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Simulation of the Properties of Nano-Grooved Back Reflectors for Increasing the Efficiency of Solar Cells

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Abstract

In recent years, both solar cell research and nanostructure research have become popular topics in design and fabrication of semiconductor devices. The need for higher solar cell efficiencies at lower cost has been the main concern of scientists and engineers. By improving synthetic control in nanoscience high-performance electronic devices are becoming possible. The reflectors that are high-conductivity metals used as back contact in solar cells. Nano-grooved back reflectors can increase the efficiency of solar cells by improving the light–matter interaction near the mirror surface. In this work, we simulate and investigate the electrical and optical properties of these reflectors and their effects on solar cell efficiency. For this purpose, the properties of the back reflector in different wavelengths are examined and output parameters of a GaAs cell with a back reflector optimized for visible wavelengths are considered to find the appropriate absorber thickness.

Keywords: Mirrors, Back reflectors, Nano-grooves, GaAs Solar cell

1. Introduction

Mirrors are key components in optical systems and currently used as back reflectors in a wide range of optoelectronic devices. These reflectors are usually metals with high-conductivity and used as back contact in solar cells. When the planar mirrors are used, the phase reversal that occurs when light is reflected from a metallic mirror produces a standing wave with reduced intensity near the reflective surface. This results in efficiency degradation in solar cells because the magnitude of the local electric field strength is suppressed near the mirror surface and leads to decreased light–matter interaction. This problem shows its importance particularly in thin film devices with sub wavelength active layers. In order to overcome this issue magnetic mirrors are exploit to cause an electric field with its highest value right at the surface of the mirrors (Schwanecke, 2007). Using these mirrors, the direction of magnetic field of an incident light wave is changed instead of the electric field, and as a result overall intensity in active layer will not be reduced. As back-reflectors they can control the reflection phase of the incident light waves and therefore manipulate the field distribution and optical resonances. The idea of incorporation of such mirrors to enhance the light absorption in sub wavelength devices is used in some recent works (Genevet, et al., 2012; Dotan, et al., 2013). Variety of metallic structures have been used for designing nanostructure surfaces (Fedotov et al., 2005; Kildishev, et al., 2012). In (Esfandyarpour, et al., 2014) a nanoscale groove array is patterned into a conventional metallic mirror to make magnetic mirrors. The phase and magnitude of the reflected wave can be controlled by choosing the dimensions of these nano-grooves.

In this work we simulate a GaAs solar cell with nano-grooved back reflector using FDTD method. The array of sub wavelength grooves in silver mirror filled with ZnO can be designed in a way that reflects the incident light with desired phases and magnitudes, therefore the light intensity can be manipulated in distances near the surface of the reflector. As a result one can optimize the absorber layer for defined back reflector structure. For this purpose, first we examine the properties of the back reflector in different wavelengths, especially in visible range, by changing the depth and width of the grooves. This helps to determine the dimensions of the grooves according to the wavelengths of solar radiation that generate more carriers. This is done by simulating the nano-grooved arrays with different dimensions in different wavelengths. Then, the electrical properties of optimized absorber which is determined by reflector design are studied in sunlight

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spectrum and compared with conventional cells with planar reflector.

2. Cell Structure and Simulation

A TCAD device simulator is exploited to analyze the influences of design parameters like groove depth and absorber thickness and examine the output parameters including absorption, optical field, voltage and current.

The cell is made of a back reflector, an absorber layer and transparent top contact. The back reflector is an array of sub wavelength grooves in silver mirror filled with ZnO that also can be serves as back contact. Absorber is an ultrathin GaAs layer that deposited on mirror surface.

