Effect of color filters on photo electrochemical solar cell of pure and rhenium doped SnSe crystals

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Article

Keywords: Efficiency, Photo Electrode, Parameters and Photo Electrochemical Solar cell

Posted Date: April 5th, 2022

DOI: https://doi.org/10.21203/rs.3.rs-1518048/v1

Abstract

Applications of photo functional materials have universally aroused tremendous interest in recent years. The development of photo electrochemistry as a field of science was stimulated by the need for developing a photo electrochemical (PEC) energy conversion as a novel technique to utilize the infinite source of energy. Here, we have demonstrated the effect of different color filters on PEC behavior on rhenium doped tin mono selenide crystals synthesized by direct vapor transport technique. Authors have been used as grown SnSeRex (x = 0, 0.1, 0.2) crystals for photo electrode in PEC solar cell. This cell has been investigated in detail to evaluate its parameters, e.g. short circuit current (I_{sc}), open circuit voltage (V_{oc}), efficiency (η) and fill factor (FF). The electrodes were prepared from further mentioned crystals showing absolutely plane faces obtained through the act of cleavage with help of an adhesive tape. Illumination of light, the electrolyte and counter electrode were kept constant. This work intends to summarize PEC behavior in order to see the effect of rhenium doping and different color filter sheet on the mentioned single crystals on their parameters.

I. Introduction

Researchers have shown excessive potential for synthesis of the materials to find out the substitute for the high-performance optoelectronics devices. Group IV-VI semiconductors may switch, absorb, store, transfer or utilize light energy. Two-dimensional (2D) layered structures compounds have recently emerged as a brand new platform for synthesis new photo active materials. They are explored and their applications are found in the areas of light-harvesting, photoluminescence, photo catalysis, biological imaging, band structure engineering, photochromic sensors, and opto-electronic devices [1–5]. SnSe crystals have a band gap of 1.0 eV wherein the layers are coupled via weak van der Waals interactions [6–8]. It exhibits typical anisotropy of a layered structure [9]. Tin-based binary chalcogenide compounds have been explored due to their potential applications in the next generation electronic, optical, optoelectronic and flexible systems. SnS and SnSe are the materials consisting nontoxic and economical earth-abundant elements significantly promote their value in sustainable electronic and photonic systems which [10–16]. SnSe has a layered orthorhombic structure. It has space group P_{nma} at room temperature [17]. The metal chalcogenides exhibit promising properties for solar energy conversion because the band gap is typically in the range of 1.2 to 1.8 eV and therefore ideally fit for the solar spectrum. The bandgap the crystals which used for sample electrode is typically 1.5eV. Authors have been carried out a lesser study on the PEC behavior of SnSeRex (x = 0, 0.1, 0.2) samples. Effect of rhenium doping and different color filter sheet on PEC solar cell has been studied in detail and the implications of this study have been pointed out.

Ii. Experimental Techniques

Fabrication of sample electrode

For the present work, single crystals of SnSeRex (x = 0, 0.1, 0.2) were grown by direct vapor transport technique. The crystals were characterized by EDAX and XRD for their compositional analysis and crystal structure. It indicated that crystal growth is nearly stoichiometrically perfect and has orthorhombic structure [18]. The optical bandgap of the grown crystals is between 1.30 eV to 1.45 eV [19]. The band gap (E_g) of the photo electrode material should be also optimum so as to match with maximum span of solar spectrum (E_g = 1.2 to 1.8 eV).

The ideal photo electrode which is the heart of a PEC solar cell. Overall performances of PEC solar cell generally rely on the type of material chosen for the construction of electrode. A glass rod which has 0.5 cm diameter with a narrow bore of 0.05cm diameter was used to make the electrode and length of that rod is 10 to 12cm. One end of thin bore glass rod was flattened by heating. For adhesive the crystal, we used flat portion as a platform [20]. The thin bore was used as a passage for traversing a good conducting copper wire. The copper wire was compressed at one end for getting a contact with the crystal [21].

In the present work, a semiconductor electrode was fabricated in such a way that the contacting material provided good ohmic contact between the copper wire and the backside of the crystal. For baking, the entire assembly was then kept in an oven for few hours at 100ºC. After proper setting of the crystal on the copper wire terminal, the semiconductor was covered with an epoxy resin (araldite) leaving a light exposed an area of 1.5-2.0mm^2 for exposure to light source.

