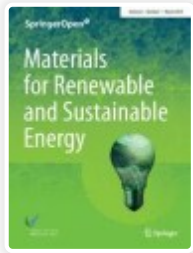


SpringerOpen®

# Materials for Renewable and Sustainable Energy





# Materials for Renewable and Sustainable Energy

[Journal home](#) > [Volumes and issues](#) > Volume 6, issue 4

Search within journal

## Volume 6, issue 4, November 2017

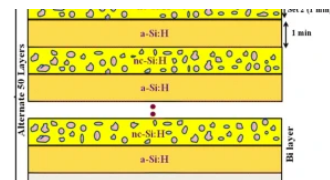
8 articles in this issue

### [Analysis of thickness-dependent optical parameters of a-Si:H/nc-Si:H multilayer thin films](#)

Ashok Kherodia & Ashish K. Panchal

Original Paper | [Open Access](#)

Published: 26 October 2017 | Article: 23

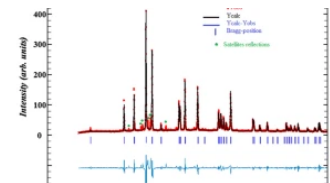


### [Synthesis, structural and electrical characterizations of LaSrCu<sub>0.4</sub>Al<sub>0.6</sub>O<sub>4-δ</sub>](#)

B. Negri, M. Leoni & R. Ben Hassen

Original Paper | [Open Access](#)

Published: 10 October 2017 | Article: 22

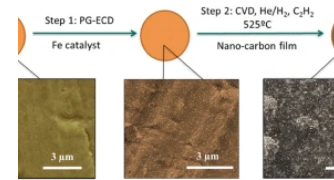


### [Processing nanoparticle–nanocarbon composites as binder-free electrodes for lithium-based batteries](#)

Marya Baloch, Pierre Kubiak ... Carmen M. López

Original Paper | [Open Access](#)

Published: 27 September 2017 | Article: 21

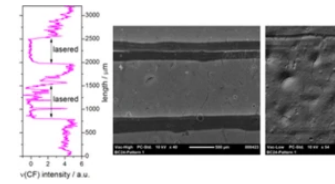


### [Modification of gas diffusion layers properties to improve water management](#)

Martin Tomas, Indro S. Biswas ... Mathias Schulze

Original Paper | [Open Access](#)

Published: 22 September 2017 | Article: 20

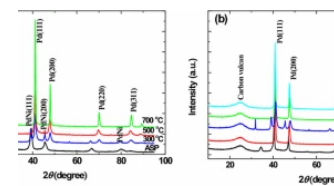


### [Preparation, characterization and electrocatalytic activity for oxygen reduction reaction in PEMFCs of bimetallic PdNi nanoalloy](#)

E. F. Abo Zeid & I. A. Ibrahim

Original Paper | [Open Access](#)

Published: 16 September 2017 | Article: 19

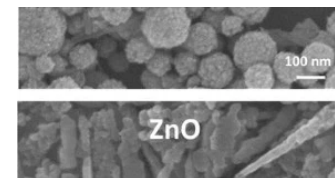


### [Heterojunction p-Cu<sub>2</sub>O/ZnO-n solar cell fabricated by spark plasma sintering](#)

Christophe Tenailleau, Guillaume Salek ... Sophie Guillemet-Fritsch

Brief Communication | [Open Access](#)

Published: 02 September 2017 | Article: 18

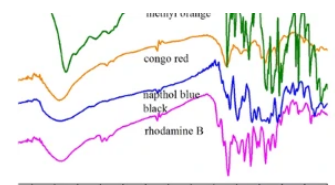


### [Affordable dye sensitizer by waste](#)

Harsasi Setyawati, Handoko Darmokoesoemo ... Ahmadi Jaya Permana

Original Paper | [Open Access](#)

Published: 31 August 2017 | Article: 17



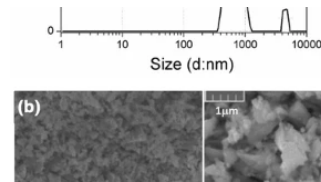
### [Electrochemical performance of the rare-earth perovskite-type oxide La<sub>0.6</sub>Sr<sub>0.4</sub>Co<sub>0.2</sub>Fe<sub>0.8</sub>O<sub>3</sub> as](#)

## [negative electrode material for Ni/oxide rechargeable batteries](#)

John Henao, Oscar Sotelo ... Lorenzo Martinez-Gomez

Original Paper | [Open Access](#) |

Published: 20 August 2017 | Article: 16



## For authors

[Submission guidelines](#)

[Manuscript editing services](#)

[Ethics & disclosures](#)

[Fees and funding](#)

[Contact the journal](#)

[Calls for papers](#)

Submit manuscript

### Working on a manuscript?



Avoid the most common mistakes and prepare your manuscript for journal editors.

[Learn more](#) →

## Explore

[Online first articles](#)

[Volumes and issues](#)

[Collections](#)

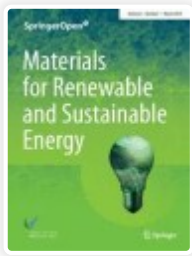
[Sign up for alerts](#)

Not logged in - 139.195.110.189

Not affiliated

**SPRINGER NATURE**

© 2022 Springer Nature Switzerland AG. Part of [Springer Nature](#).



# Materials for Renewable and Sustainable Energy.

[Journal home](#) > [Editors](#)

## Editors

### EDITOR-IN-CHIEF

#### **Vincenzo Baglio**

CNR-ITAE, Istituto di Tecnologie Avanzate per l'Energia "Nicola Giordano", Messina, Italy

Email: [vincenzo.baglio@itae.cnr.it](mailto:vincenzo.baglio@itae.cnr.it)

### FOUNDING EDITOR

#### **Enrico Traversa**

University of Rome Tor Vergata, Rome, Italy

University of Electronic Science & Technology of China, Sichuan, China

Email: [traversa.enrico@gmail.com](mailto:traversa.enrico@gmail.com)