Fig. 1b and Fig. 1c show the back reflector and compares the field distribution of it with planar back mirror (Fig. 1a). They show how the reflection of normally incident, 800 nm light from a conventional, silver mirror results in a standing wave with a suppressed electric field near its surface. A very similar field profile results when a reflector with a periodic groove array is illuminated with transverse electric (TE-polarized) light (Fig. 1c). The result changes when the grooved mirror is illuminated with transverse magnetic (TM-polarized) light (Fig. 1c). For this polarization the field profile shifts by a quarter wavelength and a standing wave with a maximum electric field near the surface of the mirror is produced.

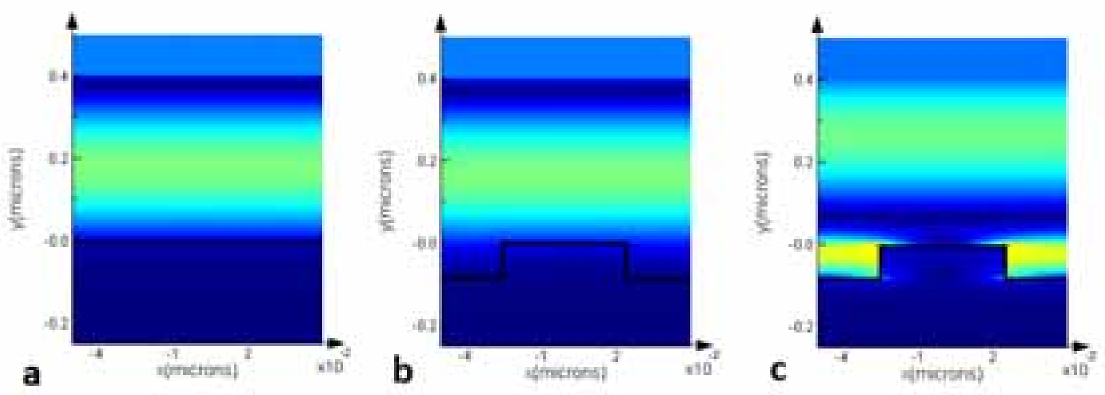

Fig. 1: Electric field distribution in a- Planar back reflector. b- Unit cell of nano-groove back reflector with TE polarization of incident light. c- Unit cell of nano-groove back reflector with TM polarization of incident light

3. Results and Discussion

In planar metallic mirrors, the reflection phase of incident light is related to the penetration and energy storage inside the metal which are fixed at each wavelength for a given metal. But in mirrors made by implementing periodic nano-grooves in silver back contact, by changing the dimensions of the grooves, different phases and magnitudes of reflected light wave in each wavelength can be reached. Fig. 2. shows $|E|^2$ which represents the light intensity, from the surface of mirror in Y-direction in three wavelengths of incident light with three groove depths and compare it with planar mirror.

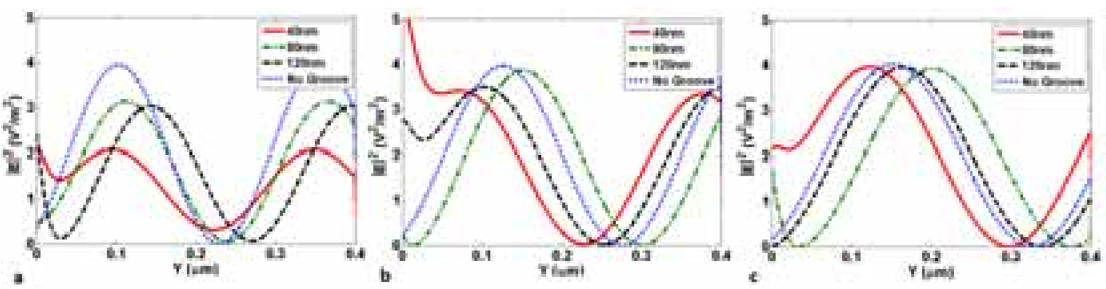

Fig2: $|E|^2$ distribution from the surface of mirror in Y-direction with incident wavelengths of a- 500nm, b- 600nm and c- 700nm with three groove depths and planar mirror.