Counter electrode

A counter electrode in PEC solar cells is essential for the electrochemical reactions in a cell for enhanced performance of PEC solar cell. Generally, Platinum or Copper is widely used material for the same [22]. For present work, authors have used platinum material for counter electrode.

Selection of appropriate electrolyte

To selection of appropriate electrolyte plays pivotal role to obtain good photo conversion from PEC solar cell. For present research work, mixture of iodine (I_2), sodium iodide (NaI) and sodium sulphate (Na_2SO_4) were employed as an electrolyte with the compositions. All the chemical products were of reagent grade and the electrolyte solutions were prepared using triple distilled water. The solutions were not stirred during the measurement. It was observed that the electrolyte with the composition 0.025MI_2 + 0.5 MNaI + 0.5MNa_2SO_4 gave the minimum dark voltage and dark current and as well provided the maximum value of photo current and photo voltage for SnSe electrode, so authors used this electrolyte to fabricate SnSeRex (X = 0, 0.1, 0.2) PEC solar cells for the present investigations [23].

PEC **solar cell Fabrication**

A usual type of the photocurrent-generated device has a semiconductor in contact with an electrolyte, and this is often referred as photo electrochemical cells. PEC solar cell with photo electrode was fabricated in same method as described in [24]. The photo electrode was immersed in an appropriate electrolyte contained in a corning beaker. As a counter electrode, platinum grid was used. The schematic diagram of PEC solar cell as shown in Fig.1.

The solar cell was illuminated with light from an incident lamp. The intensity of illumination (I_L) was fixed at $10 mW/cm^2$ .The incident intensity of illumination was measured using the light measuring instrument "Solar Meter". Photo current and photo voltage were recorded using digital multimeters. The parameters like Short Circuit Current, Open Circuit Voltage, Fill Factor and photo conversion efficiency were carried out in reference to the different color of light as wavelengths of incident radiation varied with different color filter sheet. Ideal behavior and practical behavior of PEC solar cell is depicted in Fig. 2.

Iii. Results And Discussions

The photo voltage characteristic of mentioned crystals at different color filters deviates from the expected ideal behavior.

In order to study the effect of enhancement of rhenium doping and color filters on solar cell parameters, e.g. Short Circuit current(Isc), Open Circuit voltage (Voc) of SnSeRex (X = 0, 0.1, 0.2) PEC Solar cell are given in Table I and II and Efficiency (η %), Fill Factor (FF) of SnSeRex (X = 0, 0.1, 0.2) PEC Solar cell are given in Table III and IV. Figures 3 and 4 show the variation of all parameters at different color filters. It is seen that (Isc), Open Circuit voltage (Voc), Fill Factor (FF) and Efficiency (η %) are varied with the different color filter and enhancement of rhenium in tin mono selenide pure crystals.

Table I: Parameter I_{SC} of SnSeRex (X = 0, 0.1, 0.2) PEC solar cell

Filter sheet Color	**Short Circuit Current I_{SC} (A)**		
	SnSe	**$SnSeRe_{0.1}$**	**$SnSeRe_{0.2}$**
No sheet	0.00242	0.00233	0.00224
Blue	0.0026	0.00246	0.00241
Green	0.00249	0.00244	0.00239
Orange	0.00245	0.00239	0.00233
Red	0.00197	0.0021	0.00185

Table II: Parameter V_{OC} of SnSeRex (X = 0, 0.1, 0.2) PEC solar cell

Filter sheet Color	Open Circuit Voltage V_{OC}(V)		
	SnSe	$SnSeRe_{0.1}$	$SnSeRe_{0.2}$
No sheet	0.725	0.712	0.706
Blue	0.741	0.733	0.723
Green	0.733	0.725	0.717
Orange	0.741	0.733	0.73
Red	0.744	0.734	0.723

Table III: Parameter Fill Factor of SnSeRex (X = 0, 0.1, 0.2) PEC solar cell

Filter sheet Color	Fill Factor (FF)		
	SnSe	$SnSeRe_{0.1}$	$SnSeRe_{0.2}$
No sheet	0.58188	0.58711	0.5857
Blue	0.58778	0.58104	0.59436
Green	0.58679	0.5879	0.57044
Orange	0.57987	0.58264	0.56538
Red	0.57311	0.55442	0.55907

