Analysis of Perovskite Based Schottky Photodiode

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Abstract. In this paper, a perovskite based Schottky photodiode was fabricated by sandwiching the perovskite layer between Indium tin oxide (ITO) and aluminum (Al) electrode. Field emission scanning electron microscope (FESEM) image of the perovskite thin film reveal uniform deposition of perovskite over the entire glass substrate. The measured Current-voltage characteristics of Schottky photodiode display rectifying behavior under dark condition. The reverse current level of the photodiode gets increased under illumination by green laser. The important diode parameters, such as ideality factor and barrier height was determined from the thermionic emission theory. The ideality factor under dark condition was 1.35, and increased to 6.29 under illumination condition. The charge transport mechanism of the photodiode was examined according the space charge limited conduction (SCLC) theory.

INTRODUCTION

In recent years, there has been immense interest in perovskite material systems, particularly for application in solar cells because of their ability to absorb the wide range of solar spectrum and large diffusion length [1-2]. Besides this, low cost, flexibility, tunable optical properties, easiness in processing are some of the attractive features that make it's a promising material for the next-generation electronic/optoelectronic applications[3-5]. Moreover, because these devices can be manufactured over large through low temperature solution processing methods such as inkjet printing, that can be beneficial for reducing the overall cost and has impelled considerable interest for applications in flexible displays and large area sensors.

In addition to solar cells, great progress also has been achieved for the application of perovskites in optoelectronics devices, including photodetectors and light emitting diodes (LEDs)[6-7]. The detection wavelength of photodetectors and emission color of LEDs can simply be tuned by changing the perovskite compositions. Remarkable progress has been attained in the development of perovskite based LEDs and photodetectors since last decade. The obtained performance is comparable to the state-of-art inorganic based devices and hopeful to achieve the more affordable cost effective devices in near future. Moreover, perovskite based photodiodes provide exceptional potential for application in image processing, Li-Fi, broadband band optical communication and medical science.

Metal-semiconductor (M-S) contacts of Schottkry type have gaining special interest, because of their simple structure and easiness in integration with all kind of devices. From fundamental point of view M-S contacts can be utilize to probe the interface, physical, bulk defects and electrical properties of semiconductors [8]. In this paper, we investigate the I-V characteristics of FTO/CH3NH3PbI3/Al Schottky photodiode.We have extracted and discussed the important performance parameters of Schottky contacts. Furthermore, we have explained the current conduction mechanism in the photodiode under forward condition.

EXPERIMENTAL DETAILS

Methylammonium iodide (CH_3NH_3I) was synthesized by mixing of methylamine (CH_3NH_2) and hydro iodide (HI) with the help of magnetic stirrer. The prepared solution was evaporated to obtain a white precipitate.

Thereafter, this precipitate was cleaned with the diethyl ether with continuous stirring for 30 min. that results in the formation of white powder of MAI, when precipitate were dried in vacuum oven for overnight at 60ºC. Finally, $CH_3NH_3PbI_3$ perovskite solution were formed by mixing of MAI and PbI_2in 2ml. DMF solvent with continuous stirring at room temperature for 12 h. The device was fabricated by depositing the layer of perovskite solution on the FTO substrate by spin coating techniques at 200 rpm for 60 sec and subsequently annealed at 70^0C for 10 min. For completion of device a top electrode of Al was depositedby thermal evaporation, which acts as cathode. The schematic architecture of fabricated device of the Al/$CH_3NH_3PbI_3$/FTO photodiodeis shown in Figure 1(a).

The surface morphology of perovskite thin film was evaluated by field emission scanning electron microscopy (FESEM). Electrical measurements were carried out using 2612A Keithley source meter. The photo response characteristics were studied by illuminating the photodiode by laser source of power 20 mW and wavelength of 530 nm.

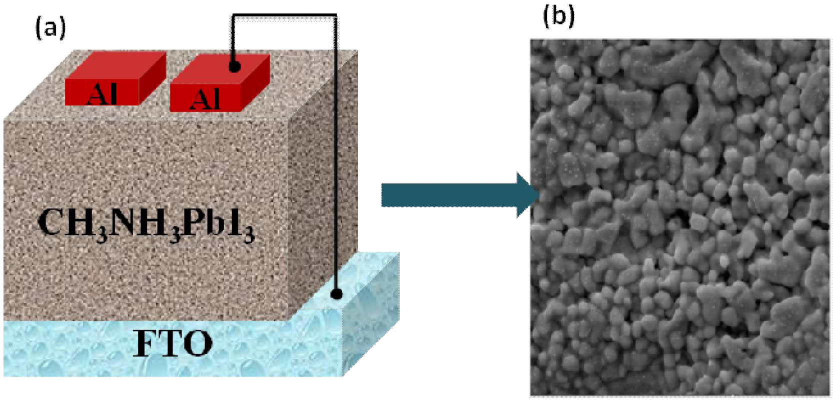

FIGURE 1.(a) Schematic diagram of device structure, (b) FESEM image of perovskite thin film grown over glass substrate.

