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MAIN ENERGY LOSSES AND EFFICIENCY IN PHOTOVOLTAIC CONVERTERS

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Abstract: Solar energy is today considered the most promising type of alternative energy. Today, solar energy has become widespread due to a number of advantages over other renewable energy sources, environmental safety and inexhaustibility of the energy source in the face of rising prices for traditional energy sources. Solar energy can be used anywhere in the world. Solar modules are increasingly used to power private homes. In addition, they are actively integrated into a centralized network as part of energy saving programs adopted in the most developed countries [1].

Keywords: Efficiency coefficient (efficiency), solar cell (SC), silicon, photovoltaic converter (PVC), antireflection coating (ARC).

Currently, the transition to renewable energy sources is regarded as a replacement for traditional electricity generation. The development of solar energy is a priority task, as the Sun provides us with enormous, almost inexhaustible energy resources. The most cost-effective devices for converting solar energy into electricity are semiconductor photovoltaic elements (PVE), since this is a direct, single-stage energy conversion process. In this case, silicon is the best material for them.

The choice of silicon as the source material for manufacturing solar batteries depends on several factors, Silicon is the second most abundant element on Earth after oxygen, The technology for producing silicon solar batteries is well established and is constantly being improved, Due to their spectral sensitivity, silicon-based solar batteries are suitable for utilizing solar radiation; Silicon devices are less sensitive to temperature changes, Silicon-based devices exhibit minimal reflection and low losses [2].

Currently, the average efficiency of silicon solar batteries is 14–18%. In laboratory conditions, samples with 22% efficiency have been achieved. Increasing the efficiency of silicon solar batteries is one of the most important problems in the overall development of solar energy and, in particular, in the creation of solar batteries.

Several factors influence the efficiency of silicon solar batteries, Resistance to metallization, Structure of the p-n junction, Quality of the production technology, Since the standard process for manufacturing solar batteries has reached its peak, one of the important ways to increase solar battery efficiency is to reduce the resistance of metallization and contact junctions [3].

The efficiency of a solar panel is calculated by the ratio of the electrical energy produced from the solar energy incident on the panel. Currently, the average efficiency ranges from 12–25%. The difference primarily depends on the materials used in manufacturing the solar panels.

The efficiency of monocrystalline batteries in mass production is 21.5%, while in space applications it reaches 38%. Monocrystalline silicon is produced from highly purified raw materials, approximately 98% to 99.9% purity. This feature makes monocrystalline silicon the most expensive, but it provides high efficiency.

The efficiency of polycrystalline batteries is about 18%, which is lower than that of monocrystalline silicon. This lower efficiency is due not only to the lower purity of polycrystalline silicon compared to monocrystalline but also to the fact that it is often produced from recycled solar panel materials.

Solar panels made from amorphous silicon are called “flexible panels.” Their main feature is their flexible structure. These panels are manufactured using amorphous silicon or cadmium

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telluride. The efficiency is determined by the semiconductor material; for silicon, it is about 10%, while for panels made from telluride semiconductor materials, it reaches 25%.

Thus, the material silicon is directly related to the efficiency of solar panels and is considered the optimal option for creating solar batteries [4].

Due to their structure, reflection of solar rays from the wafer surface is reduced by 10–15%. This occurs primarily due to texturing the surface at the initial stage. After cutting silicon into square wafers, the surface remains damaged at the nano level. Since we cannot simply remove several microns from the surface, the wafer would be smooth and fully reflect incident light; therefore, a texturing process is performed, resulting in a surface structure with randomly arranged micro-pyramids. All of this is a necessary condition for creating a reflective layer.

As mentioned above, at the initial stage, reflection losses can be reduced by 10–15%. To further reduce losses, an antireflection coating (ARC) is applied to the surface.

According to the laws of optics, when applying ARC, the refractive index is taken into account. This allows reflection losses to be further reduced by 1–2%.

Titanium oxide or silicon nitride films are used as ARC for monocrystalline silicon. These films are typically deposited using plasma-enhanced chemical vapor deposition. As a result, a layer of silicon nitride or titanium oxide film approximately 70 nm thick is “grown” on the front surface. This film achieves an anti-reflection effect regardless of the surface structure of the silicon layer [5].

The difference in efficiency values also depends on the complexity of the p-n junction in the solar battery (SB). A silicon solar battery consists of a front contact system (front surface), antireflection coating, n-layer, p-n junction region, p-layer, isotype layer, and back contact (see Figure 1).

