Type III solar cells based on quantum dots

BACHELOR'S THESIS

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Abstract

In this thesis the extensive study of possible and surly optimal materials for Quantum Dot Solar Cells (QDSCs) will be provided to the reader. One will have the opportunity to develop a rather current image of the necessary parts in their architecture which will be supported with an abundant description of the important aspects in engineering a photovoltaic device. With an introduction of its kind we will try to convey a basic but sufficient knowledge of standard terms, light with matter interaction, light spectrum analysis, quantum dots description with their behaviour and a photovoltaic device operation theory with certainly needed quantities that one has to find in order to properly describe a solar cell. In many parts we will try to outline possible enlargement of that information. With the objective of creating a possibly competitive QDSC the description of methods that we used will be included with a related to them characteristics. One will also be able to use this paper as a review of today's development phase and current technological state of the other scientific groups all around the world. After a successful development of a solar cell, the analysis and comparison will definitely be provided.

Dedication

I would like to dedicate ...

Declaration

I declare

Acknowledgements

Thanks

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Chapter 1

Introduction

We, as a society nowadays, are in constant demand for energy. Although, even with the development of calculating, conducting and studying it, we don't really know what the energy is, we are depending on that abstract quantity. One might probably say that to study physics is to endure to study energy in its every possible form. There's a brilliant quote from Bill Bryson that: "Energy is liberated matter, matter is energy waiting to happen." What might be incredible is that from this strictly mathematical quantity we can deduct anything. And what's also important it is as arbitrary as it gets, depending only on one's reference. From energy we can create few more important quantities such as *power* P, which is simply the energy provided per unit time, so:

$$E = \int P(t)\,dt$$

The energy will be represented in J (Joules) or eV (electron volt), which directly describes energy of elementary charge body ($e \approx 1.602 * 10^{-19} C$) in 1V (Volt) potential.

$$1eV = 1.602 * 10^{-19} J$$

Power will be then represented in W (Watts) ($W = \frac{J}{s}$).

The rise of energy consumption has proven that in the future we will almost certainly require even more. From Global Energy Perspective paper [3] we can learn that:

- Global energy demand will reach plateau at around 2035 despite strong population expansion and economic growth thanks to emphasis on renewable sources, more efficient service industries or more efficient industrial regions
- The energy demand and economic growth became "decoupled" for the first time in history
- Renewables will provide more than half the electricity after 2035

The reader is strongly recommended to take a look at the document.

With saying that we can produce energy there's a slick trick given with the phrase. Energy cannot be simply created, it is just converted from another source so nothing is ever lost or miraculously made. The problems we need to struggle with are then being able to obtain as much energy from the energy source as it is possible and of course, as humankind society is governed by money, keep the cost lowest. There is plenty of different energy sources that we learned to receive energy from. In Figure **??** we can see the most vivid ones nowadays. But with the human demand fulfilment come great damages and soon depleting resources of many energy sources such as fossil fuels.

