Image sensor, Color sensor, Smart device

Wavelength-recognizable novel Sb-chalcohalide photodiode

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Abstract

Anomalous wavelength-voltage depending property was discovered in originally developed SbSI:Sb_2S_3-hybrid photovoltaic (PV) device. Although there have various PV materials and devices been reported, the recognition of both light intensity and wavelength by single PV device have been challenging. We recently discovered an anomalous wavelength-responsive property in our originally developed device using antimony-chalcohalide/chalcogenide composite **(Fig. 1)**. Focusing on this behavior, we investigated its detailed property and mechanism.

Background & Results

[Background] PV devices are used in various application including solar cells, light sensors, and image sensors. Although PV devices can sense the intensity of light, the sensing of its color had not been achieved. Shockley's equation, which represents the output property of a PV device, does not contain the wavelength-related components. This indicates that output characteristics of a PV device is not affected by irradiated wavelength. However, the author recently discovered the anomalous wavelength-voltage depending on nature where short and long wavelength light irradiation provides lower and higher voltage, respectively. It was denoted as wavelength-dependent photovoltaic effect (WDPE) **(Fig. 1)**. The author thus investigated the detailed property of WDPE and its mechanism.

[Results] The PV devices **(Fig. 1)** was fabricated. Then, the output characteristics under different wavelength of monochromatic-light was evaluated. In current (*J*)-voltage (*V*) measurement, the output voltage was linearly changed along with changing the intensity ratio of UV and visible light. The time-dependent photovoltage measurement revealed that UV irradiation cause significant drop of voltage within few seconds, which can be recovered to the initial voltage after UV is stopped **(Fig. 2a)**.

We also suggested the mechanism **(Fig. 2b)**. Here, high energy hot-carrier is generated by short-wavelength light. The hot-carrier can induce the photocatalytic reaction at the surface of active-layer. The reaction provides the chemical species (such as radical ions) which act as trap sites. Thus, the increased surface trap induces the temporal decrease of voltage.

Finally, we successfully demonstrated the dual detection of light intensity and color. This is the first achievement of the dual detection of light intensity and color by using a single photovoltaic cell.

Significance of the research and Future perspective

WDPE is not only fundamentally fascinating, but also provides a new application. One of the potential applications is the minimization of image sensor (IS) **(Fig. 3)**. Conventional IS detected the different color by using color-filter, where one cell can only detect one color. To detect the different color by one cell, liquid crystal color-filter is required which is disadvantageous for minimizing or making thinner device. Thus, WDPE behavior is potentially promising for sensing use. The progress of response speed and device stability is an important task for practical use.

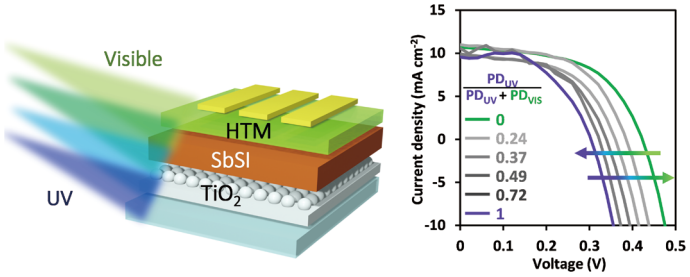

Fig. 1. Anomalous wavelength-dependent photovoltaic effect.

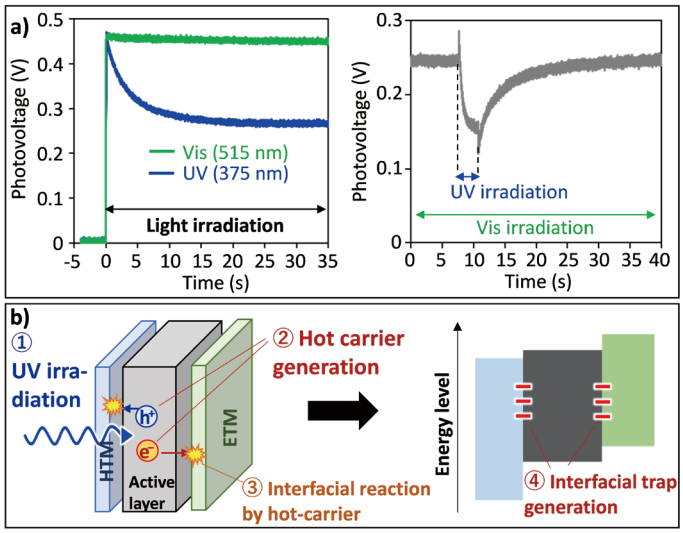

Fig. 2. a) UV-induced photovoltage drop and recovery. b) The mechanism of WDPE behavior.

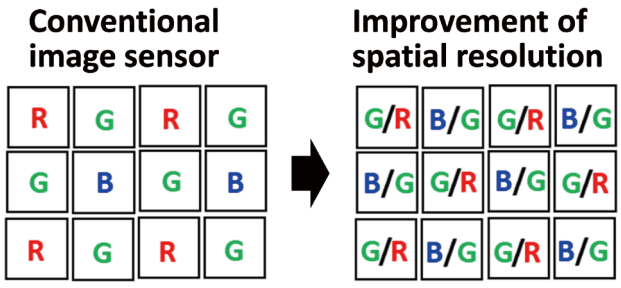

Fig. 3. The example of application for image sensor using dual detection of light intensity and color.

Patent
Treatise
Kobayashi, Tai; Nishikubo, Ryosuke; Saeki, Akinori et al. Wavelength-recognizable SbSI:Sb_2S_3 photovoltaic devices: Elucidation of the mechanism and modulation of their characteristics. Adv. Funct. Mater. 2023, Accepted. doi: 10.1002/adfm.202311794
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Nishikubo, Ryosuke; Nazeeruddin, M. K.; Saeki, Akinori et al. Optoelectronic and energy level exploration of bismuth and antimony-based materials for lead-free solar cells chem. Mater. 2020, 32, 6416-6424. doi: 10.1021/acs.chemmater.0c01503

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