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# Mathematical Simulation of Metamaterial Solar Cells

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**Abstract.** In this paper, we propose several solar cell designs based on metamaterials. Extensive numerical simulations of various designs with different materials are carried out. Our tests show that metamaterial solar cells are quite efficient, and over 80% and 90% absorption rates can be attained for solar spectrum and visible rays, respectively.

**AMS subject classifications**: 78M10, 65N30, 35L15

**Key words**: Maxwell's equations, metamaterial, solar cell, finite element method.

## 1 Introduction

A solar cell is a device that converts the sunlight energy directly into electricity through the photovoltaic effect. The high-efficient solar cell is a class of solar cells that can generate more electricity per incident solar power. Much of the industry is focused on the most cost efficient technologies in terms of cost per generated power. The two main strategies to bring down the cost of photovoltaic electricity are either by increasing the efficiency of the cells or by decreasing their cost per unit area. The challenge of increasing the photovoltaic efficiency is thus of great interest, both from the academic and economic points of view.

The Sun is a sphere of intensely hot gaseous matter with a diameter of $1.39 \times 10^9$ meters (m) and is, on the average, $1.5 \times 10^{11}$m from the Earth. The Sun has an effective black body temperature 5777 kelvins. Many solar cells are designed to absorb a wavelength range of 0.25 to 3.0 micron, the portion of the electromagnetic radiation

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that includes most of the energy radiated by the Sun. The solar cell has been continuously developed for more than four decades. The traditional energy conversion is from chemical energy to mechanical energy and then to electrical energy. The burning or heating process is used to convert chemical energy to mechanical energy. The steam power thermodynamics cycle is used to drive high pressure steam turbines to connect the generator to generate electricity. The total efficiency of generating electricity using the traditional technology is low, since the total efficiency is equal to the product of all process efficiencies. A solar cell can directly convert radiation energy to electrical energy which is more desirable compared to the traditional energy conversion technology because of zero emission of $NO_2$, $CO_2$ and $SO_2$ that are usually found from coal or natural gas combustion process. In addition, the traditional coal or gas-fired power plant is not sustainable. The major disadvantage of using solar cell to generate electricity is high cost and low efficiency. It is because the current solar cell technology is still silicon-based.

Generally speaking, solar cells can be classified into six categories: (1) monocrystalline silicon solar cells, (2) polycrystalline silicon solar cells, (3) polysilicon thin film solar cells, (4) amorphous silicon solar cells, (5) amorphous silicon thin film solar cells, and (6) multi-component solar cells. The most common single-crystal silicon cells are used for power plants, charging systems, lighting and traffic signals, and so on. The world's leading solar cell manufacturers such as Siemens in Germany, United Kingdom Oil in U.K. and Sharp in Japan have produced the single-crystal silicon-based solar cells with efficiency from 11% to 24%. Though polysilicon cells are less expensive to produce than single crystal silicon cells, they are less efficient. Various thin-film technologies have been developed to reduce the amount of material used in making solar cells. It can reduce the processing costs from using less bulk materials, but it tends to reduce the energy conversion efficiency in a range of 7% to 10%. It is known that the efficiency can be improved by using many multi-layer thin films. The thin film solar cells become more popular compared to wafer silicon technology because of high flexibility, low weight, and easy system integration. The multi-junction process has been developed to absorb most solar spectrum to improve the solar cell efficiency. But the high cost is still a big concern of using multi-junction process.

In this paper we will investigate a complete different approach on the solar cell design, which is based on the use of electromagnetic metamaterials to increase solar cell efficiency. Electromagnetic metamaterials are artificially structured media with unique and exotic properties that are not observed in natural materials. In 1968, Veselago [10] published a seminar paper addressing what would happen if the permittivity and permeability of a material are simultaneously negative rather than positive for most natural electromagnetic materials. He found that the results would be very interesting and exotic: one would find backward waves in metamaterials, and the refractive index of the metamaterial is negative. Unfortunately, materials with simultaneously negative permittivity and permeability do not exist in nature. For this reason, no further progress was made along this direction until 2000, when David Smith et al. [8] successfully constructed such an artificially structured composite material. Since 2000,