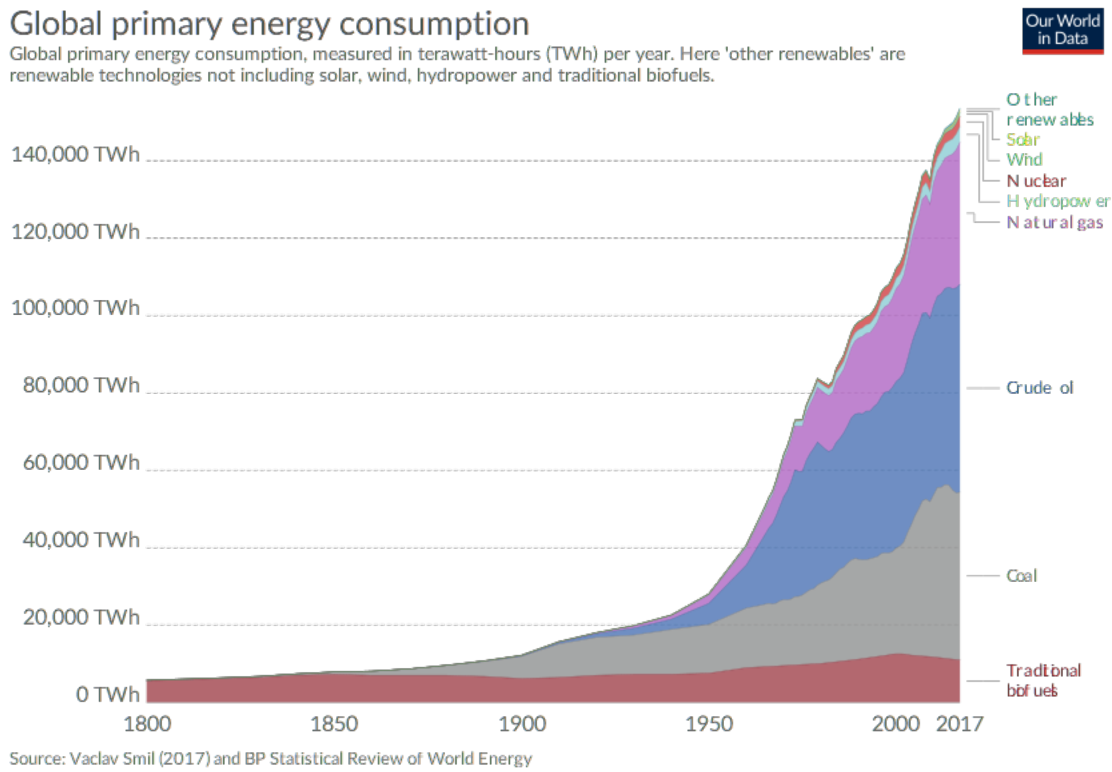

Figure 1.1: Energy sources contribution in world scale [2]

The necessity of searching new possible ways to harness it through renewable sources has become a global issue. Our concern of the environment had never been that serious before. Not only the change of methods for energy production must be enhanced because of this demand but we need to be strictly aware of the World's urging trepidation of Global Warming of which evidence is provided for example here [6].

Among all of the ideas created in a past few decades, solar energy is believed by many to be the most reliable and promising. It can be directly converted into electricity, heat or chemical energy and our only star seems to be an infinite power resource for us. In the last ten years the world solar PV electricity production has grown impressively, being almost three times bigger in 2016, than in 2010 [7]. In theory, the Sun has the potential to fulfil earth's energy demand if it is not for the technology. Annually, nearly 10^{18} EJ of energy reaches our planet and of that 10^4 EJ is claimed to be harvestable. The possibility of converting the solar energy into electric energy has been studied since discovery of the basic photovoltaic effect and the development of semiconductor technologies.

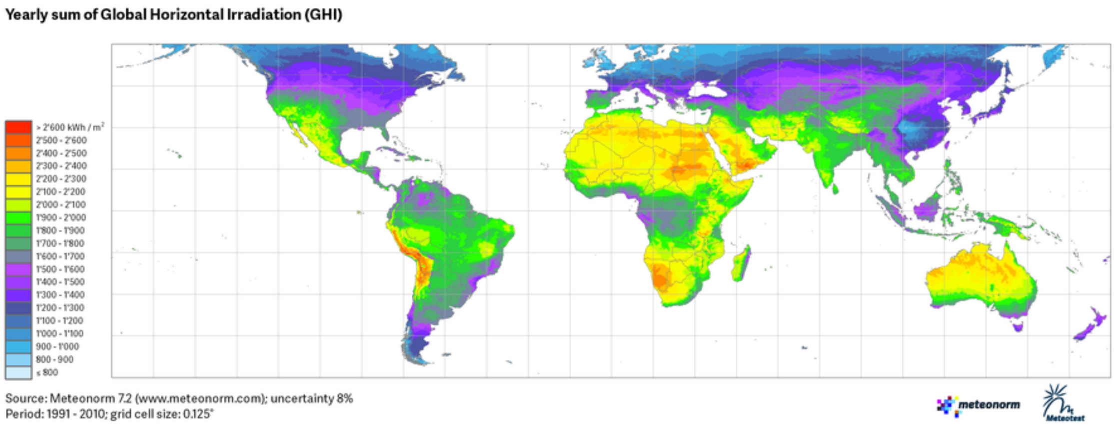

Figure 1.2: Annual yearly sum of Global Horizontal Irradiation [5]

Chapter 2

Theory

With this chapter the introduction of some theoretical concepts will be provided. Certainly some of chapters below could be omitted without missing the final result and its meaning. Nevertheless, even if the paper is laced with rather practical analysis and effects, a physicist should be sure to understand the aspects of an experiment well, not just to have a better insight into the outcome but also to be sure that during the process no foolish mistakes are made and to be able to find new methods to improve the research. Therefore, few parts will just be a reminder and introduction to notation used or to ensure the understanding and some will be treated as an inquiry of what might be searched to describe it further.

2.1 Physics and properties of solids and semiconductors

2.1.1 halo

2.2 Classical and semi classical theory of light and light with matter interaction

As in the photovoltaic physics we are constantly struggling with light itself we should be know what the light actually is and how it interacts with matter in many, rather curious and different ways. Why is that so that matter looks the way it does and what of its properties can we control. In this chapter we will embrace the phenomena just to create an image of what we are dealing with.