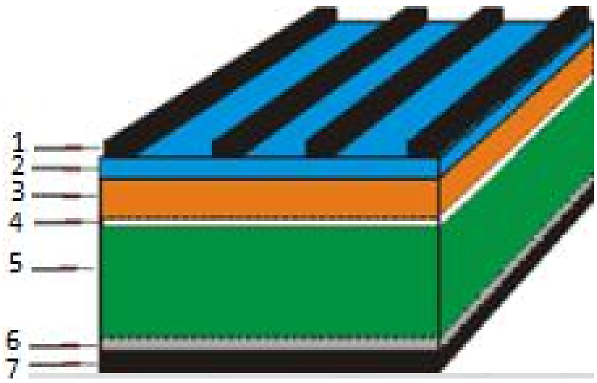

Figure 1. Cross-section of a silicon solar battery.

1 – front contact system, 2 – antireflection coating, 3 – n-region (emitter), 4 – p-n junction region, 5 – p-region (base), 6 – isotype layer, 7 – back (rear) contact.

The front surface serves to maximally absorb incident radiation. The front surface is made in a grid (finger) form. This is done to reduce optical losses due to the darkening of the working surface. When creating this surface, several important factors must be considered:

The grid lines should be as thin as possible and spaced as far apart as possible. However, they should not be too far apart, otherwise charge carriers will not have time to reach the contact and will recombine inside the material. Therefore, the distance between grid lines should not exceed a certain value.

The line width should be optimal. The thinner the line, the better from an optical point of view, but the contact’s ability to conduct current decreases.

When forming this layer, the depth of the contacts is also important. For example, the p-n junction should be located at a depth of 0.5 μm. The metal deposited on silicon must penetrate as deeply as possible into the n-layer but not reach the p-layer; otherwise, an electrical contact will form between these two layers, short-circuiting the solar battery.

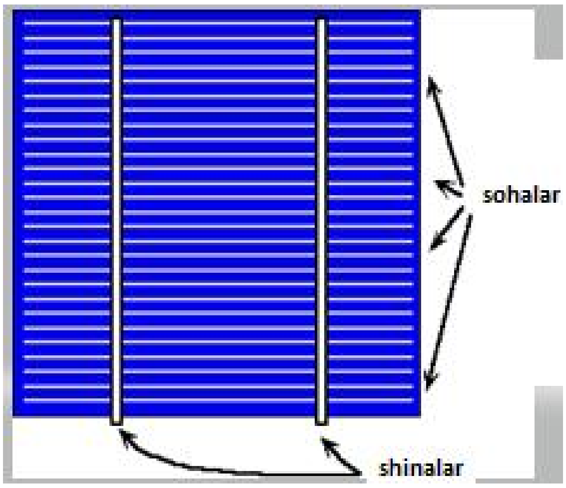

Figure 2. Front contact system.

On the back side of the solar battery, not just one type of metal is used, but two: a solid aluminum layer and silver lines (usually two or three, although continuous lines are also possible). The aluminum layer acts as a kind of energy mirror. Charge carriers have the ability to recombine, and to reduce this effect, a BSF (back surface field) layer is applied, which creates minority charge carriers. This increases efficiency by approximately 2–4% [6].

As noted above, although the technological process can reach its maximum level, it is necessary to control the actions and sequences performed during the production of solar batteries.

The complexities in manufacturing solar batteries also affect efficiency, as the entire process is labor-intensive and includes many stages that require special attention, thorough incoming and intermediate inspections. In the final stage, finished solar batteries undergo testing. These tests are primarily aimed at obtaining information on maximum current, voltage, maximum power, shunt resistance, contact and line resistance, as well as photocurrent and, most importantly, irradiance. Irradiance is the power incident on a given surface area. This parameter varies. In terrestrial conditions, the maximum power value reaches 1300 W/m², but usually 1 kW/m² is taken as standard.

Solar cells are tested with artificial sunlight using pulsed or continuous irradiation. The advantage of pulsed devices is that solar cells do not experience thermal discomfort, and measurement errors are reduced. It also depends on the choice of artificial lighting, which affects the spectral composition of the radiation. Of course, nowadays everything is automated and the computer easily performs all the necessary calculations, but it is important to remember the following:

1. Since the electrical energy produced by solar cells is directly proportional to the luminous flux, it must be accurate and constant.
2. It is important that the same luminous flux falls on the surface of the solar cells under test.
3. The temperature of the solar cell must be accurately known.
4. Any voltage drop across the contacts and circuits will cause additional measurement errors [7].

To summarize the above, it can be said that the main energy losses and efficiency of photovoltaic batteries depend on material selection. Whether monosilicon, polysilicon, or amorphous silicon; applying antireflection coatings, using various doping films—these allow reducing the main energy losses in photovoltaic batteries, improving efficiency, and achieving better performance. Testing solar batteries—the choice of testing equipment—is an important factor, as the final results must be known with 100% accuracy.

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