It is seen that near the surface of planar mirror light intensity is about zero as it is predicted, but by implementing the nano-grooves and changing the reflection phase the light intensity has different value near the surface. The groove depths determine the intensity of light at the mirror surface and distances from that. In each wavelength, according to the light intensity profile which depends on groove depths, different absorber thicknesses may be optimal. In other words, if the thickness of absorber layer varies, the depth of the groove that causes the maximum absorption may differ. For example, for incident light of 500nm, if the absorber layer is about 30nm thick, groove depth of 40nm will make more absorption in cell than the other depths. But if the thickness of absorber layer is assumed to be about 120nm, the optimum groove depth will be 80nm.

In different wavelengths, also the influence of groove depth is different. For instance, it can be seen that the intensity of light wavelength of 600nm has higher value at the surface of the mirror with 80nm groove depth than 120nm. But this is opposite, in wavelength of 700nm. These figures show that absorber thickness, wavelength and groove depth are the key parameters for designing the solar cell with nano-groove back contact (by assuming fixed period of nano-grooves). Implementing the absorber layer changes the profile of electric field because of the reflection in interfaces of the layer and its absorption. Fig. 3. shows this profile for the cell with 100nm absorber thickness, incident light wavelength of 600nm and three groove depths.

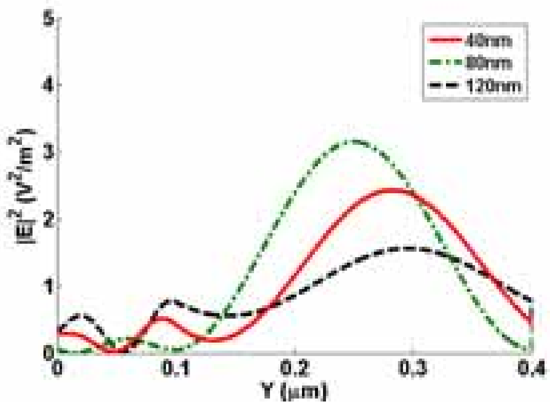

Fig. 3: $|E|^2$ distribution from the surface of the nano-grooved back reflector with existence of GaAs absorber layer and incident light of 600nm.

It is shown that light intensity has different profiles with changing the groove depth, thus, the thickness of the absorber layer which located on the surface of the mirror define the total absorption of the cell. For instance, if we assume that the absorber thickness is 100nm, it can be concluded that implementing 120nm groove depth in back reflector will result in more absorption than the other groove depths in this wavelength.

The electric field in absorber layer determines the absorption and in consequence, photogeneration in the cell. Fig. 4. shows the absorption of the cell in three wavelengths (500nm, 600nm and 700nm) with different groove depths and absorber thicknesses.

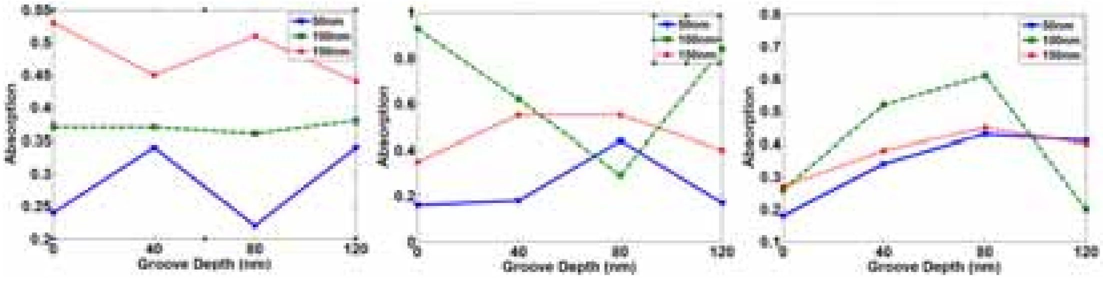

Fig. 4: Absorption of the cell with no groove and three groove depths, three absorber thicknesses and with incident wavelength of a- 500nm b- 600nm c- 700nm.

