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INCREASING ENERGY EFFICIENCY IN SOLAR PANELS BY CHANGING THE COMPOSITION OF SEMICONDUCTORS

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Abstract: Solar energy is becoming an important source of sustainable and environmentally friendly energy in the modern world. Solar panels have become one of the main directions in the energy supply for sunny countries. However, the energy efficiency of solar panels is still limited, and continuous research is being conducted in this area to increase efficiency. The method of introducing impurities (doping) into semiconductor materials allows you to significantly increase the efficiency of solar panels. This article provides information on the principle of operation of solar panels, the importance of introducing impurities.
Keywords: solar panels, semiconductors, impurities, photoelectric effect, silicon, germanium, efficiency, losses.

Introduction. Solar energy is becoming an important source of sustainable and environmentally friendly energy in the modern world. Solar panels operate on the basis of the photoelectric effect, in which semiconductor materials convert sunlight into electrical energy. Solar panels are mainly made of silicon (Si) or other semiconductor materials. When sunlight hits the panel, photons excite electrons and create an electric field. The efficiency of this process depends on the properties of the material, its structure, and its ability to absorb light. Photons excite electrons within the semiconductor, which creates an electric current. The low efficiency is due to energy loss (in the form of heat or recombination) and the optical properties of the material [1].
The efficiency of solar panels (Figure 1) depends on the following factors: the material's ability to absorb light (only a certain part of the solar spectrum is converted into energy), electron recombination (free electrons recombine, leading to energy loss), and heat loss (efficiency decreases at high temperatures).
The main materials used in solar panels include silicon, gallium arsenide (GaAs), cadmium telluride (CdTe), and perovskites. Each material has its own advantages and disadvantages:
Monocrystalline silicon - high efficiency (20-22%) and long service life, but high production cost.
Polycrystalline silicon - efficiency around 15-18%, but cheaper to produce.
Amorphous silicon - efficiency 6-8%, is the cheapest.
Gallium arsenide (GaAs) - has an efficiency of up to 30%, but is expensive and is mainly used in space technology.
Perovskites - in recent years have achieved efficiencies above 25%, but there are stability problems [2].
Doping of semiconductors is the process of adding specific chemical elements to change the electrical and optical properties of the material. Dopants are divided into two types: n-type

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dopants: Elements such as phosphorus (P) or arsenic (As) increase the number of electrons. p-type dopants: Boron (B) or gallium (Ga) create “holes” (positive charge carriers). The dopants form a p-n junction, creating an electric field, which is the basis of the photoelectric effect. By choosing the right amount and type of dopants, the efficiency of a solar cell can be increased.

RESULTS AND ANALYSIS

There are several advantages to doping. Dopants increase the density of electrons or holes, which enhances current generation. Dopants broaden the light absorption spectrum of the material. Proper dopants minimize recombination and heat loss [3].

Doping technologies

1. Thermal diffusion: Dopants are deposited onto the surface of the material at high temperatures.
2. Ion implantation: Dopant ions are introduced into the material at high energy.
3. Chemical vapor deposition (CVD): Dopants are added to the material using special gases.

Phosphorus and boron are the most commonly used dopants in silicon solar panels. Recent studies show that additional dopants such as nitrogen (N) or aluminum (Al) can increase efficiency by 1-2%. For example:

- Phosphorus doping: increases the conductivity of the n-type layer.
- Boron doping: Strengthens the p-n junction by forming a p-type layer.
- Combined doping: Efficiency can be optimized by using multiple dopants simultaneously.

High-efficiency silicon atoms, such as PERC (Passivated Emitter and Rear Cell) technology, are improved by doping. In this technology, electron recombination is reduced by using special layers and dopants [4].

Gallium arsenide and perovskite dopants:

- GaAs solar cells have high efficiency (up to 30%), but are expensive. The optical properties are improved by adding dopants such as selenium (Se) or zinc (Zn). Although GaAs is mainly used in space technology, research into its cost-effectiveness is ongoing.
- Perovskite materials have gained considerable attention in recent years, as their efficiency has exceeded 25%. By adding dopants such as methylammonium, cesium or lead, the stability and light absorption capacity of perovskites are increased. At the same time, the resistance of perovskites to moisture and heat remains a problem.

Solar panels are environmentally friendly alternatives to traditional fuels. Increasing efficiency by adding dopants further increases the economic efficiency of solar panels, as higher efficiency reduces the cost of energy production [5].

The doping process poses a number of challenges:

1. Material stability: The long-term stability of perovskite cells remains a challenge.
2. Manufacturing costs: Materials such as GaAs are expensive, limiting their widespread use.
3. Environmental impact: The chemicals used for some doping can be harmful to the environment.

The future of solar panels depends on new materials and technologies. Innovations such as self-cleaning panels, transparent solar cells, and integration with energy storage systems are driving the industry forward. Research on doping is aimed at increasing the efficiency of perovskite and low-cost materials.

Innovative approaches

Self-cleaning panels: Hydrophobic coatings reduce the impact of dust and pollution.
Transparent panels: Can be used in building windows and vehicles.

Energy storage: High-efficiency panels can provide energy supply at night in combination with batteries.

