MODEL PREDICTIVE CONTROL OF FILM SURFACE ROOT-MEAN-SQUARE ROUGHNESS AND SLOPE: APPLICATION TO THIN FILM SOLAR CELLS

Jianqiao Huang, Gangshi Hu, Gerassimos Orkoulas and Panagiotis D. Christofides*
Department of Chemical and Biomolecular Engineering
University of California, Los Angeles, California 90095

Summary

Limited conversion efficiency prevents wide application of solar cells in substitution of the carbon-based unsustainable energy. An optical model is introduced to connect the film surface morphology to the light trapping process of thin-film solar cells. In this work, a model predictive controller is developed to regulate the surface morphology, i.e., root-mean-square roughness and slope, at desired levels, which may maximize the light trapping efficiency. The controller is designed on the basis of a distributed stochastic dynamic model of film surface profiles. The proposed modeling and control approach is successfully applied to a kinetic Monte Carlo model of a silicon thin-film cell.

Keywords

Dynamics and control of chemically reacting systems, alternative energy

Introduction

Photovoltaic cell (solar cell) is an important source of clean energy for the sustainability of the world in the recent future. The most difficulty that prevents the wide application of solar cells is the limited conversion efficiency from the solar power. Thin-film silicon cells are currently most developed and applied solar cells[1].

Due to the importance of thin-film silicon solar cells, optical and electrical modeling have been widely focused and investigated to predict the optical and electrical behaviors for thin-film silicon solar cells[2, 3]. Within these behaviors, the scattering properties of the interfaces are directly related to the light trapping process and play a decisive role for the efficiencies of thin-film silicon solar cells[4, 5]. For example, a higher diffused transmittance of incident light is desired for the surface of solar cells. The scattering properties of the interfaces are characterized by the surface morphology, which includes root-mean-square (RMS) roughness and slope[6]. Therefore, it is desired that the conversion efficiency of solar cells may be improved via the regulation of surface morphology of thin-film solar cells during the manufacturing process.

Recently, modeling and control of thin film microstructure has attracted significant research attention. Molecular dynamics (MD) methods were initially introduced to simulate the evolution of thin film microstructure from first principles[7]. However, the intensive computation required during MD simulations makes MD methods impossible in the simulations with meaningful scales of time and length for practical applications. Two different mathematical models were then developed to describe dynamics of the evolution of thin film microstructure: (a) kinetic Monte Carlo (kMC) methods[8] and (b) stochastic differential equation (SDE) models[9-11]. Utilizing microscopic rules and kinetics that are obtained from MD simulations and experiments, kMC models are capable to describe the thin film growth process design feedback control laws for thin film microstructure. However, kMC models are computationally intensive for real-time monitoring and control. The fact that kMC models are not in a closed form also limits the system-wise control design. SDE models arise naturally first in the modeling of surface morphology of thin films to describe the evolution of surface profiles in a variety of thin film preparation processes. Identification and parameter estimation of SDE models have been developed[12]. Advanced control methods based on SDEs have been developed to address the need of model-based feedback control of thin film microstructure, e.g., surface roughness and porosity[13]. However, a thorough literature research indicates that regulation of RMS roughness and slope to improve the light trapping efficiency has not been addressed in solar cell applications.

* Also at Department of Chemical and Biomolecular Engineering, University of California, Los Angeles. Tel: +1(310)794-1015. Fax: +1(310)206-4107. E-mail: pdc@seas.ucla.edu.

Motivated by these considerations, this work focuses on improving the light trapping efficiency of solar cells by controlling the thin film surface morphology. An optical model is developed to connect the properties of film surface morphology, i.e., surface roughness and RMS slope, to the light trapping efficiency. The control objective is to regulate surface roughness and RMS slope at desired levels, which may maximize the efficiency of the light trapping process. The thin film growth process is modeled via on-lattice kMC simulations with two microscopic processes included, deposition process and migration process. A distributed (partial differential equation) stochastic dynamic model is used to describe the evolution of the surface height profile and is used as the basis for the design of a model predictive control algorithm that includes penalty on the deviation of film thickness, surface roughness and RMS slope from their respective set-point values. The adsorption rate is chosen as the manipulated variable. Simulation results demonstrate the applicability and effectiveness of the proposed modeling and control approach in the context of the deposition process under consideration.

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