### ADVISORY EDITORIAL BOARD

**Alberto Vomiero:** Luleå University of Technology, Sweden

**Alexey Serov:** Oak Ridge National Laboratory, Oak Ridge, USA

**Carlo Santoro:** University of Milan Bicocca, Milan, Italy

**David Sebastián:** CSIC - Instituto de Carboquímica (ICB), Zaragoza, Spain

**Eric D. Wachsman:** University of Maryland, College Park, USA

**Eric D. Wachsman:** University of Maryland, College Park, USA

**Francesca Soavi:** University of Bologna, Bologna, Italy

**Isabella Nicotera:** Università della Calabria, Rende, Italy

**Jose H. Zagal:** Universidad de Santiago de Chile, Santiago, Chile

**Luis Gerardo Arriaga:** CIDETEQ S.C., Querétaro, **Pedro Escobedo, Mexico**

**Maria Assunta Navarra:** Sapienza Università di Roma, Rome, Italy

**Mark A. Barteau:** University of Delaware, Newark, USA

**Minhua Shao:** The Hong Kong University of Science and Technology, Hong Kong

**Panagiotis Tsiakaras:** University of Thessaly, Volos, Greece

**Sangaraju Shanmugam:** DGIST, Daegu, South Korea

**Serhiy Cherevko:** Forschungszentrum Jülich GmbH, IEK-11, Erlangen, Germany

**Silvia Licoccia:** University of Rome Tor Vergata, Italy

**Stefano Fabris:** CNR-IOM Democritos Simulation Center & SISSA, Trieste, Italy

#### TOPICAL ASSOCIATE EDITORS

##### *Advanced characterization techniques and photocatalysts*

**Sanjaya D. Senanayake:** Brookhaven National Laboratory, Upton, NY, USA

##### *Batteries and supercapacitors*

**Prabeer Barpanda:** Indian Institute of Science in Bangalore, India

##### *Biofuels*

**Andrea Monti:** University of Bologna, Italy

##### *Building efficiency*

**Chi-ming Lai:** National Cheng-Kung University, Tainan, Taiwan

##### *Electrocatalysis*

**Wenping Sun:** Zhejiang University, China

##### *Electrolyzers and PEM fuel cells*

**Irene Gatto:** Istituto di Tecnologie Avanzate per l'Energia "Nicola Giordano", Messina, Italy

*Fuel cells*

**Fabio C. Fonseca:** University of São Paulo, Brazil

*Fuels and hydrogen generation*

**Jordi Llorca Pique:** Polytechnical University of Catalunya, Barcelona, Spain

*Hydrogen storage*

**Duncan H. Gregory:** University of Glasgow, Scotland, UK

*Materials modeling and theory*

**Simone Piccinin:** Istituto Officina dei Materiali (CNR-IOM), Trieste, Italy

*Organic polymers for optoelectronic applications*

**Yingping Zou:** Central South University, Changsha, Hunan, China

*Photocatalysis*

**Clemens Burda:** Case Western Reserve University, Cleveland, OH, USA

*Photovoltaics*

**Isabella Concina:** Luleå University of Technology, Sweden

*Solar cells*

**Renata Solarska:** University of Warsaw, Poland

*Supercapacitors*

**Ncholu Manyala:** University of Pretoria, South Africa

*Thermoelectricity*

**Takao Mori:** National Institute for Materials Science, Tsukuba, Japan

**SPRINGER PUBLISHING EDITORS**

Clifford Chuwah, Middle East & Africa, Springer, Dordrecht, **The Netherlands**

Nabil Khelifi, Middle East & Africa, Springer, Heidelberg, **Germany**



## For authors

---

[Submission guidelines](#)

[Manuscript editing services](#)

[Ethics & disclosures](#)

[Fees and funding](#)

[Contact the journal](#)

[Calls for papers](#)

Submit manuscript

### Working on a manuscript?



Avoid the most common mistakes and prepare your manuscript for journal editors.

[Learn more](#) →

## Explore

---

[Online first articles](#)

[Volumes and issues](#)

[Collections](#)

Sign up for alerts

## **Publish with us**

[Authors & Editors](#)

[Journal authors](#)

[Publishing ethics](#)

[Open Access & Springer](#)

## **Discover content**

[SpringerLink](#)

[Books A-Z](#)

[Journals A-Z](#)

[Video](#)

## **Other services**

[Instructors](#)

[Librarians \(Springer Nature\)](#)

[Societies and Publishing Partners](#)

[Advertisers](#)

[Shop on Springer.com](#)

## **About Springer**

[About us](#)

[Help & Support](#)

[Contact us](#)

[Press releases](#)

[Impressum](#)

## **Legal**

[General term & conditions](#)

[California Privacy Statement](#)

[Rights & permissions](#)

[Privacy](#)

[How we use cookies](#)

[Manage cookies/Do not sell my data](#)

[Accessibility](#)

Not logged in - 210.57.215.234

East Java HE Consortium (3002712836) - 6763 SpringerLink Indonesia eJourn Consortium - Higher Education (3000122892) - Universitas Airlangga Faculty of Economics and Business (2000629929) - 11741 SpringerLink Indonesia eJourn Consortium (3000951794)

---

**SPRINGER NATURE**

© 2022 Springer Nature Switzerland AG. Part of [Springer Nature](#).

# BUKTI SCOPUS

## Materials for Renewable and Sustainable Energy

<p><b>COUNTRY</b></p> <p>Switzerland</p> <p>Universities and research institutions in Switzerland</p>	<p><b>SUBJECT AREA AND CATEGORY</b></p> <p>Energy</p> <ul style="list-style-type: none"> <li>- Fuel Technology</li> <li>- Renewable Energy, Sustainability and the Environment</li> </ul> <p>Materials Science</p> <ul style="list-style-type: none"> <li>- Electronic, Optical and Magnetic Materials</li> <li>- Materials Chemistry</li> </ul>	<p><b>PUBLISHER</b></p> <p>Springer International Publishing AG</p>	<p><b>H-INDEX</b></p> <h1 style="font-size: 2em; margin: 0;">20</h1>
<p><b>PUBLICATION TYPE</b></p> <p>Journals</p>	<p><b>ISSN</b></p> <p>21941459, 21941467</p>	<p><b>COVERAGE</b></p> <p>2014-2021</p>	<p><b>INFORMATION</b></p> <p><a href="#">Homepage</a></p> <p><a href="#">How to publish in this journal</a></p> <p><a href="#">Contact</a></p>



## BUKTI KORESPONDENSI

**MRSE-D-16-00054 - Submission Confirmation** ▶ Kotak Masuk x



**Materials for Renewable and Sustainable Energy (MRSE)** <em@editorialmanager.com>

22 Okt 2016 16:58



kepada saya ▾

Inggris ▾ > Indonesia ▾ Terjemahkan pesan

Nonaktifkan untuk: Inggris x

Dear Mrs Setyawati,

Thank you for submitting your manuscript, Affordable Dye Sensitizer by Waste, to Materials for Renewable and Sustainable Energy.

