H-8-04 Extended Abstracts of the 2020 International Conference on Solid State Devices and Materials, VIRTUAL conference, 2020, pp571-572

Transparent Schottky type solar cell based on uniform WS_2 film

○Xing He[1], Toshiro Kaneko[1], and Toshiaki Kato[1,2]
[1] Graduate School of Engineering, Tohoku University
6-6-05, Aoba, Aramaki, Aoba-ku, Sendai 980-8579, Japan
Phone: +81-022-795-7046, E-mail: he.xing.q7@dc.tohoku.ac.jp
[2] JST-PRESTO

Abstract

Transition metal dichalcogenide (TMD) is one of the most attractive materials for future transparent and flexible optoelectrical devices due to their atomically thin structure, band gap in visible light range, and high optical transparency. Despite recent advances, developing a scalable approach to fabricate transparent and flexible solar cells with mono- or few-layers of TMD remains a critical challenge. Here, we improved our previous study for the fabrication of transparent solar cell with few-layered TMD under Schottky type configuration. The transparency can be improved by using indium tin oxide (ITO) as electrodes. The directly grown large area WS_2 film are also used to overcome the limited device size. After controlling the work function of ITO electrodes and optimizing the synthesis conditions of WS_2, clear power generation can be observed with ITO/WS_2 based transparent solar cell in large scale.

1. Introduction

Layered transition metal dichalcogenide (TMD) is known as a true 2D material with excellent semiconducting properties. TMD is one of the most attractive materials for future transparent and flexible optoelectrical devices due to their atomically thin structure, band gap in visible light range, and high optical transparency [1-3]. Although the solar cell of TMD has been widely investigated by many groups, those are based on the pn junction type solar cell. Since complicated structures are required to form pn junction structures in TMD such as dual gate electrodes or position selective doping, the device size of pn junction solar cell with TMD is limited within very small region (few μm). In spite of the outstanding advantages of TMD, those merits of TMD have not been applied in transparent and flexible solar cell, which is attracted intense attention as a next-generation energy harvesting technology.

Recently, we have developed a new fabrication process of TMD-based solar cell [4]. In our process, Schottky type device configuration is utilized, which can be simply formed by asymmetrically contacting electrodes and TMD. The power conversion efficiency clearly depended on the work function difference between two electrodes (ΔWF), and a higher efficiency could be obtained with higher ΔWF (Pd-Ni), which is consistent with our concept, where Ni and Pd can form large and small Schottky barriers to operate as power-generation and carrier-collect regions, respectively. Based on the optimizations of electrodes and distance, the power conversion efficiency can be reached up to 0.7 %, which is the highest value for solar cell with similar TMD thickness [4].

In our previous study, we used conventional metals such as Ni and Pd to tune the Schottky barrier height between electrode and TMD, which suppress the transparency of whole device. Furthermore, the device size was limited within μm scale because of the size of exfoliated TMD.

To improve the transparency of whole device, we use indium tin oxide (ITO) as electrodes. The directly grown large area WS_2 film are also used to overcome the limited device size. After controlling the ΔWF of ITO electrodes and optimizing the synthesis conditions of WS_2, clear power generation can be observed with ITO/WS_2 based transparent solar cell in large scale.

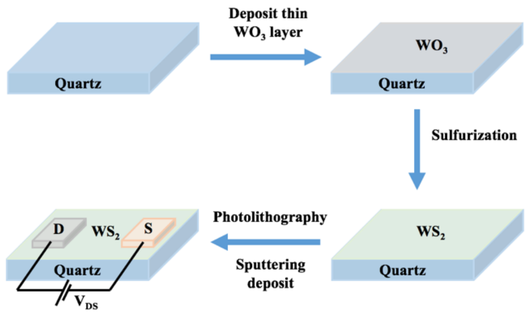

Fig. 1. Schematic diagram of transparent solar cell fabrication process.

2. Experimental

Device fabrications were carried out by following process. As shown in Figure 1, firstly, few nanometers (1-20 nm) WO_3 film was deposited on quartz substrate via vacuum evaporation. Then, WS_2 was uniformly synthesized by directly sulfurizing WO_3 film. After that, conventional photolithography, vacuum evaporation of metal, sputtering of ITO and lift off were used to fabricate the symmetric and asymmetric devices. Large scale electrode pattern (~cm^2) was carefully designed to a comb-like pattern.

Device performance was measured with an open-air probe station with a semiconductor parameter analyzer at room temperature.

3. Result and discussion

In this study, highly transparent solar cell is fabricated by using highly transparent WS_2 and functionalized ITO by thin metals.

Based on our previous study [4] for Schottky type solar cell, the power generation obtained must be caused by inhomogeneous contact between the left and right electrodes, where only one of the electrodes generates carriers with the Schottky barrier and the other electrode effectively collects the carriers with Ohmic-like contact. Higher work function difference of electrodes pair result of higher power conversion efficiency (PCE) for Schottky type solar cell.

ITO is known as an ideal highly transparent electrode, but it is not conducive to charge separation when use ITO at both sides of the electrodes. In this case, work function control of ITO electrode without sacrificing the transparency is important.

Here, different kind of thin metals (1-5 nm) are used for inserting materials between ITO and WS_2. Work function of modified ITO surface was tested by using photoelectron yield spectroscopy (PYS), transparency was measured by using UV-VIS Spectrometer (UV).

