Thin Film Hybrid Structures Perovskite and Silicon Photovoltaic Cells

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Abstract
The world economy needs new breakthrough in the technological and material efficiency and costs in the manufactured solar cells. The authors present new studies on triple junction photo voltaic structures using nano-technological solutions. The system of the amorphous a-Si:H sandwich with the scattered light particles, the plasmonic nano Si in the a-Si:H matrix structure and the silicon-germanium sandwich on the multi ZnO layer electrode- reflector was made and studied in detail.

Key words: Thin films, multijunction solar cells, nanostructures, silicon, germanium, perovskites

Introduction

Nowadays, there seems to be no breakthrough in the technological and material efficiency of the commercially available solar cells, as well as their cost . The scientific objective of this project is to develop and test experimentally a computer-controlled technology for manufacturing solar cells with quantum dots in absorbers and photonic electrodes on the basis of mixed processes: vacuum in a 5-chamber RF PECVD system, multisource ionic system, and polymer-centrifugal method. The target components have the form of amorphous, nanocrystalline, and microcrystalline thin layer cell and they can be included in the proposed two- and triple-junction structure. They are schematically presented in Figures 3, 4, 5 i 7 and have been premade and tested [1-7]. In the present proposal that continues a previous project, it is planned to assemble a multi-junction cell and to expand it with a perovskite sandwich. This gives a possibility of adjusting light absorption profile better and, by selecting the thickness of the layers, adjusting the current to the multi-junction structure better. This formula gives an additional possibility of using much thinner absorption components and it allows increasing the stability of the component with perovskite and the entire structure. Currently, perovskite cells are researched intensively, in the last few years there has been a tremendous progress in their development and nowadays these cells reach efficiency above 20% [8]. However, one of their main disadvantages that limits the development of the technology is their low stability and quick degradability. At present, scientists ensure continuous work of perovskite cells below 1000 hours [9]. The content of toxic elements, e.g. lead, is also important. On the other hand, one of their greatest advantages is the capability to absorb a broad light spectrum, e.g. iodine-based perovskite can absorb radiation with a wave length of ca. 820 nm which corresponds to its band gap of 1.5 eV. Recent literature reports [10] show clearly that tandem systems formed by a combination of perovskite sandwich with monocrystalline silicon show significant improvements in stability and efficiency. According to the authors of [10], the operation of such cells has been extended to 1000 h at 85°C and 85% humidity and the performance of such system reaches 23.6%; this is one of the latest records.

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Experiments

These objectives were pursued in parallel by modernization of the equipment and fabrication processes. Various vacuum techniques were tested using a 5-chamber RF PECVD system and multi-source system, as well as polymer-centrifuge methods for the fabrication of multilayer structures including nanostructures with special optical and pohotoconductivity properties. A dedicated Lab was built by the Authors for this purpose.

Two types of nanoparticles were obtained using a multilayer nano procedure. The first type with the dimensions of approximately 100 nm is used to disperse light, while the second, with the dimensions of 3-5 nm is used for the size effects ,including increased photoconductivity and the plasmon process that causes retransmission of light with a longer wavelength. This is schematically shown in Figures 1 and 2. Figures 3, 4 and 5 show Cross Section TEM: of a multi-layer structure (Figure 3) which was further transformed into a layer with nanoparticles Figure 4 and 5.