With incident wavelength of 500nm, increasing the absorber thickness results in more absorption, but groove depth has different effects in each thickness. The groove depth of 40nm in 50nm absorber thickness causes more absorption than the other but this is 80nm for thickness of 150nm. With two other wavelength of incident light wave, it is seen that absorber with 100nm thickness may have more absorption than 150nm thickness which is completely related to electric field distribution in this layer. Some groove depths in all wavelengths may cause less absorption in the cell than planar mirror. But total absorption in all wavelengths of solar radiation with consideration of absorber thickness will determine the absorbed power of the cell.

The absorption of the devices shows the available current they can produce in each wavelength. This analysis is necessary for all photodetectors, but is not enough for solar cells. In solar cells, the total absorption in all wavelengths of solar radiation should be considered. Thus, calculating the optimum thickness of absorber layer and groove depth is differ from single wavelength and the simulation results of light wavelengths in visible range that generate more carriers, can be a guideline to design better structures.

In solar cells, in addition to optical parameters including absorption and light intensity, electrical parameters should be taken into consideration. Therefore, semiconductors' equations also solved for the cell structure assuming a p-n junction in absorber area, and conventional output parameters of solar cells like short circuit current, open circuit voltage and efficiency are extracted. Fig. 5. Shows these parameters for three structures with different groove depths and compare them with a structure with conventional planar mirror.

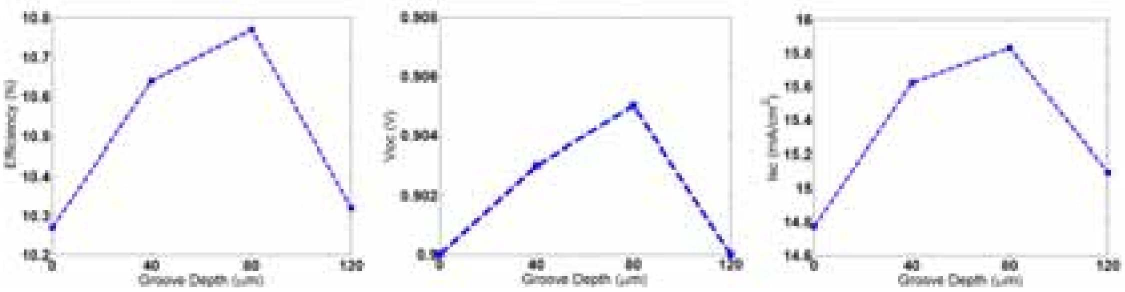

Fig. 5: a- Efficiency b- Voc and c- Isc for solar cell structure with no groove and three groove depths and absorber thickness of 100nm

It is depicted that patterning the nano-grooves in back reflector, can increase the photogenerated current and thus the efficiency of the solar cell. Open circuit voltage is changed slightly because it is strongly depends on the properties of absorber layer. Photogenerated current has logarithmic effect on this voltage. In different thicknesses of absorber layer, implementing the nano-grooves may result in different improvement and the optimum depth of groove may also change. In the simulated structure with absorber layer of 100nm, the optimum depth is 80nm.

4. Conclusion

In this work, the idea of patterning nano-grooves in back reflector of ultrathin solar cells is investigated. These grooves will make the reflector act similar to magnetic mirror which can increase the light intensity near the surface of the mirror. This improves the absorption and thus photogeneration in absorber layer and is considerable, especially in very thin solar cells. In order to examine the properties of these mirrors and finding the guidelines to design them for higher efficiency, the structure with different dimensions, incident wavelengths and in exposure of solar radiation is simulated and analyzed. Design of optimum structure depends on the constituent materials, absorber thickness and grooves' depth. Therefore, for a cell with given materials and absorber thickness, the groove thickness can be optimized by simulations. Engineering the shape and dimensions of these types of mirrors as reflectors in solar cells may lead to fabrication of new kind of ultrathin solar cells.

5. References

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