Laser-Plasma Technology for Creating Silicon-Graphene Solar Cells

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Abstract

In response to the growing concerns of global warming and the urgent need for sustainable energy solutions, the exploration of alternative energy sources has become increasingly important. Among these, solar energy stands out as a clean, abundant, and renewable option. The efficiency of solar cells depends significantly on the base semiconductor material, with silicon currently dominating global production. However, modern research focuses on enhancing solar cell performance through innovative approaches, such as the deposition of graphene layers using advanced laser-plasma technology. Laser-plasma technology integrates laser ablation and plasma deposition techniques to fabricate high-efficiency thin-film solar cells, including those based on silicon-graphene nanosystems. This approach enables precise structuring, local doping, and film growth at the nanoscale, which enhances optical absorption, electrical conductivity, and carrier collection efficiency. By optimizing the deposition process and exploring various technological conditions, graphene-enhanced solar cells can achieve improved electrical conductivity, better light absorption, and reduced energy losses, paving the way for highly efficient and environmentally friendly solar energy solutions. The presented work discusses the deposition of graphene on a solar cell using laser-plasma deposition technology and the analysis of the results obtained. Experiments were conducted under various technological conditions in order to investigate the optimal conditions for obtaining high-efficiency solar cells. In the experiments used 2-inch diameter, (100) crystallographic orientation and 400 μm thick p-type silicon wafers. Different phosphorus diffusion depths were considered to achieve n-type conductivity. In one case, silicon nitride and graphene were used as the antireflective layer, and in the other case, only graphene was used. The volt-ampere characteristic was measured and the margin action coefficient of the solar cell was estimated in each experiment. The parameters of the solar cell obtained with and without graphene were compared.

Keywords: *Semiconductor, solar, technology, diffusion, Laser*

1. Introduction

Solar cells, the foundational components of photovoltaic (PV) systems, convert sunlight directly into electricity through the photovoltaic effect. As the world increasingly seeks sustainable energy alternatives, the technology and manufacturing processes of solar cells have become pivotal in meeting global energy demands while reducing carbon emissions. This article explores the technology behind solar cell production, recent advancements, and its implications for energy sustainability. A solar cell is a semiconductor device, typically made from silicon, that absorbs photons and releases electrons to generate an electric current. The efficiency of a solar cell—defined as the proportion of sunlight converted into electricity—depends on the material quality, surface engineering, and architecture of the device.

Currently, the photovoltaics solar panels (PV modules) are about a square meter in size. In the last decade, the efficiency of average commercial Silicon single crystal wafer based solar panels increased from 15-16 % to 20-22 %, which is happening because of the increase of parameters of using semiconductor Silicon and lower losses of charge carriers in electronic circuits. The best-known efficiency for today solar cells is achieved as Fraunhofer Institute for Solar Energy Systems is reported up to 50% (using AIIIBV and more exotic materials) [1-5].

The science and technology target of the current project “Development of High Efficient Solar Energy Photo-Converting Element Based on Silicon-Graphene Nanosystem.” is to establish the team and working structure for the development of methodologies of preparation and measurement 2D material based advance solar energy conversion element.

The conversion of light to electricity depends on the electronic structure of solar cells with two or more layers of semiconductor material that can absorb photons which raise the energy level of the electrons in the semiconductor, exciting some to jump from the lower-energy valence band to the higher-energy conduction band. The electrons in the conduction band and the holes they have left behind in the valence band are both mobile and can be induced to move by a voltage [6-9].

The barrier to the widespread use of sunlight to generate electricity is the effectiveness and cost of photovoltaic systems. The application of materials science is essential in efforts to increase the efficiency of light conversion and decrease the cost to levels that can compete with those for fossil or nuclear fuels [10-12].