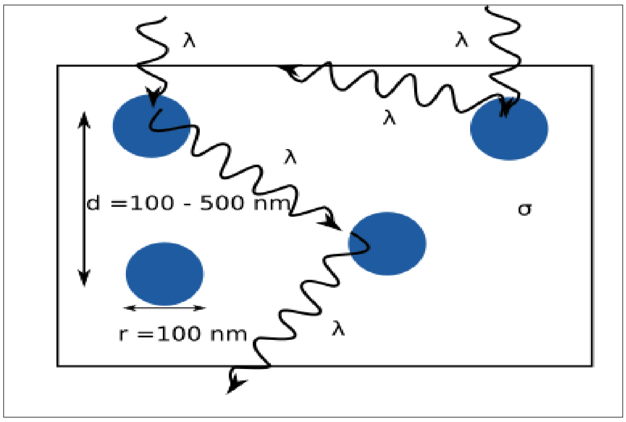

Figure 1. The idea of the process of light scattering on the nanoparticles

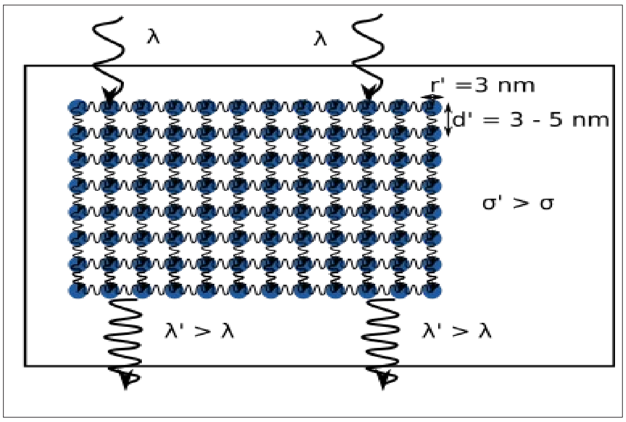

Figure 2. The idea of a size efect that increases the photo-conductivity and the plasmon process that causes retransmission of light with a longer wavelengths

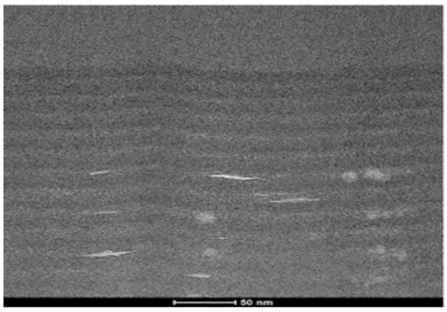

Figure 3. TEM Cross Section of nano multi-layered structure of SiOx

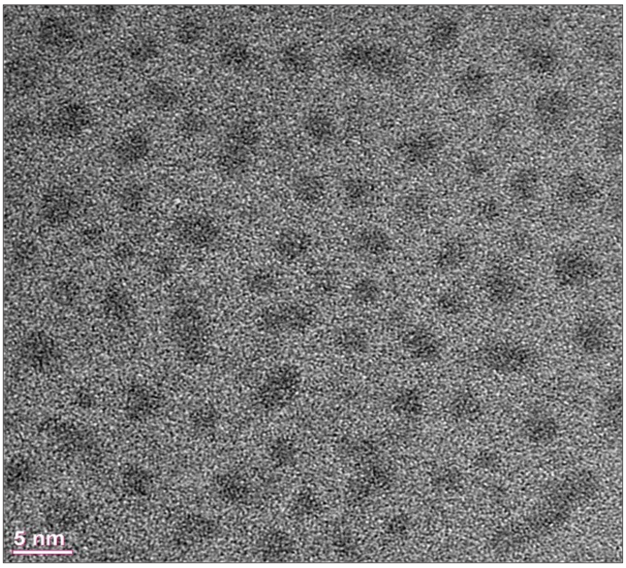

Figure 4. The structure of Figure 3 in the relaxation process transforms into a nanoparticle (Si) nc in SiOx matrix

As a result of microscopic analysis based on TEM Cross Section, it can be determined that silicon crystals (Si) nc in SiOx matrix were formed in this process. This is shown in Figure 5.

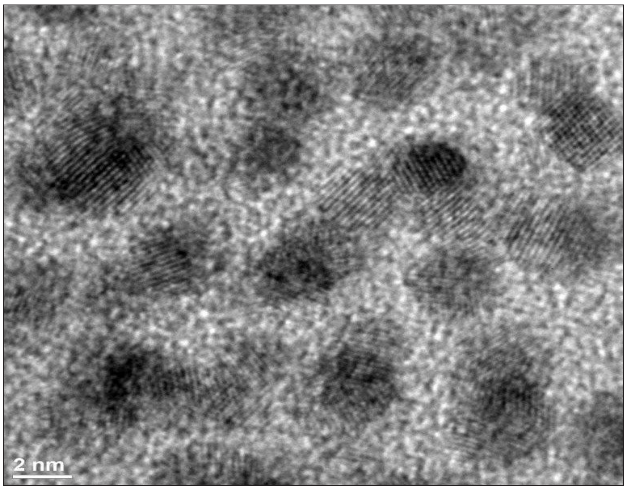

Figure 5. TEM Cross Section. Diffraction patterns and Si particles are seen in the received nano- layer as a result of the conducted process

Results and Discussion

The result obtained earlier were the basis for the design of multi-layered photovoltaic structures presented in the following drawings (Figure 6).

