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Monocrystalline silicon solar cells applied in photovoltaic system

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ABSTRACT

Purpose: The aim of the paper is to fabricate the monocrystalline silicon solar cells using the conventional technology by means of screen printing process and to make of them photovoltaic system.
Design/methodology/approach: The investigation of current – voltage characteristic to determinate basic electrical properties of monocrystalline silicon solar cells were investigated under Standard Test Condition. Photovoltaic module was produced from solar cells with the largest short-circuit current, which were joined in series.
Findings: This work presents a conventional technological process by means of screen printed method of monocrystalline silicon solar cells production. In order to obtain a device producing an electrical energy, solar cells were connected in a photovoltaic module. Then protected from damages by Schottky and Zener diodes.
Practical implications: The module was used to build a demonstration photovoltaic system – traffic light - pedestrian crossing, which shows the practical use of widely available, renewable energy source which is the Sun.
Originality/value: The key to solve ecological problems, which are effects of mass combustion of fossil fuel such as: coal and crude oil is development of renewable energy technology like photovoltaic energy.
Keywords: Monocrystalline silicon; Silicon solar cells; Photovoltaic system; Screen printing

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1. Introduction

Pollution, the depletion of conventional energy sources, the uncertainty of supply makes the world looking for alternative sources of energy like renewable energy.

Photovoltaic cells (also known as solar cells) are used to convert solar radiation into electrical energy. The development of photovoltaic began in the sixties of the twentieth century, initiated by the space research, and accelerated by the oil crisis. Photovoltaic power is given in watts peak power - a power attained in the Standard Test Conditions, that is, under the distribution of the solar spectrum Air Mass AM1.5 (Air Mass 1.5 is the apparent distribution of the Sun 42°), the intensity of radiation Pin = 1000 W/m^2 and temperature T = 288 K [1].

Photovoltaic energy industry is now one of the fastest growing industries. The dynamics of its growth is compared to the microelectronics industry growth in the initial stage of its development. Production of photovoltaic cells is increasing on average by about 43% annually over the last few years (Fig. 1). This increase is a result of advances in materials and technology, and implemented in many countries, programs that are aimed at the dissemination of photovoltaics as a safe and clean source of electricity [2,3].

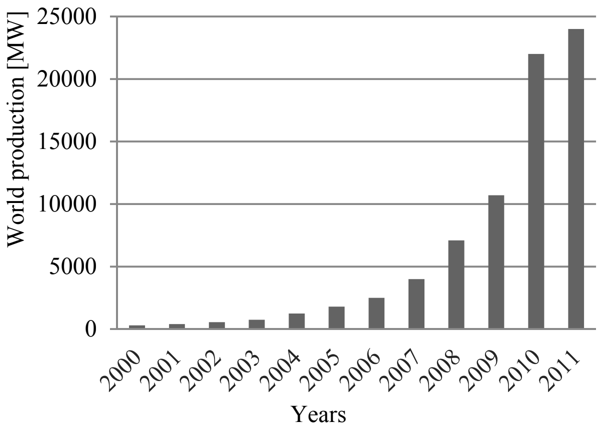

Fig. 1. World production of solar cells/photovoltaic modules in Megawatts [1,4,5]

The main groups of materials which play a role in the production of photovoltaic cells are shown in Figure 2. On the market for photovoltaic solar cells, the contribution made from crystalline silicon exceeds 90%, of which one third comprises monocrystalline silicon and two thirds polycrystalline silicon (Fig. 3) . The rest of the market falls on thin film solar cells, most of which is the structure of amorphous silicon and only 4% of the other materials. Total cost of the photovoltaic cells can be significantly reduced by using only a very thin layer (thickness of a single micron) of expensive semiconductor material on cheap substrates with large surface area [6-8].

Although nowadays an efficiency of the thin film cells is lower than monocrystalline silicon cells, it is expected that in the future production on a massive scale will be much cheaper. Currently, the most advanced thin film cells are made of amorphous silicon (a-Si) and its alloys (a-SiGe, a-SiC). Thin film cells have achieved efficiency of 13% in the laboratory scale. Amorphous silicon cells are commonly used in products requiring low power supply (pocket calculators, watches, etc.) [9,10].

Monocrystalline solar cells show the highest conversion efficiency of all silicon solar cells, but the production of monocrystalline silicon wafers requires the largest investment funds. In laboratory studies a single solar cell efficiency reaches the order of 24%. Solar cells produced on a mass scale have efficiency of around 17% [6,10].