2.2.1 Basic properties of electromagnetic field

Before we actually begin we need to state some classic information about the physics of electric charges. The electromagnetic field is represented by two generally complex vectors, even though the physical result that we are expecting is ought to be real. Those vectors are $\mathbf{E}$ – *electric field* and $\mathbf{B}$ – *magnetic induction*. The properties of those fields are of course described by the *Maxwell's equations*. For them we shall also introduce two more important quantities ρ – *the electric charge* density and $\mathbf{j}$

– *electric current density* vector. We can define them in this way:

$$e = \int \rho dV \tag{2.2.1.1}$$

$$I = \int_S \mathbf{j} \cdot \mathbf{dS} \tag{2.2.1.2}$$

Where I is electric current.

The four Maxwell equations in differential form are:

$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t} \rightarrow \textit{Faraday's induction law} \tag{2.2.1.3}$$

$$\nabla \times \mathbf{B} = \mu_0 \left(\mathbf{j} + \epsilon_0 \frac{\partial \mathbf{E}}{\partial t}\right) \rightarrow \textit{Ampere's circuital law} \tag{2.2.1.4}$$

$$\nabla \cdot \mathbf{E} = \frac{\rho}{\epsilon_0} \rightarrow \textit{Gauss's law} \tag{2.2.1.5}$$

$$\nabla \cdot \mathbf{B} = 0 \rightarrow \textit{Gauss's law for magnetism} \tag{2.2.1.6}$$

To freely describe the properties of the fields interacting macroscopically with material objects we here we can also introduce standard auxiliary fields with polarization and magnetisation of a macroscopic medium. Those vectors are $\mathbf{D}$ − *the electric displacement* and $\mathbf{H}$ – *the magnetic vector.* From Gauss's law for magnetism there is a straight implication that no magnetics monopoles exist and Gauss's law may be also treated as electric charge density definition.

$$\mathbf{D}(\mathbf{r},t) = \epsilon_0 \mathbf{E}(\mathbf{r},t) + \mathbf{P}(\mathbf{r},t) \tag{2.2.1.7}$$

$$\mathbf{H}(\mathbf{r},\ \mathrm{t}) = \frac{1}{\mu_0} \mathbf{B}(\mathbf{r},\ t) - M(\mathbf{r},\ t) \tag{2.2.1.8}$$

Where $\mathbf{P}$ is a *polarization vector* and $\mathbf{M}$ is *magnetization vector.*

And with them our former equations change to:

$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t} \rightarrow \textit{Faraday's induction law} \tag{2.2.1.9}$$

$$\nabla \times \mathbf{H} = \left(\mathbf{j} + \frac{\partial \mathbf{D}}{\partial t}\right) \rightarrow \textit{Ampere's circuital law} \tag{2.2.1.10}$$

$$\nabla \cdot \mathbf{D} = \rho \rightarrow \textit{Gauss's law} \tag{2.2.1.11}$$

$$\nabla \cdot \mathbf{B} = \mathbf{0} \rightarrow \textit{Gauss's law for magnetism} \tag{2.2.1.12}$$

If we put divergence on the Ampere's law, we can then place Gauss's theorem in the equation because of the exchangeability of partial derivatives and from that we can simply derive so called equation for *charge conservation:*

$$\frac{\partial \rho}{\partial t} + \nabla \cdot \mathbf{j} = \mathbf{0} \tag{2.2.1.13}$$

The field is said to be static if all quantities are independent of time and, of course, no currents are present. This is the special case but we cannot be so lucky every time. Optical fields are usually sources of very rapid time variety but one may deal with it thanks to the possibility to average the field over macroscopic time interval which is mostly the case in for photovoltaic needs, where for example the light source is a distant star.

Relations for substances under influence of those fields can be very complicated. There is a special case that can make life easier as well. If the material is *isotropic* (all its properties are identical in every direction) they take a simple form of:

$$\mathbf{j} = \sigma\mathbf{E} \rightarrow Ohm's law \tag{2.2.1.14}$$

$$\mathbf{D} = \epsilon\mathbf{E} \tag{2.2.1.15}$$

$$\mathbf{B} = \mu\mathbf{H} \tag{2.2.1.16}$$

Here σ is called *conductivity*, ϵ is a *dielectric constant* and μ is *magnetic permeability.* Normally, all of those are tensors. In the case of scalar conductivity we can separate macroscopic media in three different categories: conductors, semiconductors and isolators. The same goes for magnetic permeability. With $\mu < 1$ the substance is said to be diamagnetic, $\mu > 1$ paramagnetic and so with $\mu \gg 1$ ferromagnetic. Obviously this description is rather intuitive and treated as a general theory. For example for exceptionally strong fields the area of non-linear optics is needed to be got into which provides higher power terms of fields in the above equations. Also, the case where we need to include relativistic effects by extracting previous values of E acting on charges is not included as well. The information will be expanded later when needed ,but if the reader wants to really expand following discussion understanding, it can be done via [1] [4].

2.2.2 Boundary conditions at discontinuity

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Chapter 4

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Chapter 5

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Conclusion and outlook

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