Table IV: Parameter Efficiency of SnSeRex (X = 0, 0.1, 0.2) PEC solar cell

Filter sheet Color	Efficiency (η %)		
	SnSe	$SnSeRe_{0.1}$	$SnSeRe_{0.2}$
No Sheet	1.1697	1.1061	1.0543
Blue	1.2351	1.2021	1.1568
Green	1.2167	1.1793	1.1424
Orange	1.2103	1.1679	1.1339
Red	0.9771	1.0276	0.8917

Deviation from linearity of the short circuit current with respect to the incident light intensity could mainly be accredited to the existence of abundant recombination centers. The recombination centers associated with samples having surface steps results at low intensity and limit the photocurrent at higher intensity. So, for present research work, authors set illumination of light 10mW/cm^2 with white color. We attempted to summarize PEC behavior in order to see the effect different color filter sheets for mentioned crystals on their parameters. It was observed that the solar cell parameters are also diverse under different wavelength of light and rhenium doping.

Upon light illumination of the electrode, electrons are promoted to conduction band leaving the hole in the valance band upon light illumination and at longer wavelength of light. This causes band bending and drifting of electrons into the semiconductor and the holes into the electrolyte, where they take part in oxidation reaction. The progressive electrons pass towards counter electrode producing a current in the external load, and take part in reduction reaction with the electrolyte.

We also observed that we attained higher value when we used blue color filter sheet for all parameters compare than other light colors. Longer wavelength of blue color spectrum may be responsible for that value. In addition, rhenium doping did not satisfy our needs, there is no drastic change in efficiency after rhenium doping.

Photo generation of charge carriers within the sample electrodes and charge transfer process across the semiconductor electrolyte interface are the key factors for the performance of PEC solar cell. Thus, after evaluation of these parameters, we can predict how ideal the behavior of a solar cell is. In order to make PEC solar cell sustainable, their conversion efficiencies have to be better so as to reach ideal values. Numerous possible efficiency augmentation processes for PEC solar cells such as: electrode surface modification, photoetching, electrolyte modification etc. are discussed [25]. They have also noticed that a high degree of precision of the electrode surface is essential to obtain higher solar energy conversion efficiency from a PEC solar cell.

Conclusion

To fabricate photo electrochemical solar cell, we used as grown SnSeRex (X = 0, 0.1, 0.2) crystals by direct vapor transport technique Also discussed how the various solar cell parameters are varies with rhenium doping in tin selenide and incident different color light. We noticed higher efficiency for pure tin selenide electrode using blue filter sheet. The performance of PEC parameters is also improved by choice of different counter electrode, improved electrolyte and doping with different transition metal etc.