Polycrystalline silicon solar cells are made of a large blocks of silicon. They are produced in special crucibles, which slowly cool down the molten silicon to make the growth of polycrystalline with large grains. Next blocks are cut on the wafer by sawing. Polycrystalline cells are less efficient than monocrystalline (Fig. 4), but their production cost is lower, due to the skip of energy-intensive manufacturing single crystal [7,10].

The basic advantages of photovoltaic cells made of silicon are [1,11-13]:

- good efficiency of solar cells in series production up to 20% and 24% obtained in laboratory scale,
- ability to use the experience of a well-developed electronics industry,
- unlimited amount of feedstock,
- simplicity and very good stability,
- good compliance with environmental requirements.

The primary disadvantages of silicon photovoltaic cells are [1,11-13]:

- the need for thick absorber area (> 100 microns) to achieve high efficiency
- the use of large quantities of expensive high-purity silicon, which is the main factor behind the high cost of production,
- difficult to dispose compounds from the production of solar cells.

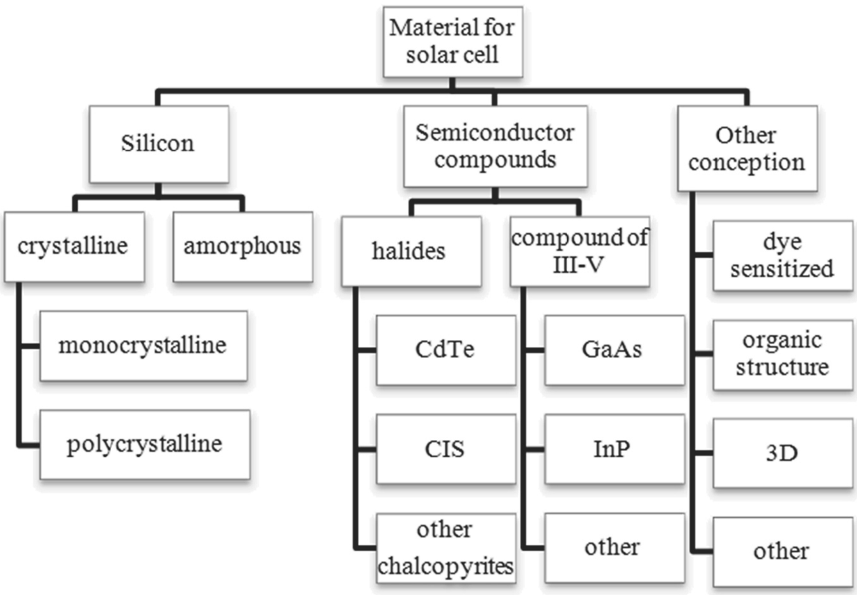

Fig. 2. Classification of solar cells materials [6]

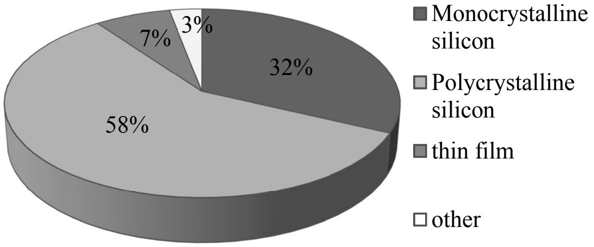

Fig. 3. Participation of different types of silicon in the global production of solar cells [11]

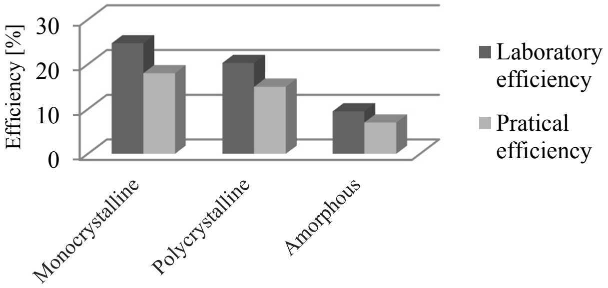

Fig. 4. The efficiency of silicon cells depend on the implementation conditions [11,14]

In a thin surface layer of the wafer (p type) made of monocrystalline cylinder by phosphorus diffusion the n type area with a few micrometers thick is applied. In that way at a depth of about 1 μm the p-n junction is obtained. Junction is an active area of solar cells. The task of the front and back electrodes is to carry off the electric charge. The main methods of applying the electrodes are: screen printing, chemical deposition of nickel and vacuum evaporation [15,16]. Back electrode covers almost the whole surface, while the front electrode should cover an active surface as little as possible and on the other hand properly carry off electrical charge. To increase the absorption coefficient of solar radiation front surface is textured and antireflection coating (e. g. silicon nitride) is applied. The construction of monocrystalline silicon solar cells is shown in Figure 5 [17-22].