The structure proposed and tested in the last project and consisting of three silicon-germanium sandwiches and also proposed structure of the perovskite and silicon-germanium in a substrate version are shown in Figures 7, and 8. They include a layer of silicon nano-crystals and the front and back optical-electrode layers with different silver nano-crystals.

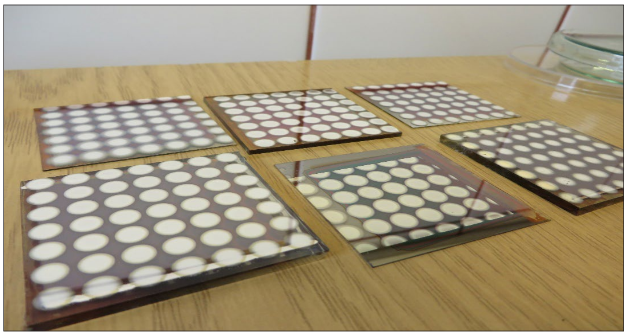

Figure 6. Photo of several obtained by the authors triple junction samples

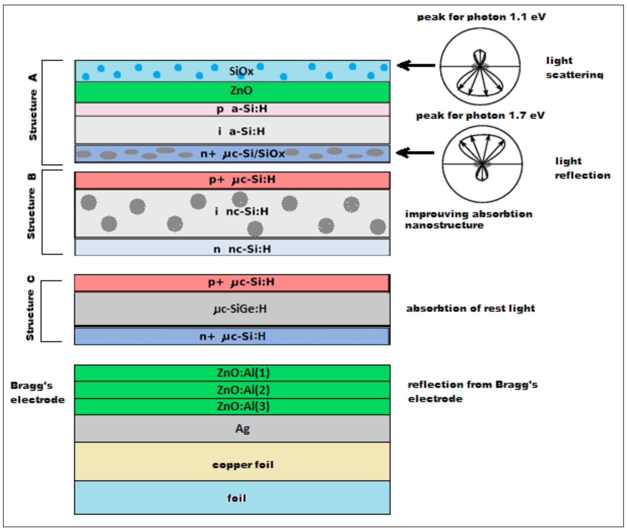

Figure 7. The concept structure of three silicon-germanium sandwiches in a substrate version

The new proposed structure with nanosilicon and perovskite sandwiches is schematically shown in figure 8.Apart from choosing perovskite and other barrier and conducting compounds, an additional important goal of this proposal is to limit maximally the thickness and to mount the whole structure in an inter--layer system for optimal stability.

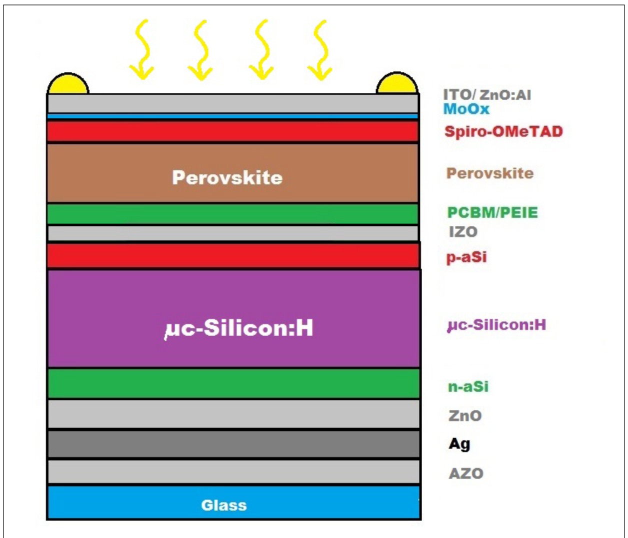

Figure 8. The concept of a planned tandem structure with nanosilicon and perovskite sandwiches

The sample solar cells (Figure 9) are characterized by the following parameters:

1. Cell1:V_{mp}=0,63[V], I_{mp}=-0,0059[A/cm^2], V_{oc}=0,91[V], I_{sc}=--0,0089[A/cm^2], FF=0,56, PM=-0,0037[W]
2. Cell2:V_{mp}=0,70 [V], I_{mp}=-0,0131[A/cm^2], V_{oc}=0,84[V], I_{sc}=-0,0141[A/cm^2], FF=0,77, PM=-0,0092[W],where: V_{mp} – voltage when maximal power, I_{mp} – current when maximal power, V_{oc} – open circuit voltage, I_{sc} – short-circuit current, FF - fill factor, PM – maximal power.
3. In the case of the cell 3 from figure 9, there are no statistical averaged results yet. However, in each trial a very high Voc was obtained. The further experiment requires reduction of serial resistance and better current-optical adjustment between individual sandwiches. It should be emphasized that in single structures with silicon nanocrystals, an increased photocurrent was obtained and these structures were stable. Described in publications [1–5]. This gives a real chance to increase photocurrent in the cell 3.

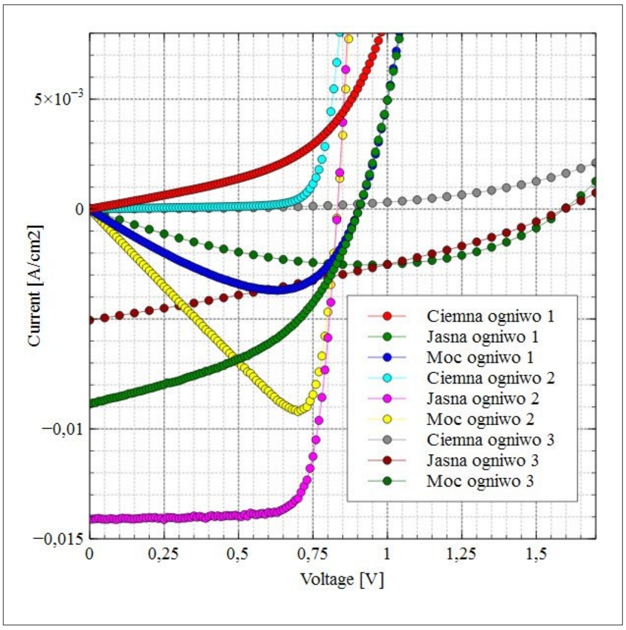

Figure 9. The light and dark characteristics. Cell 1 – microcrystalline; cell 2 – nanocrystalline; cell 3 – triple-junction. Also maximum power points of the manufactured cells are shown

Next, Figure 10 presnets the TEM Cross-Section of the recently produced a triple-junction cell (cell 3) characterized by very high voltage V_{oc} = 1.65, which requires optimization due to too large series resistance. This test is the foundation for further efficiency optimization of this structure.

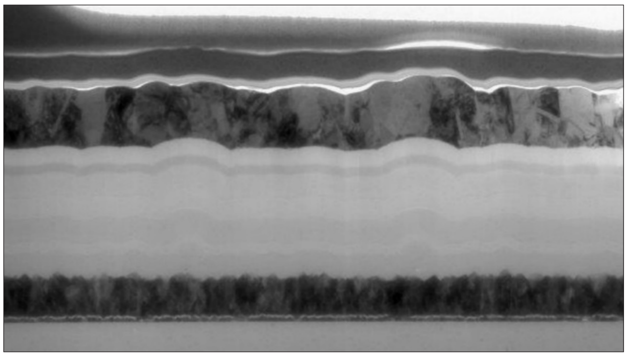

Figure 10. TEM cross section of a triple-junction structure composed of silicon-germanium, nanosilicon and amorphous silicon sandwiches. This structure was preliminary formed and yielded high VOC of 1.65 V

Conclusions

The authors have analyzed thin film triple junction silicon-germanium photovoltaic structures with success, for example raising the Voc. They believe that the considered triple junction proposition with nano-electronic solutions with using perovskites is a new road map for our scientific activity. On this way the light absorption, the carrier transport, the serial resistance, the leak currents, and the photovoltaic structure stability and efficiency can be significantly improved.

Acknowledgments

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