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Figures

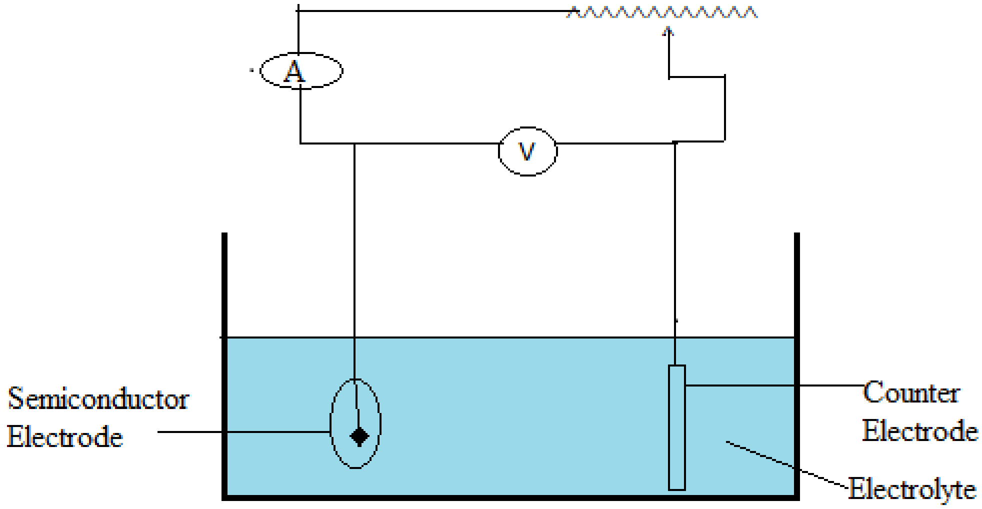


Figure 1

Diagram of PEC solar cell

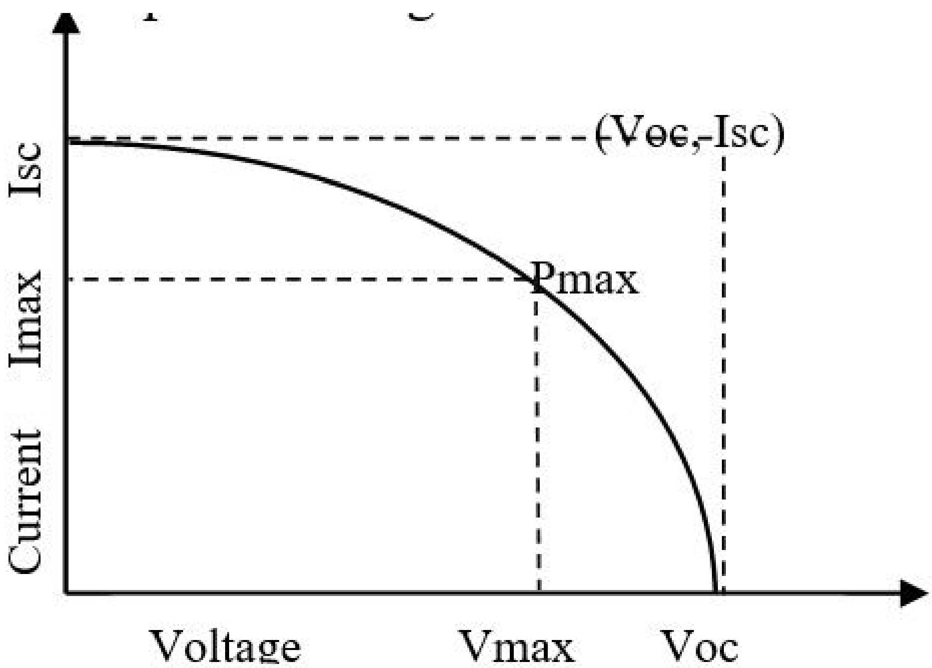
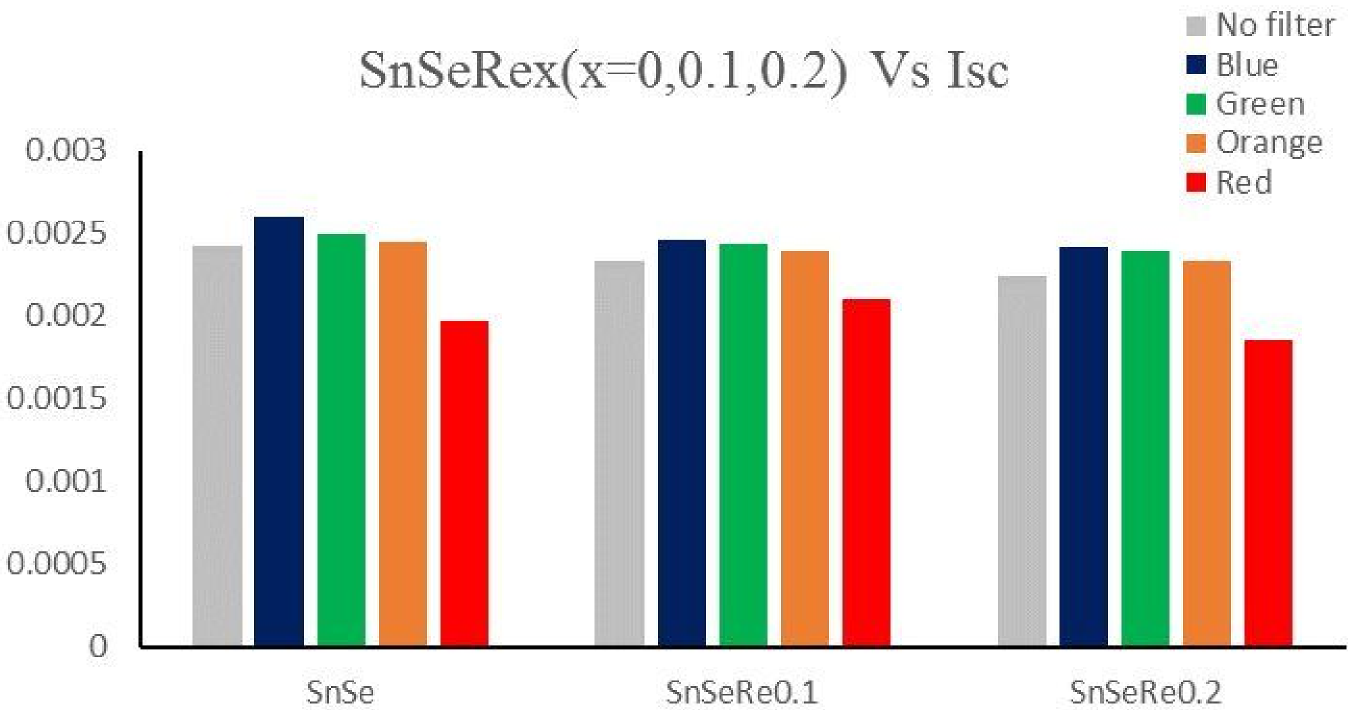