The first series-produced monocrystalline silicon solar cells had the shape of a circle. They were obtained directly from slicing a cylindrical single crystal silicon. Currently, round cell is cut in half to form a semicircle or cut into squares to increase density on the surface of the PV module. The optimal filling is that one in which cells occupy 90% of the PV module. Due to a the thermal expansion the certain area in the photovoltaic module must remain free. In order to obtain higher power modules are connected together to form a photovoltaic panel (Fig. 6). Parallel connection of modules allows to increase the current level, while the serial connection - voltage [23-25].

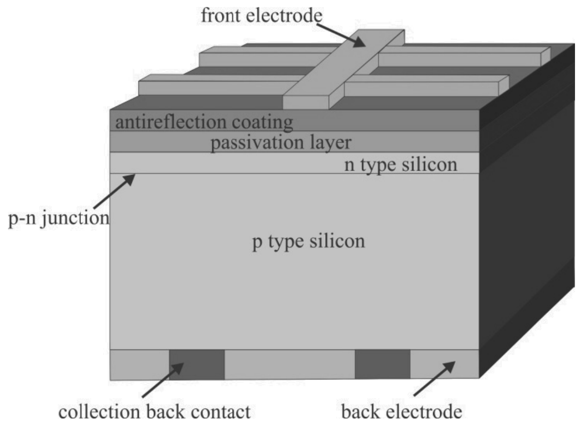

Fig. 5. Construction of monocrystalline solar cell [24]

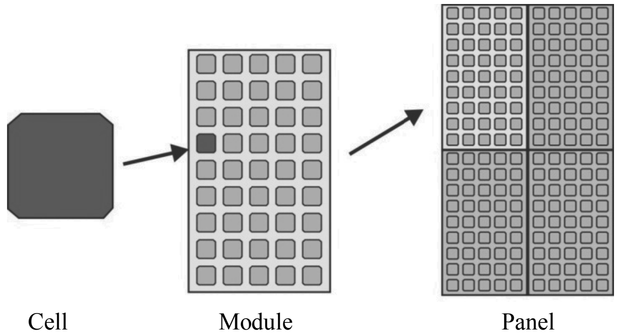

Fig. 6. Construction of a photovoltaic panel [25]

The main objective of present work is to produce monocrystalline silicon solar cell with screen printing method and make of them photovoltaic module. The basic electrical and optical properties of monocrystalline solar module were obtained. The design module was used in demonstration photovoltaic system: traffic light - pedestrian crossing, which shows the practical use of widely available, renewable energy source which is the Sun. In addition, this research is concentrated on information about design of photovoltaic modules and systems. Practical part of this paper includes determining basic electrical properties of solar cells and making photovoltaic module and system.

2. Experimental procedure

The base material used for experiment was monocrystaline silicon wafer. Table 1 contains the base parameters of the wafer.

The production steps of monocrystalline silicon solar cells were shown in Figure 7. First of all silicon wafer surface has been degreased and cleaned. In order to remove surface contamination and degrease the wafer was:

- immersed in acetone, which dissolves organic pollutants,
- ultrasonically washed,
- anisotropically digested,
- rinsed with deionized water,
- dried.

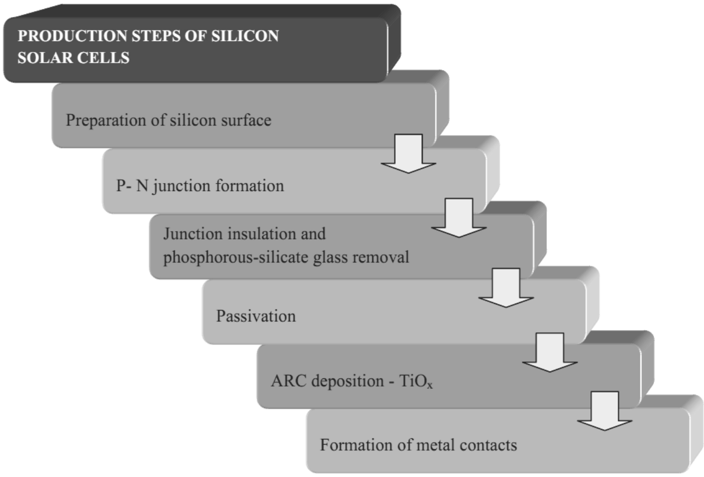

Fig. 7. Production steps of monocrystalline silicon solar cells

In order to reduce reflection of solar radiation texturing the surface of the wafer in crystallographic orientation (100) was carried out. The pyramidal structure was obtained by immersing them in KOH solution at temperature of around 80°C according to the reaction:

$$2KOH + Si + H_2O \rightarrow K_2SiO_3 + 2H_2 \quad (1)$$

The p – n junction was formed by diffusion of dopant donor to the base wafer (type p) with $POCl_3$ used as a dopant source. As a carrier gas N_2 and as a protective and reaction gas O_2 were used. Diffusion reaction takes place in furnace at about 800 °C due to chemical reaction:

$$4POCl_3 + 3O_2 \rightarrow 2P_2O_5 + 6Cl_2 \quad (2)$$

$$2P_2O_5 + 5Si \rightarrow 5SiO_2 + 4P \quad (3)$$

As a result of diffusion during the manufacture of p - n junction on the surface of silicon wafer was phosphorus-silicate glass, which is removed from the wafer by dipping them in HF solution. Moreover the p-n junction formed on the edges of the wafer has to be removed by immersing them in a solution of HNO_3: CH_3COOH: HF.

Surface passivation significantly reduces velocity of the surface recombination. A thin layer of silicon dioxide (SiO_2) with controlled thickness were obtained by annealing silicon wafer in a stream of inert gas (nitrogen) with the addition of dry oxygen.

To reduce reflection on the front of the wafer, antireflection TiO_x coating was deposited on the heated wafer by CVD method with $(C_2H_5O)_4Ti$ precursor used.

In order to apply the metallic contacts a conventional screen printing method was used (Fig. 8). Front contact was printed on the surface of silicon with silver paste and back contact used aluminium paste. Screen printed contacts were burned in a infrared belt furnace at temperature 800ºC.

Metallic contacts of the cell should have the following properties:

- ohmic contacts with silicon,
- low contact resistivity,
- good adhesion to silicon.

Solar cell with the lowest current determines the current in the PV module. Because of that the 31 from 36 with the highest short-circuit current were chosen. In order to achieve the highest possible voltage produced by the photovoltaic module solar cells were connected in series.

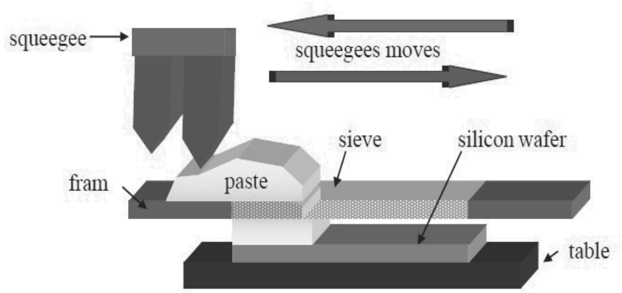

Fig. 8. The screen printing method

Schematic diagram of traffic lights system powered by solar energy is shown in Figure 9.

Figure 10 presents simplified electrical diagram of the photovoltaic system. Photovoltaic system consists of the following elements:

- photovoltaic module,
- step-down converter,
- battery pack,
- astable generator,
- traffic lights.

Photovoltaic module loads four NiMH batteries with a voltage of 1.2 V each. Batteries store electrical energy and ensure its steady supply at night, when the generator only consumes electricity from the batteries. In order to match the voltage of the photovoltaic module with battery life converter lowering voltage was used, which also protects the batteries from overcharging and protects the system from a variable input voltage.

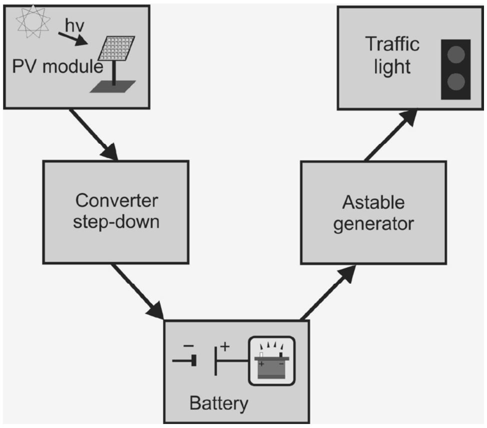

Fig. 9. Schematic diagram of traffic light - pedestrian crossing powered by solar energy