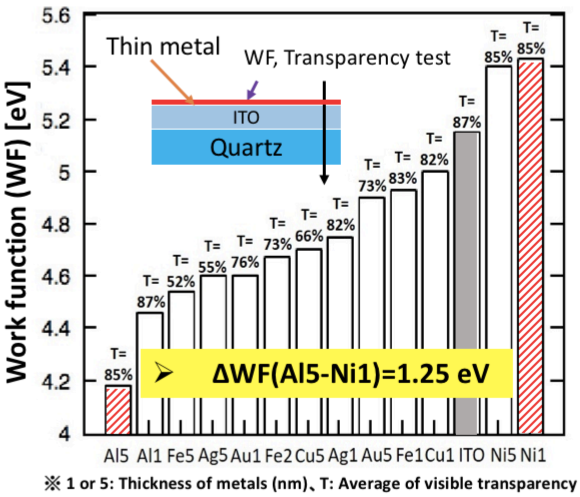

Fig. 2. Work function of different thin metal modified electrodes.

As shown in Figure 2, for ITO, transparency and WF of ITO on quartz substrate is 87% and 5.15 eV, respectively. When deposit Ni for 1 (5) nm, WF increases to 5.4 (5.43) eV, while high transparency (85 %) still keeps within this thickness range. When modulate by Al, Fe, Ag, Au and Cu, WF decrease. Especially for Al in 5 nm, WF decreases down to 4.18 eV, and transparency still keeps 85%.

Since WS_2 is naturally n-doped by some impurities, the Fermi energy of our WS_2 can be assumed to be around 5 eV. Thus, Ni1/ITO (WF = 5.43 eV), which has the highest work function in this measurement, can form a large Schottky barrier at the contact region with WS_2. Al5/ITO (WF = 4.18 eV) can work as an Ohmic-like contact for WS_2.

A Schottky-type solar cell with an asymmetric electrode pair was fabricated with Ni1/ITO and Al5/ITO as electrodes in large scale (~1 cm^2) (Fig. 3(a)). The transparency reaches up to 80% (Fig. 3(b)). Clear power generation could be observed under light illumination with a solar simulator (Fig. 3(c)).

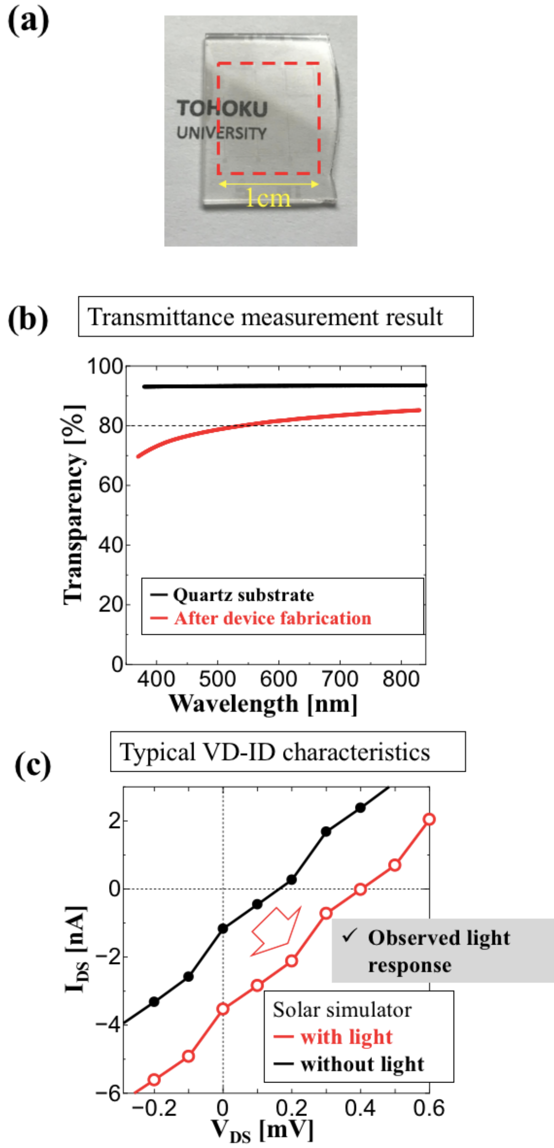

Fig. 3. (a) Optical image of WS_2 based highly transparent solar cell. (b)Transmittance of device comparing to bare quartz substrate (c). Typical I_{DS}-V_{DS} characteristics of WS_2 Schottky solar cells with light illumination.

4. Conclusions

Large scale WS_2 based transparent solar cell has been successfully fabricated by controlling the ΔWF of ITO electrodes. Since our simple fabrication process includes high potential for large scale fabrication, this achievement is very important for realizing the industrial application of TMD as a transparent and flexible solar cell.

References

[1] T. Kato and T. Kaneko, ACS Nano **8** (2014)12777.

[2] T. Kato and T. Kaneko, ACS Nano **10** (2016) 9687.

[3] C. Li, Y. Yamaguchi, T. Kaneko, and T. Kato, Appl. Phys. Express **10** (2017) 075201.

[4] T. Akama, W. Okita, R. Nagai, C. Li, T. Kaneko, and T. Kato, Sci. Rep. **7** (2017) 11967.