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"Basic idea, advance approach": Efficiency boost by sensitization of blended dye on chemically deposited ZnO films

Prashant Kishor Baviskar[a], Deepak Prakash Dubal[b], Sutripto Majumder[c], Ahmed Ennaoui[d], Babasaheb Raghunath Sankapal[c,*]

[a] Department of Physics, School of Physical Sciences, North Maharashtra University, Jalgaon, M.S. 425001, India
[b] Catalan Institute of Nanoscience and Nanotechnology (ICN2), CSIC and The Barcelona Institute of Science and Technology, Campus UAB, Bellaterra, 08193 Barcelona, Spain
[c] Nano Materials and Device Laboratory, Department of Applied Physics, Visvesvaraya National Institute of Technology, South Ambazari Road, Nagpur, 440010 M.S. India
[d] Qatar Environment and Energy Research Institute and Hamad Bin Khalifa University, Education City, Doha, Qatar

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ABSTRACT

The state of art is shown to develop attractive, low cost, colorful, and device grade dye sensitized solar cells using chemically synthesized ZnO. Metal free organic dyes showing unlike absorption coverage in the visible part of solar spectrum has been used to produce colorful solar cells. By mimicking the basic idea of blending two individual colors of the dyes namely, Coumarin 343 (yellow) and Eosin-Y (red) to get orange color which has been utilized toward advanced colorful approach in order to boost the device performance. Correlation is made between the optical absorption spectra of individual and blended dyes with incident photon to current conversion efficiency (IPCE). The solar cell performance under illumination (100 mW/cm^2, AM 1.5G) of individual and blended dyes on ZnO films have been investigated. The obtained efficiency ranges from 0.02 to 1.98% for individual dyes whereas the efficiency boosts up to 2.45% has been observed for blended dye.

1. Introduction

Due to the increase in global energy demand, a renewable energy source is to be determined which is cost effective and reliable. A great attention has been devoted to dye sensitized solar cell (DSSC) as inexpensive and environmentally benign candidate toward a new generation solar cell [1,2]. DSSC have many advantages: mainly low production cost, works also at diffuse sun light, flexible, see through and multicolor options are available. Numerous dyes were utilized for DSSC application in combination with TiO_2 and/or ZnO as photo anodes. Typically, nanocrystalline TiO_2 has been used as a photoanode in DSSCs [3,4]. Alternative to TiO_2, zinc oxide (ZnO) is a charming material in DSSCs due to its higher electronic mobility, similar electron affinity and optical band gap with that of TiO_2 [5] along with a similar electron injection process from excited dyes [6]. Furthermore, ZnO with wide surface architecture can be effortlessly synthesized via low cost chemical methods using easily accessible raw materials for the mass production. To date, the anisotropy inherent in the wurtzite ZnO can also be tailored by several methods leading to various nanostructures [7]. Ru-metal based dyes were frequently used as photo sensitizer with TiO_2 and/or ZnO semiconductor [8–10]. In contrast, metal free organic dyes were emerged out to replace Ru-metal based dyes resulting into remarkable efficiencies [11–14], since Ru-metal dyes are too expensive to be utilized for massive production of solar panel at lower cost. On contrary, the metal free organic dyes have more reward such as cost effective, eco-friendly, high molar extinction coefficient and with easy tuning properties like photophysical and electrochemical [15]. Wang et al. have reported 0.54 and 1.67% device efficiencies for Eosin-Y and Coumarin 343 dye, respectively with TiO_2 as photoanode and I^-/I_3^- as liquid electrolyte [16]. Otaka et al. reported multi colored DSSCs based on TiO_2 and observed values of efficiency in the range of 1.6–2.7% [17]. Yoshida et al. observed the improvement in photoelectrochemical performance for electrochemically deposited self-assembled nanoporous ZnO/eosinY hybrid thin films by dye re-adsorption and achieved 2.3% power conversion efficiency [18]. Suri et al. observed the enhancement in efficiency from 0.7 to 1.9% for ZnO sensitized with metal free Eosin-Y dye by replacement of electrolyte from I^-/I_3^- to Br^-/Br_3^- [19]. Pradhan et al. reported 0.7%

* Corresponding author. Fax: +91 712 2223230.
E-mail addresses: brsankapal@gmail.com, brsankapal@phy.vnit.ac.in (B.R. Sankapal).

