SCHOTTKY SOLAR CELL WITH GRAPHENE/AL_2O_3/SI INTERFACE

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Abstract

In the field of applied research the combination of graphene and a semiconductor to form a Schottky solar cell (SSC) was found to be very significant. When compared to other types of solar cells being developed (organic or perovskite solar cells), the simple production process is an undisputable advantage of an SSC composed of graphene and silicon semiconductor. This simplicity and compatibility with well-established semiconductor technologies ultimately result in a low production price. The main problem relating to the Schottky solar cells with a graphene/silicon interface is the decreased efficiency of photocharge collection due to a recombination on the interface. In order to decrease the effect on the efficiency due to the recombination, the graphene/silicon interface has been modified with 2 nm Al_2O_3.

Keywords: Graphene, Al2O3, solar cell, RTA, EBIC, EQE

1. INTRODUCTION

Graphene that belongs among carbon 2D materials shows a high value of transmission in visible light, from which it only absorbs 2.7 % [1]. By contrast, the widely applied material, i.e. Indium Tin Oxide (ITO), used for the production of transparent electrode of touch panels and solar cells features an absorption value of 9 % [2]. Thanks to the lower absorption, graphene could replace ITO in solar cells and touch panels in future. The first SSC with a transparent graphene electrode based on a silicon (Si) semiconductor was made in 2010 [3]. This SSC with graphene/Si interface showed an efficiency of only 1.5%. This low value was caused by the resistance of graphene layer prepared by chemical vapour deposition (CVD), achieving up to several kΩ. To reduce the resistance and to increase the efficiency, the doping of graphene with gold, nitrogen and other substances was used [4]. It has led to the reduction of graphene resistance down to Ω units. In addition, own reflectance is another factor decreasing the efficiency of SSC with graphene/Si interface. Its negative impact on SSC can be decreased by the application of a suitable coating layer composed, for example, of graphene oxide [5] or colloidal titanium [6], or by the surface treatment of silicon substrate prior to the application of graphene. Efficiency of the solar cell is also negatively affected by the charge recombination in the area of graphene/Si interface. This recombination occurs in incomplete silicone bonds on the Si surface due to having the silicone dioxide (SiO_2) etched away prior to the application of graphene. The number of recombination centres can be reduced through the passivation of the surface with oxide layer [7]. For this cell, aluminium oxide (Al_2O_3) with a thickness of 2 nm was selected as an oxide.

2. EXPERIMENTAL

2.1. Preparation of SSC with graphene/Al2O3/Si interface

For the SSC preparation, a wafer made of monocrystalline Si (100) with a 280 nm SiO_2 layer and a resistivity of 1.8 Ω/□ was used and cut using WEDM [8-11] to obtain samples with a size of 10x17 mm^2 each. Using ultraviolet lithography (UVL), a temporary polymeric mask having a shape of the future upper collector electrode was created on the sample cut like that and doped with a layer consisting of 3 nm titanium and

100nm gold. Then, a 4x3 mm window was etched in the middle of the prepared gold electrode. For this purpose, optical lithography was used again, and silicone oxide was etched for a period of 4 minutes in a solution of 40% hydrochloric acid (HF) and ammonium chloride (NH_4HF) mixed in a ratio of 1:7. A passivation layer of 2nm Al_2O_3 was subsequently applied in the aforesaid Si window using atomic layer deposition (ALD). The lower emitter electrode was made of a 400 nm aluminium layer. The last step in the SSC completion included the application of a graphene layer using *'wet transfer process'* [12]. For a schematic illustration of the preparation of SSC with graphene/Al_2O_3/Si interface using ultraviolet lithography, refer to **Figure 1**.

