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A STOCHASTIC GRADIENT DESCENT METHOD FOR THE DESIGN OF OPTIMAL RANDOM INTERFACE IN THIN-FILM SOLAR CELLS

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Abstract. Random rough texture design can be used to find the optimal design of random surfaces in thin film solar cells to increase their absorbing efficiency. We formulate the design problem as an optimal control problem under a PDE constraint. To lower the computational cost, the stochastic gradient method is employed to find the optimal surface. Numerical results show that the optimally obtained random texture has a much higher absorption rate in comparison with flat panels.

Key words. Optimal design, Helmholtz equation, transverse magnetic polarization, stochastic gradient decent method.

1. Introduction

Solar energy may be the cleanest renewable energy among all kinds of energy at present. With the traditional fossil fuel energy sources such as oil, coal, and gas running out, the energy crisis is aggravating. On the other hand, the solar energy can be used widely to meet the rapidly increasing energy demand [1].

Photovoltaics (often shortened as PV) is the conversion of solar light into electricity using semiconducting materials that exhibit the photovoltaic effect. A photovoltaic system converts the Sun's radiation, in the form of light, into usable electricity with the help of solar cell panels. Each of the solar cell panel contains a number of solar cells. There are mainly two types of solar cells: crystalline silicon and thin film solar cells.

Due to the high cost of crystalline silicon solar cells, the material purity and manufacturing process are limited. Compared to crystalline silicon solar cells, the lower cost of thin film solar cells undoubtedly provides favorable conditions for its development. A typical thin film solar cells are coated with p-i-n semiconductor film on the transparent conductive oxide film under the glass surface, and an electrode plate is plated on the back. Thin film solar cells consume fewer materials and only need tens of nanometers to hundreds of nanometers in thickness to achieve photoelectric conversion. However, the thin film solar cells have lower efficiency.

Since the first reports on practical microcrystalline cells in 1994, much research effort has been done worldwide into the development of both fundamental knowledge and technological skills that are needed to improve thin film silicon multi-junction solar cells. In addition, an efficient trapping structure can be designed to make amorphous silicon films absorb and utilize sunlight as much as possible. The absorption of more photons also provides a guarantee for improving the photoelectric conversion efficiency of thin film cells. There are many ways to increase the absorption efficiency of solar cells. The commonly used trapping techniques are: surface velvet, antireflection film, surface plasmon, reflector on the back of battery , and so on [2, 3, 4]. Another type of way to increase the efficiency is using randomly

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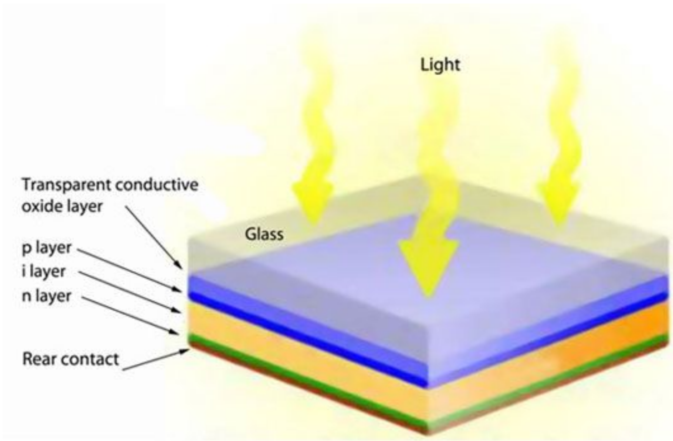

FIGURE 1. A typical structure of thin-film solar cells.

textured interface to trap the optical light [5, 6, 7, 8]. When the random interface is introduced into the contact surface of the solar cell, the light is reflected into the cell for many times to increase the optical path. In this way, the optical thickness of the thin film cell can be increased as much as possible without changing the physical thickness of the thin film cell. It is worth mentioning that by controlling the deposition parameters of TCO thin films sputtered on glass substrates, we can realize the fabrication of TCO surface layer can greatly improve the efficiency of thin film solar cells [9, 11]. The existing commercial solar cells have Asahi-U structure, Neuchatel structure and so on. Here we refer to some deterministic texture optimization design [10, 12], as well as the following deterministic shape optimization problems in physics and engineering. Most of the previous research on random texture optimization is based on certain ad hoc schemes. Mainly by calculating the absorption of several selected statistical parameters to select the parameter values that produce the maximum absorptivity. The optimal solution obtained in this way depends to a large extent on the selected set of statistical parameters. If the optimal parameters are not in the set, we will not be able to find the corresponding parameter values of the optimal solution.

There are two basic polarizations of light waves: transverse electric (TE) polarization and transverse magnetic (TM) polarization. These two kinds of polarization provide the basic for determining the light wave electric field and magnetic field at a certain position in the solar cell structure. The TE model was studied in [8]. In this paper, we focus on the transverse magnetic polarization. As in [8], we first reduce the modeling problem to an optimization problem with a PDE constraint. Unlike [8] where the gradient descent method was used to find the optimal interface minimizing the radiation, in this study, we use the stochastic gradient descent method (SGD) [13] for the same purpose. In the gradient descent method, the Monte-Carlo method is used to approximate the expectation of the cost function, which makes it extremely expensive when a large size of samples needs to be used to match the error of discretizing the Helmholtz equation. On the other hand, only one sample is used at each iteration for the SGD method. Our numerical experiment indicates that, with the same accuracy, the cost of the SGD method is only a tiny fraction of that for the gradient descent method.