Supplemental Document

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High-responsivity broadband photodetection of an ultra-thin In_2S_3/CIGS heterojunction on steel: supplement

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This document provides supplementary information to "High-responsivity Broadband Photodetection of ultra-thin In_2s_3/CIGS Heterojunction on Steel: supplemental document".

1. Fabrication and characterization methods

The In_2S_3/CIGS heterojunction photodiode was fabricated by different research groups involved in European H2020 ARCIGS-M project. The thin low-carbon steel substrate with a dielectric coating on top was fabricated by AC&CS in CRM group. The top layers of In_2S_3/CIGS photodiode were fabricated in Midsummer by the DUO sputtering tool, which is consist of three groups of sputtering chambers [1, 2]. Na-doped Mo and Mo were deposited in the first group of chambers by DC sputtering as a stack of back contact. The sample was then transferred to an intermediate chamber for heating and the second group of chambers to deposit CIGS composed of different layers by pulsed DC sputtering. To extend the Ga-grading, a thin layer of CuGaSe2 (CGS) was firstly deposited from CGS target and followed by the sputtering of a thin CIGS from CIGS targets with different Ga/(In+Ga)-ratios. The bulk part of CIGS was sputtered by quaternary targets containing Cu, In, Ga and Se. The sample was then rapidly cooled down by He in the intermediate chamber and sent to the third group of chambers for In_2S_3 sputtering from a compound target. Finally, IZO/ITO were sputtered as transparent conductive oxide (TCO) bilayers in the third group of sputtering chambers and Ni/Al grids were screen-printed on top of the sample.

Four-point probe measurements were performed to extract the current-voltage (IV) curves of In_2S_3/CIGS heterojunction photodiode on a low signal probe station (PM8PS) combined with Agilent B1500A Semiconductor Device Analyzer at dark and under the illumination of light emitting diodes (Thorlabs, LED375L-LED1050L) specifically at 375, 395, 430, 450, 490, 505, 525, 555, 590, 630, 680, 760, 810, 870, 910, 970, 1050 nm. The LED light densities were measured by a power meter (Ophir Optronics, Ophir Nova 1Z01500), integrating a standard silicon photodetector PD300 with detection range from 200 to 1100 nm. A shadow mask was used to fix the effective photodetection area of the In2S3/CIGS photodiode. All the measurements were performed at a constant chuck temperature of 25 °C.

2. Photoelectrical performances at 680nm

The current density-voltage (J-V) characteristics of In_2S_3/CIGS heterojunction photodiode have been measured in Fig. S1(a) under 680 nm LED light at varied incident light densities from 20 to 500 μW/cm^2, indicating a linearly proportional increase of light current density with increasing incident light density. Such behavior is attributed to increased photo-generated carriers in photodiode excited by an increase of incident photon density from the illumination, corresponding to a power law, $I_{photo} \sim P^{\alpha}$, where P is the incident light density, and α is an exponent factor [3, 4]. This factor would ideally be equal to 1 but relates to the balance of generation, separation, and recombination of photogenerated carriers in CIGS heterojunction. In this work, the factor α is extracted to be ~0.75 by fitting photocurrent as a function of light density at 680 nm under 1 V reverse bias.

Additionally, the responsivity, EQE and detectivity of In_2S_3/CIGS heterojunction photodiode at 680nm are calculated in Fig. S1(b-d) with light density variation from 20 to 500 μW/cm^2 under 0, 0.5 and 1 V reverse biases. The In_2S_3/CIGS heterojunction photodiode exhibits an excellent optical sensitivity, while working under 1 V reverse voltage with a very low light density of 20 μW/cm^2 at 680 nm, reaching an ultimate high responsivity of 1.65 A/W, an EQE of 302 % and a detectivity of 1.8×10^{11} Jones. Considering that such structure is normally utilized in solar cells, photovoltaic effect is expected to exist, which makes In_2S_3/CIGS heterojunction photodiode heterojunction photodiode possibly working as a self-powered photodiode. The Detectivity reaches a stable value of ~3.1×10^{12} Jones under 0 V bias at different light densities, while keeping a good responsivity of ~0.4 A/W and an EQE of ~74 %, which shows a great potential of CIGS-based photodiodes to be used as photoelectrical sensors without external energy consumption.

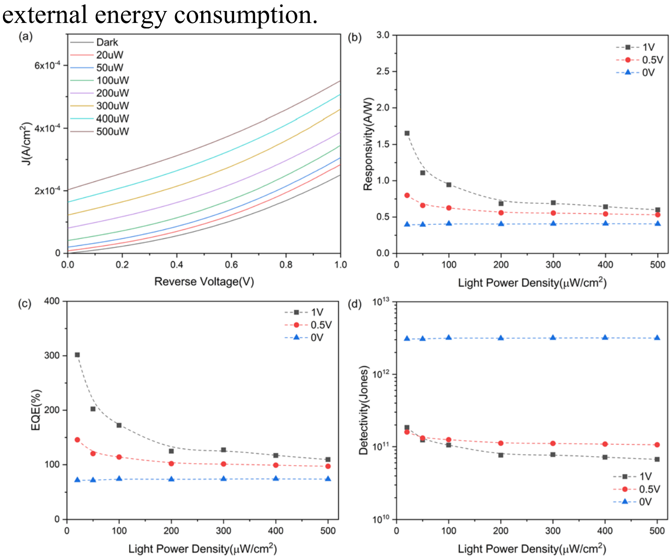

Fig. S1. (a) J-V curves in the dark and under 680 nm illumination at different incident light power densities; (b) Responsivity, (c) EQE, and (d) Detectivity as a function of incident light densities under 680 nm illumination with 0, 0.5 and 1 V reverse biases

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