RESULTS AND DISCUSSION

Figure 1(b) displays FESEM image of perovskite nanoparticles grown on glass substrate. The image clearly shows the formation of perovskite nanoparticle of uniform size, which nearly covering substrate completely. Figure 2(b-d) shows the measured I-V characteristics of fabricated Schottky photodiode under dark and illumination condition at room temperature under ambient environment. As can be apparent in the dark I-V characteristics curve, the current increases appreciably with increase in the forward applied voltage while current remain nearly constant over the applied reverse voltage range, indicating the device exhibit good rectification property. Schottky barrier formed at perovskite/Al interface play imperative role in determining the I-V characteristics of the device. Under forward bias, the barriers get reduced with voltage, which propels injection and transportation through the device, resulting in the high current. In reverse bias, the carriers face difficulty in injection due the increase in barrier height with the voltage; hence give rise to only a small constant current flow in the device. As seen, under irradiation by green light, the reverse current level increases significantly as compared to that of dark. The energy band diagram shown in Fig. 2(a) can illustrate the photocurrent generation in the device. The light absorbed in the perovskite layer generates additional electron hole pairs. With reverse bias, these pairs are separated by the electric field. Electrons and holes get swept towards the Al and FTO electrodes, respectively and thus produce photocurrent in the device.

Next we extract the important Schottky parameters by using thermionic emission theory to the obtained I-V curves.

The ideality factor and reverse saturation current can be determined from the slope and intercept at V=0, respectively in the forward bias region of the I-V characteristics curves redrawn in the semi-logarithmic scale as shown in Fig. 2(c)[9]. The ideality factor, reverse saturation current and Schottky barrier height of the photodiode are found to be equal to 1.35, 3.07X10-5, and 0.6853 eV, respectively in the dark. The ideality factor nearly close to idea value 1, suggest the formation of good quality intimate contact between metal and perovskite. Under illumination, the ideality factor increased to 6.25, barrier height reduced to 0.6406 eV and reverse saturation current increase to $1.730X10^{-4}$ A. Increase in the ideality factor attributed to the enhancement in the generation-recombination in the active layer due to the photoconductive nature of perovskite.