The submission id is: **MRSE-D-16-00054**

Please refer to this number in any future correspondence.

During the review process, you can keep track of the status of your manuscript by accessing the following web site:

<http://mrse.edmgr.com/>

Your username is: harsasi85

Your password is: available at this link [http://mrse.edmgr.com/Default.aspx?pg=accountFinder.aspx&firstname=Harsasi&lastname=Setyawati&email\\_address=harsasi85@gmail.com](http://mrse.edmgr.com/Default.aspx?pg=accountFinder.aspx&firstname=Harsasi&lastname=Setyawati&email_address=harsasi85@gmail.com)

Should you require any further assistance please feel free to e-mail the Editorial Office by clicking on "Contact Us" in the menu bar at the top of the screen.

With kind regards,

**MRSE: Your manuscript entitled Affordable Dye Sensitizer by Waste** ▶ Kotak Masuk x



**Enrico Traversa** <em@editorialmanager.com>

Sab, 3 Des 2016 22:12



kepada saya ▾

Inggris ▾ > Indonesia ▾ Terjemahkan pesan

Nonaktifkan untuk: Inggris x

Ref: Ms. No. **MRSE-D-16-00054**

Affordable Dye Sensitizer by Waste

Materials for Renewable and Sustainable Energy

Dear Mrs Setyawati,

Reviewers have now commented on your paper. You will see that they are advising that you revise your manuscript. If you are prepared to undertake the work required, I would be pleased to reconsider the revised manuscript.

The reviewers' comments can be found at the end of this email or can be accessed by following the provided link.

This is your login information:

Your username is: harsasi85

Your password is: available at this link [http://mrse.edmgr.com/Default.aspx?pg=accountFinder.aspx&firstname=Harsasi&lastname=Setyawati&email\\_address=harsasi85@gmail.com](http://mrse.edmgr.com/Default.aspx?pg=accountFinder.aspx&firstname=Harsasi&lastname=Setyawati&email_address=harsasi85@gmail.com)

When revising your work, please submit a list of changes or a rebuttal against each point which is being raised when you submit the revised manuscript.

## BUKTI KORESPONDENSI

**MRSE** - Your revision is due  



**Materials for Renewable and Sustainable Energy (MRSE)** <em@editorialmanager.com>

Sen, 26 Des 2016 15.00



 kepada saya ▾

 Inggris ▾ > Indonesia ▾ [Terjemahkan pesan](#)

Nonaktifkan untuk: Inggris x

Ref.: Ms. No. **MRSE-D-16-00054**  
Affordable Dye Sensitizer by Waste  
Materials for Renewable and Sustainable Energy

Dear Mrs Setyawati,



We are expecting the revision of **MRSE-D-16-00054** by 02-01-2017.

If you require more time, please contact the journal office. If you are ready to submit your revision, then please go to <http://MRSE.edmgr.com/> and submit the revision.

Your username is: harsasi85

Your password is: available at this link [http://MRSE.edmgr.com/Default.aspx?pg=accountFinder.aspx&firstname=Harsasi&lastname=Setyawati&email\\_address=harsasi85@gmail.com](http://MRSE.edmgr.com/Default.aspx?pg=accountFinder.aspx&firstname=Harsasi&lastname=Setyawati&email_address=harsasi85@gmail.com)

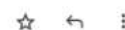
With kind regards,  
Springer Journals Editorial Office


**MRSE**: Your manuscript entitled Affordable Dye Sensitizer by Waste  



**Enrico Traversa** <em@editorialmanager.com>

Kam, 4 Mei 2017 13.12



 kepada saya ▾

 Inggris ▾ > Indonesia ▾ [Terjemahkan pesan](#)

Nonaktifkan untuk: Inggris x

Ref.: Ms. No. **MRSE-D-16-00054R1**  
Affordable Dye Sensitizer by Waste  
Materials for Renewable and Sustainable Energy

Dear Mrs Setyawati,

Reviewers have now commented on your paper. Some minor revisions have been suggested. If you are prepared to make the revisions, I would be pleased to consider publication.

The reviewers' comments can be found at the end of this email or can be accessed by following the provided link.

This is your login information:

Your username is: harsasi85

Your password is: available at this link [http://mrse.edmgr.com/Default.aspx?pg=accountFinder.aspx&firstname=Harsasi&lastname=Setyawati&email\\_address=harsasi85@gmail.com](http://mrse.edmgr.com/Default.aspx?pg=accountFinder.aspx&firstname=Harsasi&lastname=Setyawati&email_address=harsasi85@gmail.com)

When revising your work, please submit a list of changes or a rebuttal against each point which is being raised when you submit the revised manuscript.

Your revision is due by 03 Jun 2017.

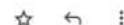
## BUKTI KORESPONDENSI

**MRSE: Submission Confirmation for MRSE-D-16-00054R2** ▶ Kotak Masuk x



**Materials for Renewable and Sustainable Energy (MRSE)** <em@editorialmanager.com>

Sen, 29 Mei 2017 11:10



kepada saya ▾

Inggris ▾ > Indonesia ▾ [Terjemahkan pesan](#)

Nonaktifkan untuk: Inggris x

Ref.: Ms. No. **MRSE-D-16-00054R2**

Affordable Dye Sensitizer by Waste

Dear Mrs Setyawati,

Materials for Renewable and Sustainable Energy has received your revised submission.

You may check the status of your manuscript by logging onto Editorial Manager at <http://mrse.edmgr.com/>.

Kind regards,

Editorial Office

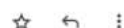
Materials for Renewable and Sustainable Energy

**MRSE: Your manuscript entitled Affordable Dye Sensitizer by Waste** ▶



**Enrico Traversa** <em@editorialmanager.com>

Kam, 24 Agu 2017 21:54



kepada saya ▾

Inggris ▾ > Indonesia ▾ [Terjemahkan pesan](#)

Nonaktifkan untuk: Inggris x

Ref.: Ms. No. **MRSE-D-16-00054R4**

Affordable Dye Sensitizer by Waste

Materials for Renewable and Sustainable Energy

Dear Mrs Setyawati,

I am pleased to inform you that your manuscript has now been accepted for publication in the journal Materials for Renewable and Sustainable Energy.

Thank you for submitting your work to our journal. We are looking forward to receiving other contributions from your group in the future.