The energy efficiency of solar panels is currently around 15-22%, and continuous research is being conducted to increase it. Silicon-based solar panels are the most common, and efficiency can be significantly increased by adding other substances (dopants) to them. This article discusses the technological basis of doping silicon, its impact on efficiency, opportunities for Uzbekistan, and future prospects. Photons excite electrons in silicon, which creates an electric current. Efficiency limitations are due to the following factors:

Light absorption: Silicon can only absorb a certain portion of the solar spectrum.

Recombination: Free electrons recombine, resulting in energy loss.

Heat loss: Efficiency decreases at high temperatures.

Silicon is the most common material in solar panels because it is stable and has a long lifespan (25-30 years). It is one of the most abundant elements on Earth. It is relatively inexpensive to manufacture.

Silicon solar panels are divided into three main types:

Monocrystalline silicon: Has a high efficiency (20-22%) but is expensive to manufacture. It has a single crystal structure and is efficient at absorbing light.

Polycrystalline silicon: Has an efficiency of around 15-18% but is cheaper. It is easier to manufacture due to its multi-crystalline structure.

Amorphous silicon: Has an efficiency of 6-8% and is the cheapest but is used in low-efficiency and thin-film panels.

Each type has its own advantages and disadvantages, and their efficiency can be increased by adding additives. Doping is the process of adding specific chemical elements to silicon to modify its electrical and optical properties. Dopants increase the density of electrons or holes, which increases current generation. Dopants broaden the light absorption spectrum of silicon. Proper doping minimizes recombination and heat loss [6].

Thermal diffusion: Dopants are implanted into the surface of silicon at high temperatures.

Ion implantation: Dopant ions are introduced into silicon at high energy.

Chemical vapor deposition (CVD): Dopants are added to silicon using special gases.

The most commonly used dopants in silicon solar cells are phosphorus and boron. However, other materials are also being used to improve efficiency. Phosphorus is used as an n-type dopant because it provides additional electrons when added to silicon. This increases the conductivity of the n-type layer and strengthens the p-n junction. High-concentration doping of phosphorus can increase efficiency by 1–2%. Boron is used as a p-type dopant, creating holes. This is important in forming the p-type layer. Boron doping enhances the electric field of the p-n junction and improves the movement of electrons. By adding nitrogen, the optical properties of silicon are improved, allowing it to absorb a wider spectrum of light. Aluminum can be used as a p-type dopant and increases heat resistance. When gallium is used instead of boron, long-term stability and efficiency can be improved [7].

The simultaneous use of multiple dopants (for example, phosphorus and nitrogen) further increases efficiency. This method helps to adjust the bandgap of silicon and reduce recombination. A number of modern technologies are used to increase the efficiency of silicon-based solar panels:

PERC (Passivated Emitter and Rear Cell) technology uses special layers and inclusions to reduce electron recombination, and the efficiency exceeds 22%.
In HJT (Heterojunction Technology), the efficiency is increased to 24% by combining silicon and amorphous silicon layers and introducing dopants.
In TOPCon (Tunnel Oxide Passivated Contact) technology, the efficiency is increased to 25% by using dopants and a thin oxide layer.
In these technologies, the doping process plays an important role, as it optimizes the movement of electrons and reduces energy loss.
The process of introducing dopants into silicon poses a number of problems. High-quality doping processes are expensive. It is important to ensure the long-term stability of the doped silicon. Some dopants (for example, phosphorus) can generate chemical waste during production.

Conclusion

Although silicon is the most common material in solar panels, germanium (Ge) is being used in high-efficiency solar panels due to its unique properties. Its efficiency can be significantly increased by introducing other substances (dopants) into germanium. Germanium absorbs the infrared part of the solar spectrum well, making it useful in multilayer cells. Free electrons recombine, causing energy loss. Efficiency decreases at higher temperatures.
Germanium has some advantages in solar panels. Germanium's band gap (0.67 eV) allows it to absorb infrared light. The fast movement of electrons enhances current generation. Germanium is combined with gallium arsenide (GaAs) to create panels with high efficiency.
There are also some disadvantages to the use of germanium. Germanium is more expensive than silicon. Germanium is one of the rarest elements on Earth. There is a risk of oxidation with long-term use.
Germanium is mainly used in multilayer (tandem) solar cells, because it has a lower band gap and is effective at absorbing the infrared part of the solar spectrum. It is usually used in combination with gallium arsenide or silicon. Germanium-based panels are widely used in space technology (e.g. satellites) and in projects requiring high efficiency. Multilayer panels consist of layers of different materials (e.g. GaAs, Ge, InGaP), each layer absorbing a specific part of the solar spectrum. Germanium is used as a substrate in this system and absorbs infrared light. These panels can achieve efficiencies of up to 40%. Doping germanium is the process of adding specific chemical elements to improve its electrical and optical properties. Dopants are of two types: n-type dopants - phosphorus (P), arsenic (As) or antimony (Sb) - increase the number of electrons. p-type dopants - gallium (Ga), indium (In) or boron (B) - create "holes" (positive charge carriers). Insertions create an electric field by forming a p-n junction, which is the basis of the photoelectric effect. Proper insertions play an important role in increasing the efficiency of germanium. Insertions increase the density of electrons or holes, which enhances current generation. Insertions broaden the light absorption spectrum of germanium. Proper insertions minimize recombination and heat loss.

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