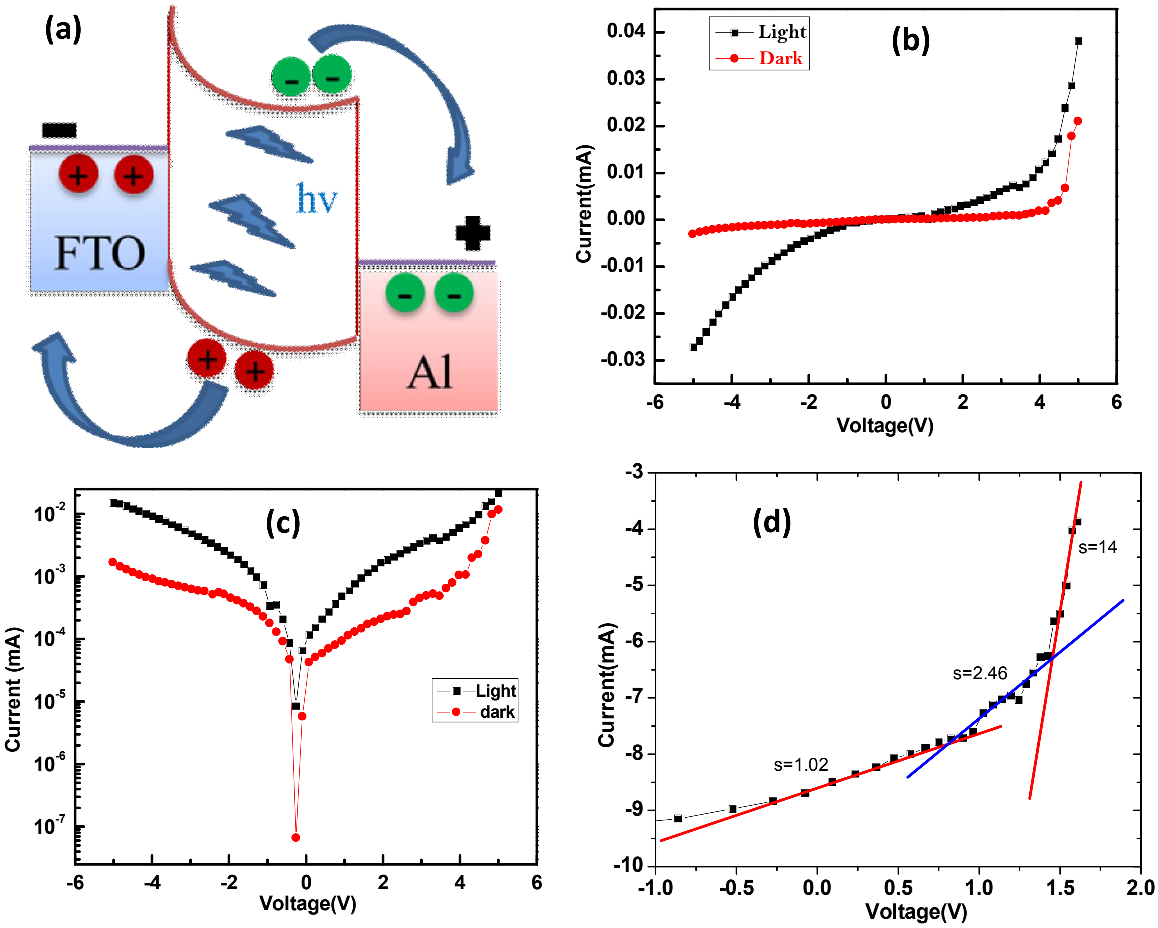

FIGURE 2. (a) Energy level diagram of the Schottky photodiode in reverse bias and under illuminationcondition (b) I-V characteristics photodiode in linear scale (c) I-V characteristics photodiode in semi-logarithmic scale(d) double logarithmic I-V plot forSchottky photodiode.

The charge transport in the device can be more clearly understood from the log-log I-V plot shown in Fig. 2 (d). The curves show three distinct charge transport mechanisms distinguished by the different slopes shown in the figure. At low voltage, injection in insufficient, so thermally generated charge carriers play dominant role in the transport process and decide the current transport process [10-11]. These thermally generated background carriers drift under the influence of electric field leading to a liner variation of current with the applied voltage i.e. Ohmic conduction, as pointed by the slope=1 in the figure. At large voltage, injected carriers become sufficient to dominant the transport process. Under this condition transport is not limited by the injection, rather than it is limited by the bulk properties of the active layer, such as traps, defects and mobility. The space charge region is formed inside the active layer due to limited mobility of the carriers. The region of slope=2 in the figure is the feature of the space charge limited conduction (SCLC). With further increase in the applied voltage, the slope changes to 13. The traps get sufficient energy from the field and get excited to the trap level. This process removes the charges from the space charge region, which enable the further injection of carriers from the electrode, leading to the increase in the carrier density, which results in the rapid change in current with applied voltage. Thus, the current is directed by the trap controlled space charge limited conduction (TCLC) process[12].

CONCLUSIONS

$CH_3NH_3PbI_3$ was synthesized using chemical route, and used in the fabrication of FTO/perovskite/Al Schottky photodiode. I-V characteristics measured under dark and illumination condition was studied to extract the important Schottky diode parameters. The ideality factor in dark was increased from 1.35 to 6.29 under illumination condition. The charge transport studied according to the framework of SCLC theory depicts three distinct charge transport mechanisms.

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REFERENCES

1. R. Wu, J. Yang, J. Xiong, P. Liu, C. Zhou, H. Huang, Y. Gao, and B. Yang, Organic Electronics 26, 265-272 (2015).
2. Y. S. Jung, K. Hwang, F. H. Scholes, S. E. Watkins, D. Y. Kim, and D. Vak, Scientific reports 6, 20357 (2016).
3. J.Liu, G.Wang, K.Luo, X.He, Q.Ye, C.Liao and J. Mei, Chem.Phys. Chem, 18 617-625 (2017).
4. L. C. Chen, Z. L. Tseng, J. K. Huang, C. C. Chen and S. H. Chang, Coatings, 6 53 (2016).
5. Y. H. Kima, H. Choa, and T-W. Lee, PNAS. **113**,11694–11702 (2016).
6. Y. Li,Z-F. Shi, S. Li, L-Z. Lei, H-F. Ji, D. Wu,T-T. Xu, Y-T. Tiana and X-J. Li, J. Mater. Chem. C. **5**, 8355-8360 (2017)
7. A. Upadhyayaa, C. M. S. Negi, A. Yadav, S. K. Gupta,A. S. Verma, Superlattices&Microstruct., **122**, 410-418 (2018).
8. C. Yim,N. McEvoy, Hye-Y. Kim, E. Rezvani, and G. S. Duesberg, ACS Appl. Mater. Interfaces, **5**, 6951−6958 (2013)
9. A.K. Singh, R. Prakash, RSC Adv. **2**, 5277 (2012).
10. A. Yadav, A. Upadhyaya, S.K. Gupta, A.S. Verma, C.M.S. Negi, Superlattices& Microstruct.,120, 788 (2018).
11. A. Upadhyaya, C. M. S. Negi, A. Yadav, S. K. Gupta and A. S.Verma, Semi.Sci. and Tech.33, 06012 (2018).
12. Z. Chiguvare, and J. Parisi, ZeitschriftfürNaturforschungA 67(10-11), 589-600 (2012).