2. Experimental

The article discusses the technology of creating a solar converter and the laser-plasma deposition technology for coating surface of the solar cell by the graphene. Graphene is a so-called zero forbidden gap semiconductor/semimetal with a robust but flexible structure possessing unusual phonon modes. In some sense, Graphene brings together issues in quantum gravity and particle Physics, and also from soft and hard condensed matter.
The steps involved in creating a solar cell are as follows:

- **Chemical treatment of P-type silicon.**

In the experiments were used P type, 2cm×2cm square, (100) orientation, 400 μm thick and 1-10 ohm.cm resistivity monocrystalline silicon wafers. The process of solar cells is starting with chemical treatment of silicon. Silicon wafers are degreasing in acetone or dimethylformamide at 45^0C – 50^0C for 5 minutes. Washing in deionized water and treatment in a solution of $NH_4OH + H_2O_2 + H_2O$ (1:2:4) at 45^0C – 50^0C for 5 minutes. Washing in deionized water. Decompiling in a solution of $HF + H_2O$ (1:50) 1 minute, washing in distilled water and drying in a centrifuge.

- **Silicon oxidation.**

After chemical treatment of silicon it is necessary to make P^+ layer on the rare side of the silicon wafers for ohmic contact. For this purpose, at 1150^0C for 20 minutes, in an environment of deionized water vapor and oxygen for 5 minutes is proceed oxidation of silicon (Fig.1). The thickness of the resulting oxide is ≈ 0.3-0.4 μm.

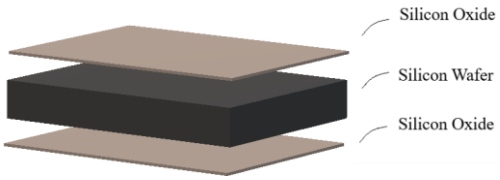

Fig. 1. Silicon Oxidation at 1150^0C

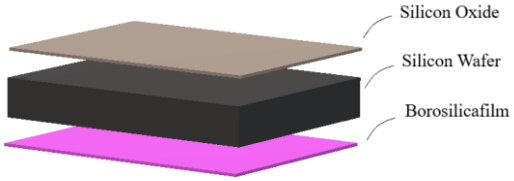

Fig. 2. Deposition of Borosilicafilm

From the non-working side (rare side) of the silicon wafer is removed oxide by solution HF (2 minutes), followed washing in deionized water and drying in a centrifuge.

- **Boron diffusion.**

After this step on the rare side of Si is deposited borosilicafilm by a centrifuge at a speed of 3000 rpm (Fig. 2). Followed drying at 100^0C for 5 minutes.The next step is boron diffusion, which is carried out at 1150^0C for 10 minutes in an argon atmosphere in a high temperature oven. After diffusion the borosilicate glass is removed from the back side of the Si in a HF + H2O (1:20), approximately 1 minute. Then washing in deionized water and drying in a centrifuge. After diffusion on the back side is measured Surface resistance by the four-probe method.

- **Phosporous diffusion.**

For creating p-n junction it is necessary to process diffusion phosphorus from the front side of Si. Prior to diffusion, silicon is oxidizes at 1150^0C with O_2 (5 min) + H_2O (steam 20 min) + O_2 (10 min). Then removes oxide from the front side and by centrifuge is deposited phosphorosilicafilm (Fig. 3). Followed diffusion 1050^0C for 4 min in an argon atmosphere.

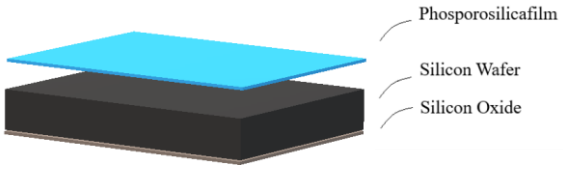

Fig. 3. Deposition of Phosphorosilicafilm

After diffusion phosphorus silicate glass removed by HF + H2O (1:20), about 1 min. Washing in deionized water and drying in a centrifuge. Measurement of parameters as a result of phosphorus diffusion such as surface resistance, grinding and measurement of diffusion depth. The next steps are shown on the figures 4-12, which consists:

- aluminum deposition on the back side of Si (Fig. 4), baking at 475^0C for 25 min in an argon atmosphere.
- Aluminum deposition on the front side of the Silicon (Fig. 5).
- Photolithography on aluminum from the front side (Fig. 6 – Fig. 9).
- Aluminum etching $H_3PO_4 + HNO_3 + CH_3COOH + H_2O$ at 40-50^0C, 1-2 min, photoresist removal (Fig. 10).
- Remove photoresist (Fig. 11).
- Baking at 4750C for 4-7 min in an argon atmosphere.