With kind regards

Enrico Traversa

Editor-in-Chief

Materials for Renewable and Sustainable Energy

# BUKTI KORESPONDENSI

Proofs for your article in Materials for Renewable and Sustainable Energy ( 101)  

spr\_corrections@sps.co.in

 kepada saya 

Rab, 30 Agu 2017 15:15

 Inggris  > Indonesia  Terjemahkan pesan

Nonaktifkan untuk: Inggris 

Learn. Discover. Achieve

**SPRINGER NATURE**

Article Title : Affordable dye sensitizer by waste

DOI : 10.1007/s40243-017-0101-9

MRSE-D-16-00054.4

Dear Author,

We are pleased to inform you that your paper is nearing publication. Your article proofs are available at:



# Affordable dye sensitizer by waste

Harsasi Setyawati<sup>1</sup> · Handoko Darmokoesoemo<sup>1</sup> · Faidur Rochman<sup>1</sup> ·  
Ahmadi Jaya Permana<sup>1</sup>

Received: 22 October 2016 / Accepted: 27 August 2017  
© The Author(s) 2017. This article is an open access publication

**Abstract** The development of dye sensitizer is growing in line with the increasing demand for renewable energy. A research to obtain a dye sensitizer that is economical, safe, and produces a great value of DSSC efficiency is a challenge unresolved. On the other hand, the efforts for waste reduction are also intensively conducted to create better environment. In this paper, the variation of synthetic dye wastes from batik industries have been successfully applied as dye sensitizer and fabricated on DSSC cells. Congo red (1.0133%) yielded higher efficiency than rhodamine B (0.0126%), methyl orange (0.7560%), and naphthol blue black (0.0083%). The divergence of the efficiency of DSSC is very dependent upon the chromophore group owned by dye. This study has proven that the more chromophore group possessed by dye, the higher the efficiency of DSSC generated. This research concludes that the dye wastes have a bright future to be implemented as dye sensitizer on solar cells.

**Keywords** Affordable · Batik waste · Dye sensitizer · DSSC · Chromophore

## Introduction

Batik industries in Indonesia are great contributors of liquid waste originating from the dyeing process. During the production process, about 10–15% of the dye will be

released into the environment and causing environmental pollution [1]. In addition to substances of high color, batik and textile industry waste contain synthetic ingredients poorly soluble or hard to decompose. Coloring process in batik will produce cloudy and dark liquid waste. Usually the color of liquid waste depends on the dye used [2]. Actually, dye compounds in aquatic environments can decompose naturally by the presence of sunlight. However, the reaction is relatively slow because the intensity of UV light reaching the earth surface is relatively low. In addition, the energy needs of the world prompted many researchers to pursue alternative renewable energy such as DSSC. DSSC is promising renewable energy resource because of zero waste, low cost and eco-friendly [3–5]. DSSC is a solar cell that utilizes a sensitized dye to harvest sunlight [6]. The dye plays important role to harvest solar energy and convert it to electrical energy [7, 8]. The effort to combine the dye wastes as a dye sensitizer on DSSC is a novel solution to overcome the problem of waste and energy at once. In this research, dye wastes from batik home industries in Indonesia (congo red, rhodamine B, methyl orange, naphthol blue black) are applied as dye sensitizer on DSSC. Thin layer titanium dioxide is used as semiconductor and prepared in various synthesis methods. KI<sub>3</sub> is used as electrolyte and graphite as counter electrode. FTO glass is used in the body of DSSC cell.

## Experimental

All chemicals were purchased from commercial sources (Sigma Aldrich) except liquid dye wastes which were collected from batik home industries in Indonesia. The dye wastes were rhodamine B, congo red, methyl orange, and naphthol blue black. Materials for preparation of DSSC

✉ Harsasi Setyawati  
harsasi85@gmail.com

<sup>1</sup> Department of Chemistry, Faculty of Science and Technology, Airlangga University, 60115 Surabaya, Indonesia

**Table 1** The maximum wavelength of dye wastes matched with color theory [12]

Dye	$\lambda$ max (nm)	Absorbed color	Complementary color
Rhodamine B	554	Green	Red
Congo red	498	Green	Red
Methyl orange	464	Blue	Orange
Naphthol blue black	619	Orange	Blue

were titanium(IV) isopropoxide( $\text{Ti}(\text{OC}_3\text{H}_7)_4$ ) (TTIP), 4-(1,1,3,3-tetramethylbutyl) phenylpolyethylene glycol (Triton X-100), iodine ( $\text{I}_2$ ), potassium iodide (KI), ethanol ( $\text{CH}_2\text{CH}_3\text{OH}$ ), hydrochloric acid (HCl), ether and acetic acid ( $\text{CH}_3\text{COOH}$ ). Fluorine doped tin oxide (FTO) (10  $\Omega$ , 25 × 25 × 3.2 mm) was used as the conductive glass plate and purchased from Latech scientific supply Pte. Ltd Singapore. The top and the left of FTO glass was isolated by adhesive tape about 0.5 cm for the clamp side and to control the thickness of the coating of  $\text{TiO}_2$ . Graphite was used as a counter electrode.

### Preparation of semiconductor

In this study, synthesis of semiconductor (titanium dioxide) was done by two techniques. First, thin film of titanium dioxide was prepared using surfactants triton X-100 by sol-gel method. Second, thin film of titanium dioxide was prepared without surfactants triton X-100 by sol-gel method. First technique, 5 mL of triton X-100 was added into acetic acid and transferred into a 225 mL ethanol while being stirred for 3 min. Then 15 mL TTIP was added to 1 mL of concentrated hydrochloric acid in the solution. The mixture was stirred for 2 h to form a sol [9]. In the second technique, 15 mL TTIP in 1 mL of concentrated hydrochloric acid in the solution was stirred for 2 h to form a sol.

### Preparation of working electrode

First, the FTO glasses were washed with deionized water and then dried at 80 °C for 10 min. The conductive side of the FTO glass was covered on two edges with adhesive tape to control the thickness of  $\text{TiO}_2$  film. Subsequently, the FTO glass was coated with  $\text{TiO}_2$  sol 3 times. Then each FTO glass was dried at 80 °C for 10 min. In the last coating, FTO glasses were calcined at 450 °C for 2 h and then cooling down in ambient temperature [10]. The electrode was immersed in the each solution of dye (0.1 mmol  $\text{L}^{-1}$ ) for 24 h at room temperature and then dried [11]. The dyes were congo red, rhodamine B, methyl orange and naphthol blue black.