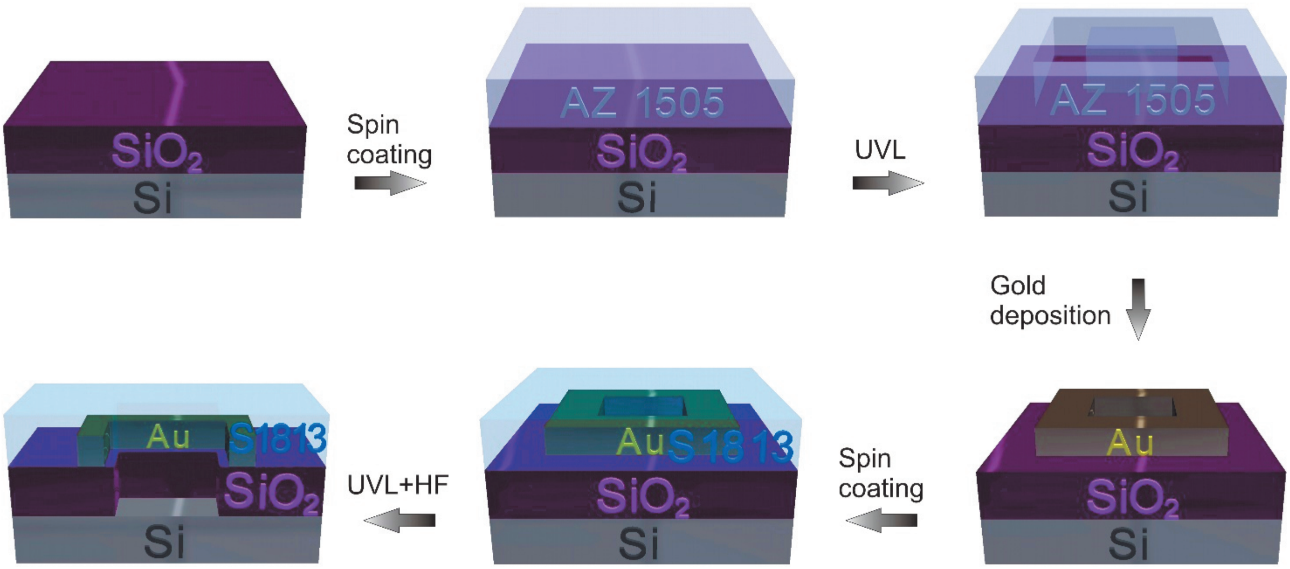

Figure 1 Schematic illustration of the preparation of SSC with graphene/Al_2O_3/Si interface using ultraviolet lithography

2.2. Measurement of SSC with graphene/Al_2O_3/Si interface

To determine the efficiency of SSC with graphene/Al_2O_3/Si interface, the apparatus intended for the measurement of current-voltage characteristics with an illuminance of 250 W/m^2 was used; this apparatus consisted of a halogen lamp, an infrared filter, a positioning system by Thorlabs, a current source, and an ammeter by Keithley. External Quantum Efficiency (EQE) was measured with an equipment consisting of a powerful 1 000 W xenon lamp, a monochromator, a bundle splitter, a picoammeter, and a calibrated photodiode. The EQE measurement itself was made at a light wavelength ranging from 400 to 700 nm. For the detection of depletion region width, the method of Electron Beam Induce Current (EBIC) and LYRA 3 electron microscope by TESCAN were used.

3. RESULTS OBTAINED

The solar cell with graphene/Al2O3/Si interface was measured using current-voltage characteristics. Based on the measurement, an efficiency of 0.08% was determined. This low value was probably caused by the surface contamination of graphene due to wet transfer. In order to verify the hypothesis, the cell was heated to a temperature of 300 °C for a period of one hour in a vacuum. The efficiency of the solar cell treated as above equalled to 4.43%. This value represents an efficiency improved by 5500 %, see **Figure 2**. The depletion layer width of the annealed SSC was detected by means of EBIC method and determined to be 3.72 µm, see **Figure 3**.

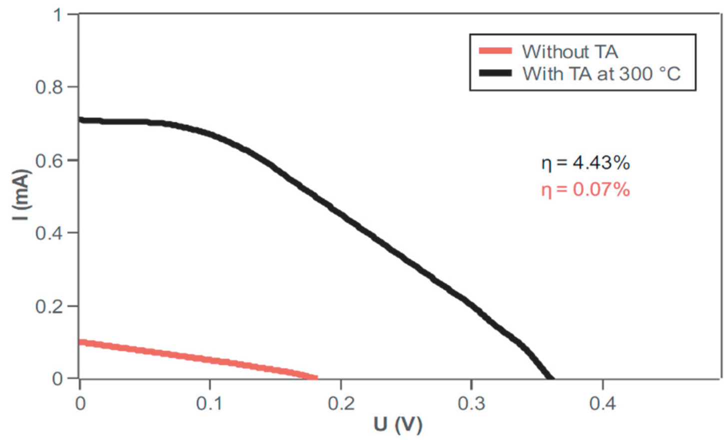

Figure 2 Results of measurements of the SSC with graphene/Al_2O_3/Si interface using current-voltage characteristics