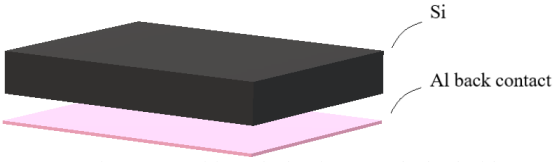

Fig. 4. Deposition of Aluminum on the back side.

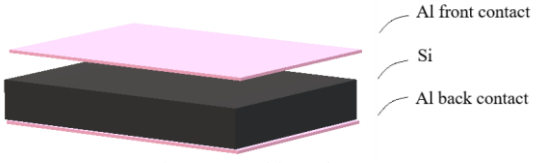

Fig. 5. Deposition Al top contact.

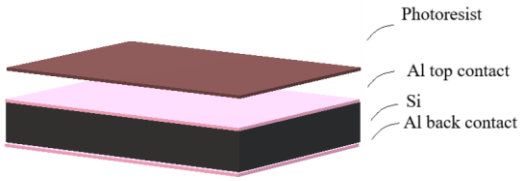

Fig. 6. Deposition of Photoresist

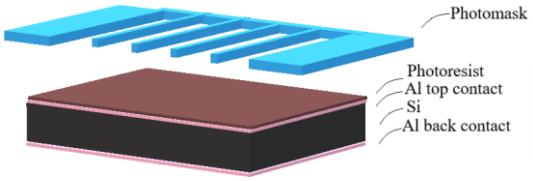

Fig. 7. Photolithography process.

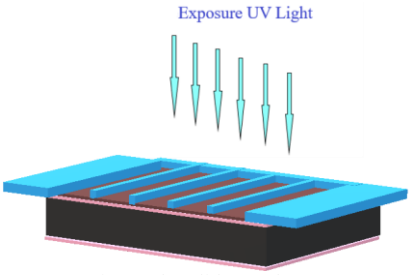

Fig. 8. Photolithography process – exposure by UV light.

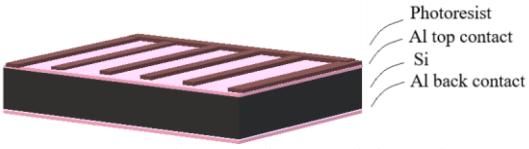

Fig. 9. Development of photoresist

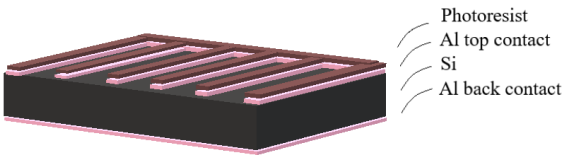

Fig. 10. Etching of top Al contact

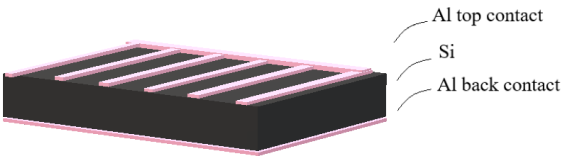

Fig. 11. Etching photoresist.

After the solar cell is formed, graphene is deposited on the surface using laser-plasma technology in various modes and compared the obtained results.

2. Results and Discussion

The properties of nanomaterials prepared by laser plasma technique (Fig. 12) are unique, and they are not reproducible by any other method including chemical ones. The usage of resonance light heat creates the opportunity to energize the selected atoms as well as their groups (assemble) and to produce plasma with the necessary properties relevant to structures which must be prepared. [13,14]. The nanosize graphene nanolayer, which is deposited on the silicon surface play the role of charge carrier pump. Using the unique electronic and spintronic properties of Graphene (electron mobility at room temperature -15000 $cm^2V^{-1}s^{-1}$; thermal conductivity 3000-5000 W/mK at room temperature), the Silicon solar energy conversion efficiency is fully realized in the Silicon-Graphene photoconversion element [15].