### Preparation of counter electrode

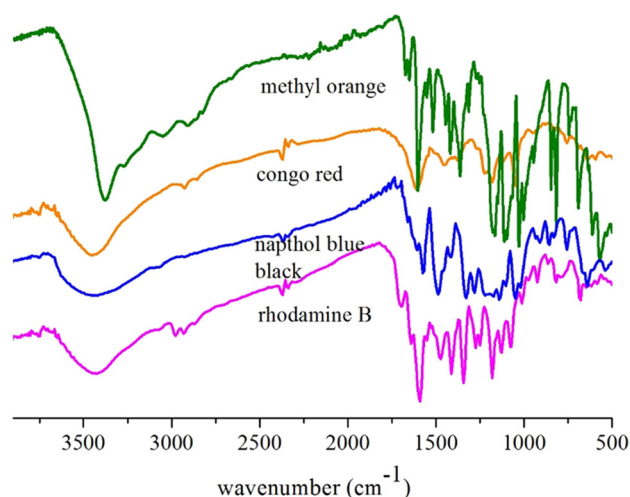
The counter electrode was prepared by coating the conductive side of FTO glass with carbon from a graphite pencil until evenly distributed. Then, FTO glasses were heated at 450 °C for 30 min and then washed and dried. Graphite was chosen as a counter electrode because less costly and easily prepared.

### Fabrication of DSSC cells

Before the working electrode and counter electrode were assembled, the electrolyte solution was prepared by dissolving the iodine ( $\text{I}_2$ ) into potassium iodide (KI) solution until formed  $\text{KI}_3$ . The DSSC cells were assembled by sandwiched working electrode and counter electrodes, respectively, and then sealed with crocodile clips.

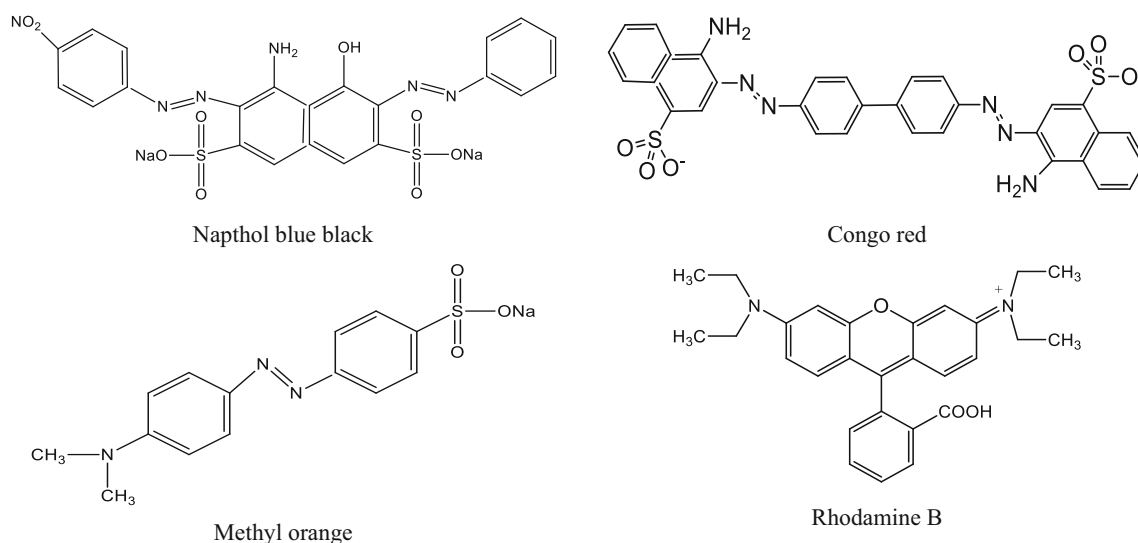
### Characterizations

The maximum wavelength of each synthetic dye was measured using UV-VIS Shimadzu 1800. The functional groups and infrared spectra were recorded using Jasco FTIR 5300. The electrical conductivity of dye was analyzed using

**Fig. 1** FTIR spectra of dye wastes

**Table 2** The functional groups of dye wastes and the wavenumber

Methyl orange		Congo red		Naphthol blue black		Rhodamine	
Functional groups	Wave number (cm <sup>-1</sup> )	Functional groups	Wavenumber (cm <sup>-1</sup> )	Functional groups	Wavenumber (cm <sup>-1</sup> )	Functional groups	Wavenumber (cm <sup>-1</sup> )
C=C aromatic	1604.77 [13]	C=C aromatic	1612 [14]	C=C aromatic	1573.91 [15]	C=C aromatic	1589.34 [13]
RSO <sub>3</sub> <sup>-</sup>	1118.71 [13]	RSO <sub>3</sub> <sup>-</sup>	1149.28 [14]	RSO <sub>3</sub> <sup>-</sup>	1141.86 [16]	C-H aromatic	925.83 [13]
N=N	1365.60 [13]	N=N	1458.15 [14]	N=N	1419.61 [17]	Cl-	794.67 [18]
		NH <sub>2</sub>	3448.72 [14]	NH <sub>2</sub>	3749.62 [17]	C=N	1342.46 [13]
		C-S	594.08 [14]	NO <sub>2</sub>	1489.05 [17]	-CH <sub>3</sub>	1411.89 [13]
				O-H	3441.01 [19]	C=O	1697.36 [13]
						O-H	3425.58 [13]

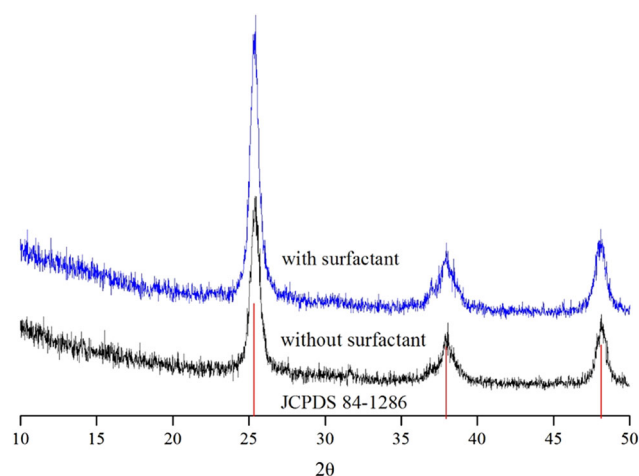
**Fig. 2** Structure of dye wastes**Table 3** Theoretical calculation of the amount of chromophore