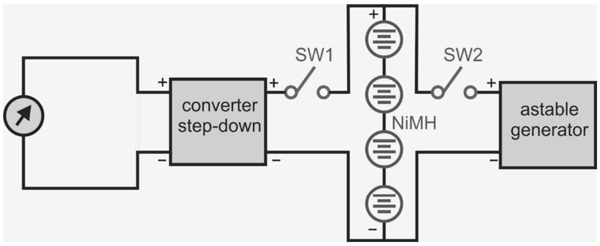

Fig. 10. Simplified electrical diagram of the photovoltaic system

Converter MC34063, which together with the external elements such as resistors, capacitors and the inductor plays the role of the converter "step - down". The main task of converter “step-down” is voltage regulation in a standalone system – traffic light. Additionally, the Zener and Schottky diodes were used. In order to maintain constant voltage at the specified load changes and input voltage Zener diode was used with a value of 13 V. This diode is the simplest of the available devices to stabilize the voltage and is intended to prevent breakdown and early damage to the device. The Schottky diodes are necessary due to the unstable conditions of light and prevents the discharge of the batteries during cloudy weather.

The NiMH battery charging begins when the switch SW1 is closed. The four batteries connected in series temporary feed astable generator, which was used to imitate traffic light. To build a astable generator (multivibrator) timer 555 was used. Astable generator is powered when the switch SW2 is closed. The system is designed to charge without turning on the astable generator. It also allows for simultaneously battery charging and operation of the astable generator.

3. Result

First of all, as the result due to conventional technological by means of screen printing process monocrystalline silicon solar cells were obtained.

In order to determine the basic electrical properties of 36 monocrystalline silicon solar cells, their current - voltage characteristics were measured under Standard Test Condition STC (Fig. 11). The system for measuring the current-voltage characteristics can be divided into three main components, which have a decisive impact on the quality of measurements:

- a light source,
- measuring system,
- table and probes.

The main electric properties of PV module are presented in Table 1. In Figure 12 current - voltage characteristics of the PV module is shown.

The module was used to build a demonstration photovoltaic system - traffic light - pedestrian crossing, which shows the practical use of widely available, renewable energy source which is the Sun. Converter step down was used to protect photovoltaic system against variable input voltage and adjusts the voltage of the PV module to the battery life and protecting them from overcharging, in the case of unstable lighting conditions prior to discharge. Astable generator allows to change color in every 5 s by imitating the same effect of traffic light. During operation, astable generator is powered by NiMH batteries, which simultaneously load photovoltaic module. Battery collects the energy and ensure its steady supply at night and in low sunlight. It is also possible the continuous charging of NiMH batteries without turning on the generator-Control. Schema of the photovoltaic system is shown in Figure 13 and electrical diagram of photovoltaic system in Figure 14.

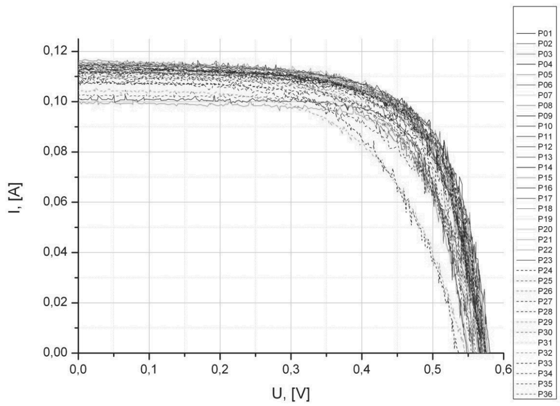

Fig. 11. Current-voltage characteristics of 36 solar cells

Table 1.
Electric properties of photovoltaic module

Parameter	Value
I_{SC} [mA]	101
U_{SC} [V]	17.58
I_{max} [mA]	84
U_{max} [V]	12.93
P_M [W]	1.08
E_{ff} [%]	9.7
FF [%]	61

