the finite-element package COMSOL Multiphysics will be adopted.

Work plan. The proposed numerical studies will be undertaken by a PhD student in the School of Mathematics under the supervision of TGM. Advice on the practicalities of the various STF configurations under investigation will be provided by VCV.

Collaboration. The proposed study will facilitate a new collaboration between Fiat Lux Technologies and the School of Mathematics. Fiat Lux Technologies specializes in thin film optics, modelling of nanostructures, design of sensor systems and algorithms for manufacturing process control, and green engineering. Their track record is reflected in over 15 successful years of innovation in semiconductor manufacturing equipment design, thin film optics research, and information technology. It is envisaged that the proposed project will act as a springboard for future collaborative work on PV applications of STFs, involving major research council funding.

References.

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