Compound	Chromophore				Total
	C=O	N=N	S=O	Benzene	
Methyl orange	0	1	2	2	5
Congo red	0	2	4	6	12
Naphthol blue black	0	2	4	4	10
Rhodamine	1	0	0	3	4

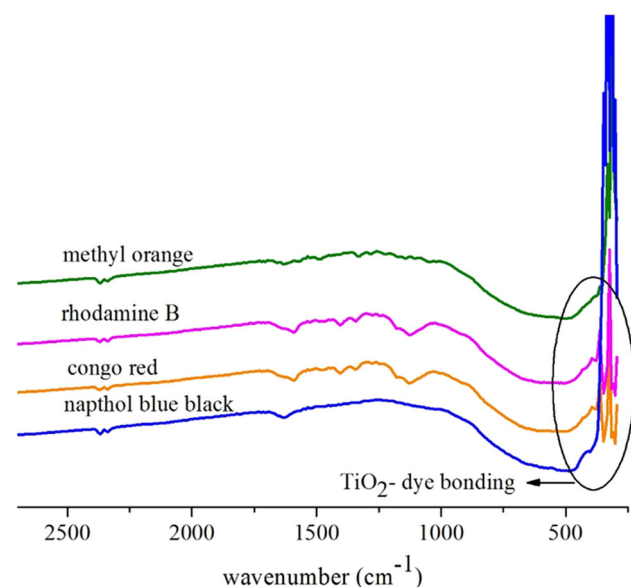
EUTECH conductometer. The crystallinity and phase analysis of two kinds of thin film titanium dioxide was characterized using X'pert PRO Diffractometer. Photovoltaic performance of DSSC cells for each dye sensitizer was measured by measuring current density–voltage curves under solar irradiation in real condition (outdoor) as long as 5 days. The voltage and current density of the cell were measured with multimeter Dekko using potentiometer circuit while intensity of light was measured with Light Meter Krisbow KW06-288.

## Results and discussion

This research successfully developed a novel dye sensitizer from dye wastes. Liquid dye wastes used are rhodamine B, congo red, methyl orange and naphthol blue black obtained from batik industries. At batik home industries, dyeing process is generally done manually by immersion of fabric into the dye in large vat. Each vat containing a particular dye. Liquid dye wastes in the study came from the vat dye



**Fig. 3** XRD pattern of thin layer titanium dioxide as semiconductor on DSSC



**Fig. 4** FTIR spectra of the interaction bonding of  $\text{TiO}_2$ -dye wastes

that can be ascertained dye waste is not mixed with each other.

### Characteristic of dye wastes

Characterizations of dyes have been done to determine the characteristics of each dye that support their dye sensitizer performance. The result of measurement spectrophotometer UV–VIS is shown in Table 1. All of dyes show the maximum wavelength in the 400–600 nm range as the absorbed color is blue–orange. This result indicates that each dye can absorb the visible light from solar light. These properties are very advantageous because the visible

energy range is so wide that allows many levels of energy to be absorbed by the dyes [11].

Figure 1 shows the fourier transform infrared spectra of rhodamine B, congo red, methyl orange and naphthol blue black. The spectra have been recorded using Jasco FTIR 5300 in the wave number range  $500\text{--}4000\text{ cm}^{-1}$ . Each dye has specific functional group and is tabulated in Table 2.

Table 2 shows that each dye has chromophore group in their structure which is able to support their performance as dye sensitizer on DSSC. Chromophore is the part of molecule that is sensitive to light [20, 21]. The chromophore owned by dye will increase the dye's ability for capturing the photon from sunlight so the amount of photon used to generate a cycle of electrons in DSSC cells will increase. This process will generate a continuous electrical current. The number of chromophore groups highly influences the ability of dye on capturing photon of solar light. The more of chromophore groups the more photons absorbed. Thus, the current produced will be higher. Description of the structure and the amount of dye chromophore are presented in Fig. 2 and Table 3.

### Characteristic of thin layer $\text{TiO}_2$ as semiconductor on DSSC

Figure 3 shows the result of semiconductor characterization using XRD X'pert PRO Diffractometer. In this work, preparation of thin film titanium dioxide was varied by adding surfactants and without surfactants. The result shows that the patterns of thin film titanium dioxide by adding and without surfactants is similar and refers to the structure of  $\text{TiO}_2$  anatase according the database JCPDS 84-1286. If we see the intensity, thin film with surfactants is different from that without surfactants. It means that surfactants that added contributed to form structure in film layer titanium dioxide [22, 23].

In DSSC, dye sensitizer was attached to the semiconductor. Therefore, the interaction of  $\text{TiO}_2$  and dye was characterized using FTIR to determine the bonding of  $\text{TiO}_2$  and dye. Figure 4 shows that the interaction of  $\text{TiO}_2$  and dye was chemical interaction of Ti and O from dye formed Ti–O bonding at  $400\text{--}500\text{ cm}^{-1}$  [18]. This interaction highly supports the flow of electron transfer from dye to the semiconductor [7, 8].

### Photovoltaic performance

The performance of dye wastes as dye sensitizer is shown in Fig. 5 and Table 4. The current density–voltage (J–V) curve of dye wastes are shown in Fig. 5. Table 4 shows that congo red yielded the highest efficiency (1.9%) among