Figure 2

Ideal and Practical I-V characteristics of solar cell



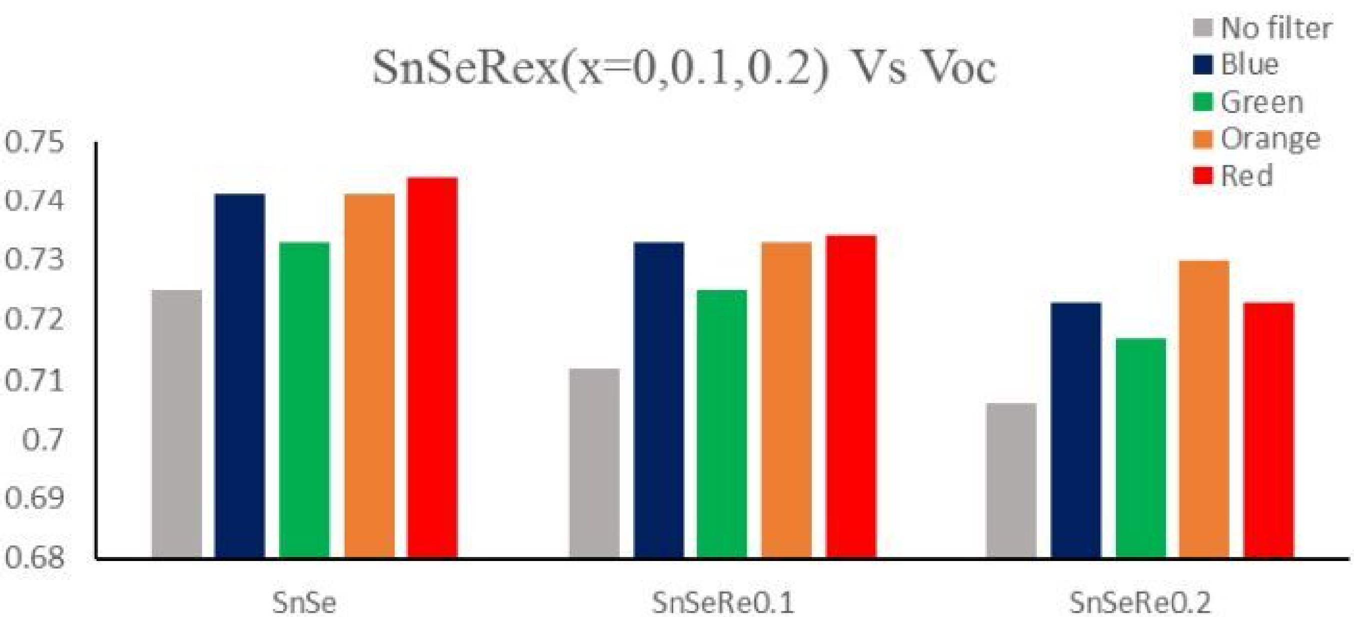


Figure 3

Comparison of I_{SC} and V_{OC} between