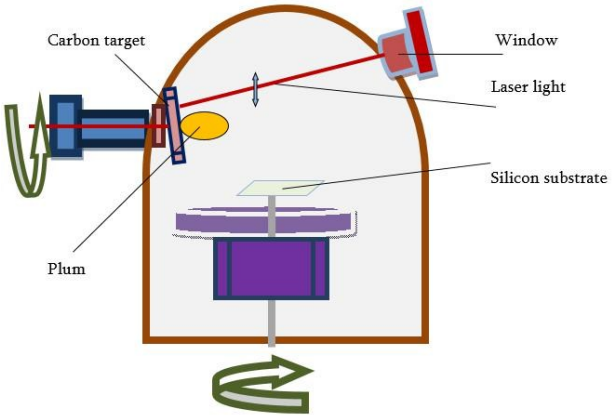

Fig. 12. Scheme of Graphene nanolayer deposition on monocrystalline Silicon substrate by laser-plasma method.

In the experiments several silicon wafers were used in the process of making solar cells, which were obtained by the same technological process. In order to compare a graphene-coated solar cell with a non-graphene-coated solar cell and to understand the role of graphene in the conversion of solar energy, graphene was coated on some of them and were measured electrical parameters. On some of them without graphene coating were measured parameters such as the depth of diffusion of impurities, surface resistance, volt-ampere characteristic. Table 1. shows the measured parameters for solar cells with and without graphene. After completing solar cell, it was cut into rectangular shape form with surface area 0.75 cm^2 and put into laser-plasma coating machine. Inside the vacuum chamber are located carbon target, silicon wafer and heater. Laser source is mounted outside the vacuum chamber on the view window and the laser light cross the quartz window, incidents on the carbon target and evaporates it. Under the carbon target is located silicon solar cell. The power of the laser was 20 mW and duration of evaporation was 2 hours. Vacuum in the chamber was $5 \cdot 10^{-5}$ torr. Was measured deposited graphene thickness by profilometer and it was about 15 nm.

Tab. 1. The text of the table caption will be here.

Parameters	Without graphene	With graphene
Short-circuit current (I_SC), mA	180	213
Open-circuit voltage (V_OC), V	0.57	0.57
Maximum power point (MPP), mW	102.6	121.41
Conversion efficiency (η), %	13.7	16.23
Diffusion depth, μ	0.8	0.8

The I-V measurement was carried out on solar simulator device (Fig. 13), which gives the same spectral contents as sun.

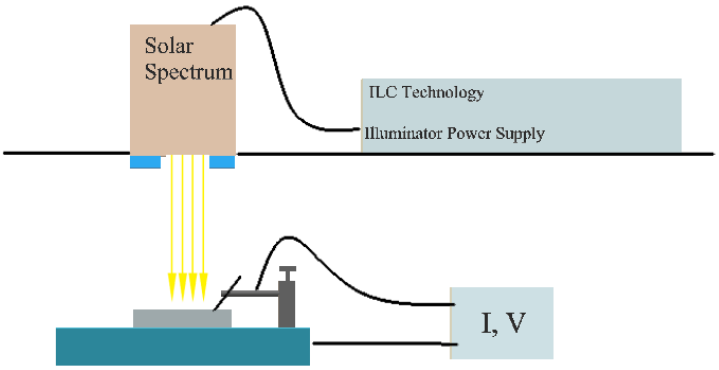

Fig. 13. Solar simulator for I-V measurement

As from the Table. 1 is shown the increase in current is equal to 33 mA, which means in terms of conversion coefficient it increases by 2.53 %.

3. Conclusion

P-type silicon wafers were considered in the experiments. The P-N junction is obtained by phosphorus diffusion. Diffusion occurs at high temperatures (~1050^{0}C) in a special high-temperature furnace. On the rare side of the solar cell, boron diffusion is also performed for good ohmic contacts. Aluminum is used as contacts, which is completed by the vacuum deposition method and subsequent lithography processes. After the formation of aluminum contacts, graphene is deposited on the solar cell by the laser plasma deposition method. The volt-ampere parameters of the resulting element are compared with the solar cell obtained without graphene. It revealed that conversion coefficient with graphene increases by 2.53%.

Acknowledgments

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