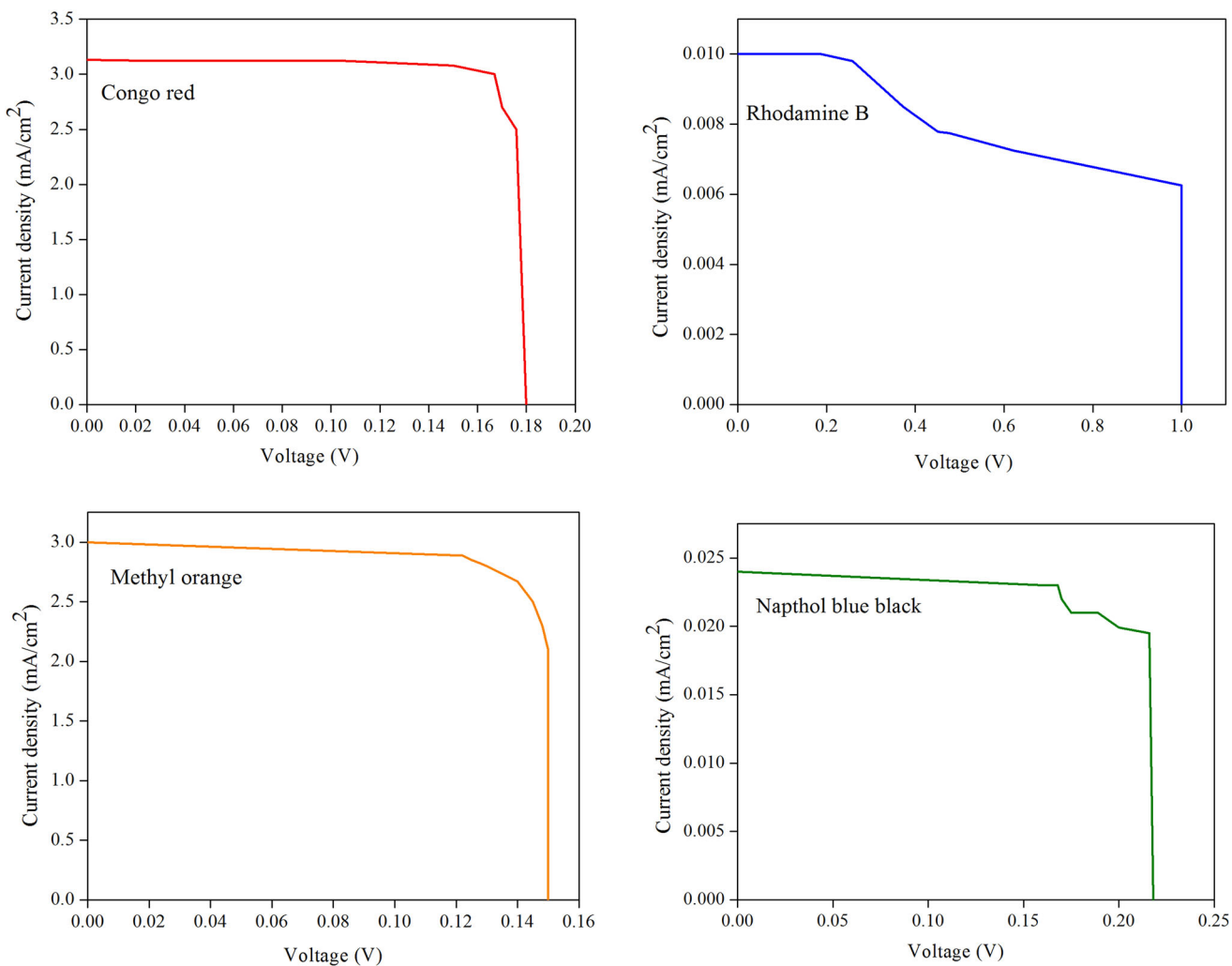


Fig. 5 J-V characteristic curve of dye wastes on DSSC

Table 4 The photovoltaic parameters of the DSSC cells

Dye	$J_{Sc}$ (mAcm <sup>-2</sup> )	$V_{oc}$ (V)	$J_{max}$ (mAcm <sup>-2</sup> )	$V_{max}$ (V)	P Lux (W m <sup>-2</sup> )	FF	$\eta$ (%)
Congo red	3.130	0.18	3	0.167	49.44	0.8892	1.0133
Rhodamine B	0.010	1	0.00625	1	49.44	0.6250	0.0126
Methyl orange	3	0.15	2.67	0.14	49.44	0.8306	0.7560
Naphthol blue black	0.024	0.218	0.019	0.216	49.44	0.7844	0.0083

Area of DSSC cells: 4 cm<sup>2</sup>

dyes because congo red has the highest number of chromophore group, i.e., benzene rings, azo (N=N), and sulfoxide (S=O). This result indicates that congo red has the best ability in capturing photon from solar energy because of the supporting of their chromophore group. The highest efficiency means that the most photon of solar energy can be absorbed by dye sensitizer [10, 20, 21].

Table 4 shows that dye wastes generate diverse efficiency of DSSC value; the efficiency of DSSC reached is 1.0133%. This value is considerably higher than those of the

DSSC sensitized by other synthetics dyes or natural dyes. Synthetics dyes from hydrazonoyl and their derivatives reported obtain the efficiency of DSSC of 0.00009–0.003% [24]. Natural dyes from five plants *Amaranthus caudatus*, *Bougainvillea spectabilis*, *Delonix regia*, *Nerium oleander* and *Spathodea campanulata* obtained the highest efficiency of DSSC reached 0.610% from *Amaranthus caudatus* [25]. Natural dyes from beet, red cabbage, strawberry, spinach, mallow, and henna extract obtained the highest efficiency of 0.229% [26]. Chlorophyll and xanthophyll from



*Cladophora* sp. reported obtained the highest efficiency of 0.08% [27]. This result indicates that dye waste was potentially applied as dye sensitizer on DSSC.

## Conclusion

In this work, DSSC were assembled using four dye wastes from batik industries in Indonesia as dye sensitizer. Congo red has been proven to yield the highest efficiency among the dye wastes, i.e., 1.0133%. This is because congo red has the most of chromophore group than the other dyes. This study proves that the chromophore group greatly contributes to improving the efficiency of DSSC.

**Acknowledgements** The authors gratefully acknowledge the financial support provided by the research Grant “Hibah Dosen Muda” sponsored by Faculty of Science and Technology, Airlangga University and Penelitian Unggulan Perguruan Tinggi (PUPT) sponsored by Ministry of Research, Technology and Higher Education (RISTEKDIKTI) and also Department of Chemistry, Faculty of Science and Technology, Airlangga University Surabaya, Indonesia for support the facilities.

**Open Access** This article is distributed under the terms of the Creative Commons Attribution 4.0 International License (<http://creativecommons.org/licenses/by/4.0/>), which permits unrestricted use, distribution, and reproduction in any medium, provided you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license, and indicate if changes were made.