SnSeRex (X = 0, 0.1, 0.2) crystals

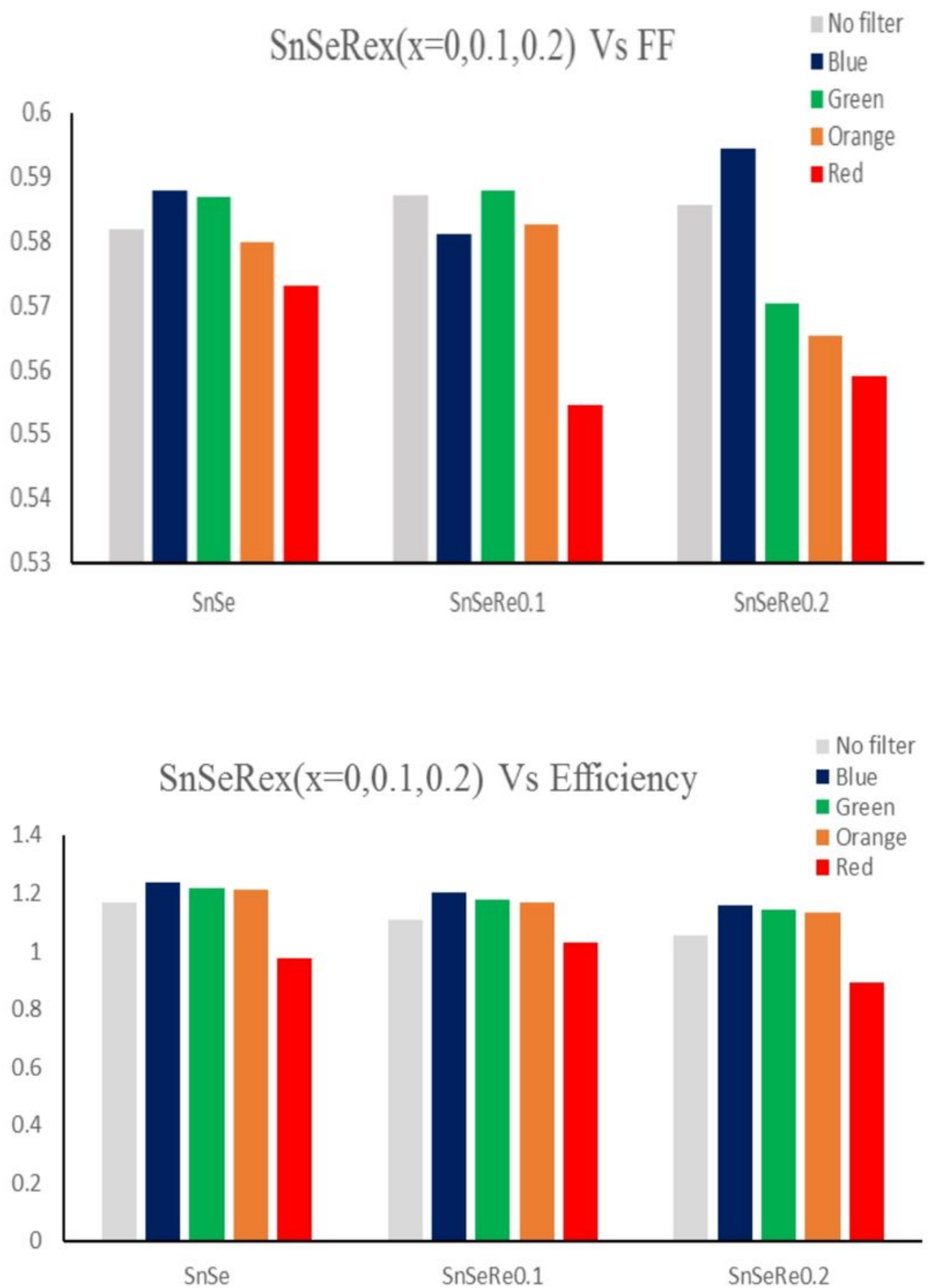


Figure 4

Comparison of FF and η% between SnSeRex (X = 0, 0.1, 0.2) crystals