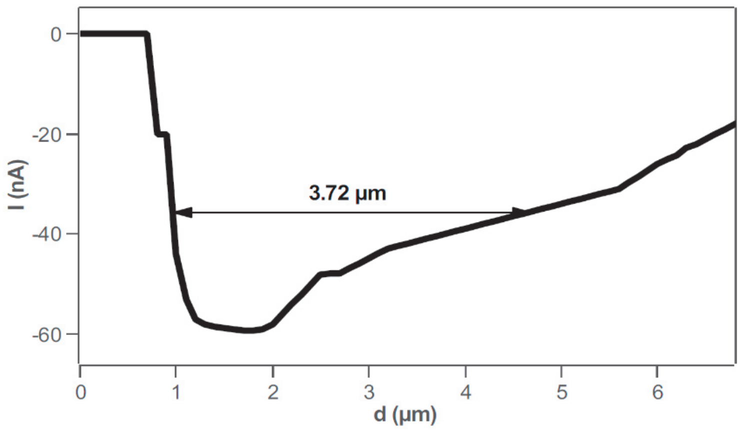

Figure 3 Results of measurements of the SSC with graphene/Al_2O_3/Si interface using EBIC method

Together with the measurements of current-voltage characteristics, the cell with and without Al_2O_3 passivation layer was subjected to continuous EQE measurements to determine the effect of such passivation. In the cell without Al_2O_3 passivation layer, the external quantum efficiency achieved its maximum value of only 23% at λ=500 nm. By contrast, the cell with 2 nm Al_2O_3 showed an EQE value of 38 % at λ=500 nm. For a comparison of both measurements, refer to **Figure 4**.

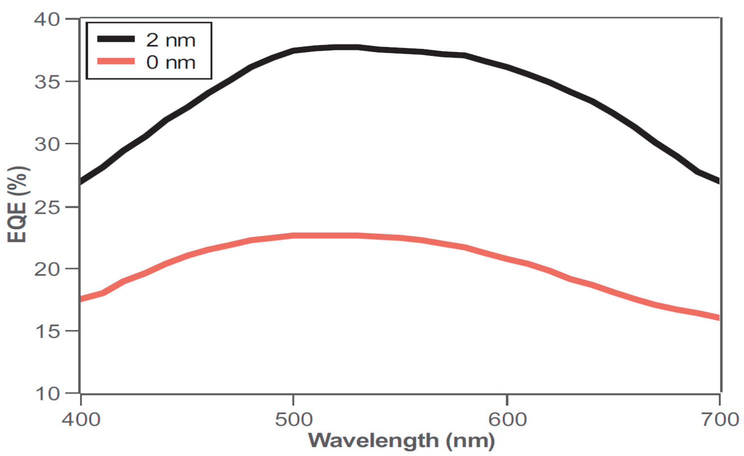

Figure 4 Results of measurements of the SSC with graphene/Al_2O_3/Si and graphene/Si interfaces using EQE method

4. CONCLUSION

The Schottky solar cells without interface modifications show a low efficiency that is caused by the recombination of photocharge on the graphene/Si interface. This recombination can be reduced by the interface passivation using a suitable oxide layer. For this work, Al_2O_3 with a thickness of 2 nm was used as oxide unlike SiO_2 layer that was used for the SSC passivation by the MIT research group [7]. The SSC efficiency was also affected by the graphene layer resistance caused by the nanometric contamination due to polymethyl methacrylate (PMMA) remained on the surface after wet transfer. The resistance reduction was achieved by having the sample heated to 300 °C in a vacuum, which reduced the PMMA contamination. This procedure of graphene resistance reduction was taken from the available literature and modified so as to be applied at our workplace [13]. The Schottky solar cells with the modified graphene/Al_2O_3/Si interface were prepared and studied using current-voltage characteristics and EBIC and EQE methods. The solar cell efficiency prior to and after the annealing at a temperature of 300 °C for a period of one hour equalled to 0.08% at the beginning, and 4.43% thereafter. The depletion region width determined was 3.72 µm. With the passivation layer applied, the value of external quantum efficiency increased from 23 % to 38 %. Based on the data obtained, it is obvious that the application of sufficient passivation layer and subsequent post-treatment lead to an increased efficiency of the SSC with graphene/Si interface.

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