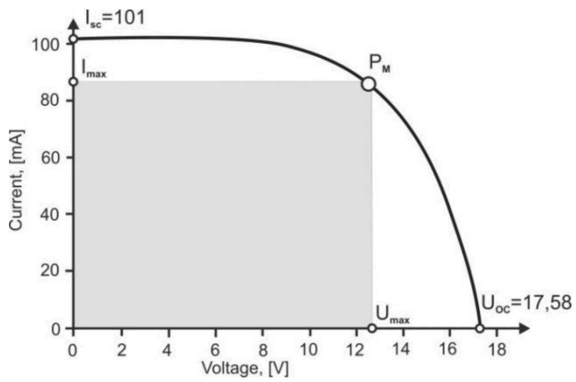

Fig. 12. The determinate current - voltage characteristics of the PV module

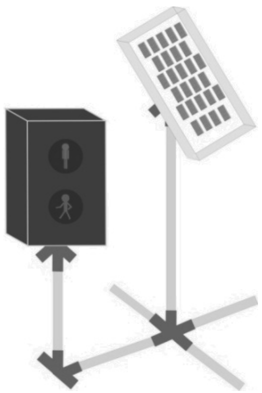

Fig. 13. Schema of the photovoltaic system

4. Conclusions

The most commonly used material for photovoltaic cells is silicon, whose share in world production is about 90% [3,13]. Both cells of polycrystalline silicon and monocrystalline base plays a major role in photovoltaics. The production of aamorphous silicon is much cheaper than mono- and polycrystalline silicon and it is expected that in the future solar cells based on a-Si will achieve higher efficiencies. Photovoltaic industry is one of the fastest growing sectors of the market. Increasing the use of solar cells on Earth is related to the sharp increase in their efficiency (approximately 20%), reduction of production costs, as well as the depletion of conventional energy sources and reducing pollution.

In this paper, the monocrystalline silicon solar cells were produced**.** Passivated thin layer was obtained by oxidation of the silicon surface. In order to increase the absorption of solar radiation wafer was textured. On the surface anti-reflective layer was applied by CVD method. Electrical contacts were prepared by screen printing method.

Based on the measured current - voltage characteristics of 36 photovoltaic cells 31 were selected with the highest short-circuit current. Next, solar cells were used to build solar module with open circuit voltage of 17.58 V and short circuit current of 101 mA. The module was used to build a demonstration photovoltaic system -traffic light.

Photovoltaic system-traffic light consists of: converter step-down, astable generator, battery, solar module and traffic light. Converter step-down was used to protect photovoltaic system against variable input voltage and adjust the voltage of the PV module to the battery life and in the case of unstable lighting conditions protect battery from overcharging. Astable generator provide changing of illumination color in order to imitating traffic light. Practical use of widely available, renewable energy source which is the Sun has been presented.

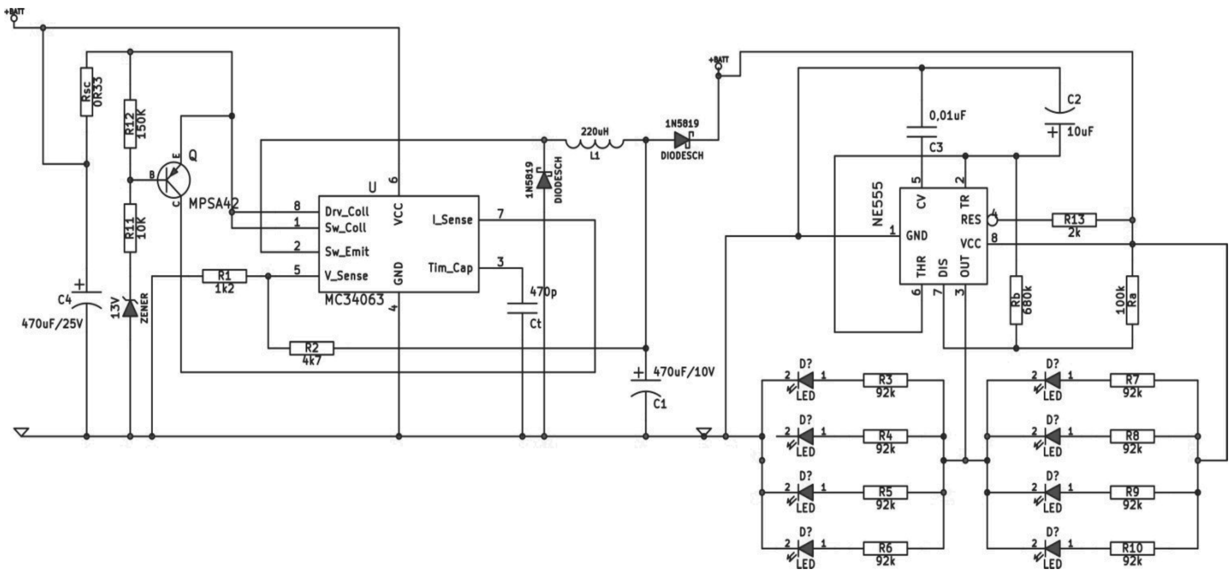

Fig. 14. Electrical diagram of traffic lights powered by solar energy

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