## References

- Amaliasani, R.: Pengolahan Limbah Batik Dengan Menggunakan Metode Elektrolisis Dengan Anoda dan Katoda Platinum (Pt). Universitas Islam Indonesia, Yogyakarta (2013)
- Suprihatin, H.: Kandungan Organik Limbah Cair Industri Batik Jetis Sidoarjo dan Alternatif Pengolahannya Pusat Penelitian Lingkungan Hidup Universitas Riau (2014)
- Giribabu, L., Sudhakar, K., Velkannan, V.: Phthalocyanines: potential alternative sensitizers to Ru (II) polypyridyl complexes for dye-sensitized solar cells. *Curr. Sci.* **102**(7), 991–1000 (2012)
- Baldenebro-Lopez, J., Flores-Holguin, N., Castorena-Gonzalez, J., Glossman-Mitnik, D.: Molecular design of copper complexes as sensitizers for efficient dye-sensitized solar cells. *J. Photochem. Photobiol. A* **267**, 1–5 (2013). doi:10.1016/j.jphotochem.2013.06.005
- Bignozzi, C., Argazzi, R., Boaretto, R., Busatto, E., Carli, S., Ronconi, F., Caramori, S.: The role of transition metal complexes in dye sensitized solar devices. *Coord. Chem. Rev.* **257**(9), 1472–1492 (2013)
- Grätzel, M.: Dye-sensitized solar cells. *J. Photochem. Photobiol. C* **4**(2), 145–153 (2003)
- Alhamed, M., Issa, A.S., Doubal, A.W.: Studying of natural dyes properties as photo-sensitizer for dye sensitized solar cells (DSSC). *J. Electron Devices* **16**(11), 1370–1383 (2012)
- Tennakone, K., Kumara, G., Kumarasinghe, A., Sirimanne, P., Wijayantha, K.: Efficient photosensitization of nanocrystalline TiO<sub>2</sub> films by tannins and related phenolic substances. *J. Photochem. Photobiol. A* **94**(2), 217–220 (1996)
- Fagnern, N., Letphayakkarat, R., Chawengkijwanich, C., Glee-som, M.P., Koonsaeng, N., Sanguanruang, S.: Effect of titanium-tetraoxopropoxide concentration on the photocatalytic efficiency of textile dyes. *J. Phys. Chem. Solid* **73**, 1483–1486 (2012)
- Setyawati, H., Darmokoesoemo, H., Hamami, H., Rochman, F., Permana, A.J.: Promising dye sensitizer on solar cell from complexes of metal and rhodamine B. *Int. J. Renew. Energy Res.* **5**(3), 694–698 (2015)
- Setyawati, H., Purwaningsih, A., Darmokoesoemo, H., Hamami, H., Rochman, F., Permana, A., P.: Potential complex of rhodamine B and copper (II) for dye sensitizer on solar cell. In: ICOWOBAS 2015, Indonesia, pp. 070004-1–070004-6. AIP Publishing, New York (2016)
- Denny, R., Sinclair, R.: Visible and Ultraviolet Spectroscopy, Analytical Chemistry by Open Learning. Wiley, New York (1987)
- Pavia, D.L., Lampman, G.M., Kriz, G.S., Vyvyan, J.A.: Introduction to Spectroscopy. Cengage Learning, Boston (2008)
- Pretsch, E., Clerc, T., Seibl, J., Simon, W.: Tables of Determination of Organic Compounds. 13C NMR, 1H NMR, IR, MS, UV/Vis, Chemical Laboratory Practice. Springer-Verlag, Berlin (1989)
- Farhadyar, N., Rahimi, A., Ershad Langroudi, A.: Synthesis and characterization of inorganic-organic hybrid produced from tetraethoxysilane and epoxy-aromatic amine. In: IUPAC World Polymer Congress Macro, pp. 2 (2004)
- Pretsch, E., Clerc, T., Seibl, J., Simon, W.: Tables of Spectral Data for Structure Determination of Organic Compounds. Springer Science and Business Media, Berlin (2013)
- Yuen, C., Ku, S., Choi, P., Kan, C., Tsang, S.: Determining functional groups of commercially available ink-jet printing reactive dyes using infrared spectroscopy. *Res. J. Text. Appar.* **9**(2), 26–38 (2005)
- Nakamoto, K.: Infrared and raman spectra of inorganic and coordination compounds. In: Handbook of Vibrational Spectroscopy. Wiley, New York (2006). doi:10.1002/0470027320.s4104
- Duygu, D.Y., Udoh, A.U., Ozer, T.B., Akbulut, A., Erkaya, I.A., Yildiz, K., Guler, D.: Fourier transform infrared (FTIR) spectroscopy for identification of *Chlorella vulgaris* Beijerinck 1890 and *Scenedesmus obliquus* (Turpin) Kützing 1833. *Afr. J. Biotech.* **11**(16), 3817–3824 (2012)
- Qin, P., Wiberg, J., Gibson, E.A., Linder, M., Li, L., Brinck, T., Hagfeldt, A., Albinsson, B., Sun, L.: Synthesis and mechanistic studies of organic chromophores with different energy levels for p-type dye-sensitized solar cells. *J. Phys. Chem. C* **114**(10), 4738–4748 (2010)
- Zhang, G., Bala, H., Cheng, Y., Shi, D., Lv, X., Yu, Q., Wang, P.: High efficiency and stable dye-sensitized solar cells with an organic chromophore featuring a binary  $\pi$ -conjugated spacer. *Chem. Commun.* **16**, 2198–2200 (2009)
- Černigoj, U., Štangar, U.L., Trebše, P., Krašovec, U.O., Gross, S.: Photocatalytically active TiO<sub>2</sub> thin films produced by surfactant-assisted sol-gel processing. *Thin Solid Films* **495**(1), 327–332 (2006)
- Inoue, M., Hirasawa, I.: The relationship between crystal morphology and XRD peak intensity on CaSO<sub>4</sub>·2H<sub>2</sub>O. *J. Cryst. Growth* **380**, 169–175 (2013)
- Abdel-Latif, M.S., Batniji, A., El-Agez, T.M., Younis, M.J., Ghamri, H., Thaher, B.A.A., Qeshta, B.S., Abu-Awwad, F.M., Taya, S.A.: Dye sensitized solar cells based on hydrazoneoyl synthetic dyes. *J. Nano Electron. Phys.* **8**(4), 4038 (2016)
- Godibo, D.J., Anshebo, S.T., Anshebo, T.Y.: Dye sensitized solar cells using natural pigments from five plants and quasi-solid state electrolyte. *J. Braz. Chem. Soc.* **26**(1), 92–101 (2015)
- Torchani, A., Saadaoui, S., Gharbi, R., Fathallah, M.: Sensitized solar cells based on natural dyes. *Curr. Appl. Phys.* **15**(3), 307–312 (2015)
- Lim, A., Haji Manaf, N., Tennakoon, K., Chandrakanthi, R., Lim, L.B.L., Bandara, J., Ekanayake, P.: Higher performance of DSSC with dyes from *Cladophora* sp. as mixed cosensitizer through synergistic effect. *J. Biophys.* (2015). doi:10.1155/2015/510467