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efficiency for Rose Bengal dye with ZnO electrode [20]. Guillen et al. reported 0.15–1.2% efficiency for nanostructured ZnO sensitized with xanthene dyes [21]. Our earlier report shows 1.26% power conversion efficiency for chemically synthesized ZnO nanobeads with metal free rhodamine B dye as sensitizer [22]. Recently, Nakajima et al. discuss the wavelength-dependence of azo dyes sensitized on TiO_2 [23]. In a recent time, we have check the influence of processing parameters on chemically grown ZnO films sensitized with low cost Eosin-Y dye and reached the maximum efficiency of 2.16% [24].

One of the most important and challenging factor attributed to the lower efficiency of the DSSC is the limited spectral coverage of dyes (400–700 nm), which is smaller than that of crystalline silicon (500–1100 nm) [25]. The sensitizer (dye) is one of the key components and plays a vital role toward improvement in the efficiency of DSSC by photon harvesting in complete part of the visible spectrum, which is presently difficult by using only a plural metal free low cost dye. Individual organic sensitizers can only absorb a relatively narrow range of the solar spectrum. The strategy to obtain a broad optical absorption extending throughout the visible region is to use a combination of two dyes which complement each other in their spectral response. The strategy is encouraging in such a way that the optical effects of the two sensitizers were found to be additive, opening up the system for testing a multitude of other dye combinations [26]. There are several reports available on the enhancement in performances of the DSSC by mixing two are more ruthenium based dyes as a cocktail dye with TiO_2 [27,28]. Recently, Sirimanne and group achieved 4.6% efficiency for cocktail dye (mixture of N719 and black dye) with TiO_2 film [29]. Some reports are also available on TiO_2 sensitized with cocktail dye prepared by combination of ruthenium complex dye and ruthenium metal free organic dye [30,31]. A certified new record efficiency of 11.4% was achieved for TiO_2 using novel co-adsorbent by Han et al. [32]. It is well known that organic dyes have excellent photophysical properties, i.e., higher molar absorption and excitation coefficient than the transition metal complexes [33,34]. Very few literatures are available on sensitization of TiO_2 using cocktail dye prepared by mixing only metal free dyes [35–37]. Chen et al. suggested that the ZnO is, next only to TiO_2, a popular photoelectrode material in DSSCs by virtue of its morphological versatility. They have reported the synthesis of ZnO tetrapod via chemical vapor transport deposition (CVTD). ZnO tetrapod sensitized with Mercurochrome and mixture of Mercurochrome and N719 dye, which shows the improvement in J_{sc} is attributed due to the additional light harvesting for mixture dye [38]. One report is available based on ZnO sensitized with cocktail dye prepared by mixing expensive metal-free organic indoline dyes. Magne et al. reported the enhancement of photovoltaic performances for electrochemical deposited nanoporous ZnO sensitized by using cocktail dye with co-adsorbent and achieved maximum efficiency of 4.53% [39]. To the best of our knowledge and from the literature survey, not a single attempt was made for the ZnO electrode sensitized using blended dye prepared by combining low cost metal free organic dyes toward DSSC fabrication. Even though ZnO is easy to produce with large diversity of nanostructures by using a variety of synthesis methods, but it exhibits less chemical stability compared to that of TiO_2. The low performance of ZnO based dye sensitized solar cells with the most common ruthenium-based dyes having wide absorption of light in region of visible spectrum has been ascribed to partial dissolution of the ZnO surface and formation of dye aggregates, resulting less stability of the device [40].

A good prospective way is to use two different metal free low cost dyes having absorption in the short and long wavelength region of visible spectrum. In this respect, we wish to demonstrate the attempt toward blending of two dyes having different absorption region to get new color toward enhancement in device grade efficiency. Recently, we have reported the synthesis of ZnO films by using simple solution chemistry with assorted morphologies having high surface area [41].

In present article, we promote to use the high surface area ZnO having cactus morphology with metal free organic individuals and blended dye toward development of attractive, colorful and low cost DSSCs. Hence, attempt has been focused toward the development of colorful and low cost device grade DSSCs by using inexpensive and commonly available dyes toward eco-friendly source of green energy. In this concern, different dyes as Eosin-Y (EY), Rose Bengal (RB), Coumarin 343 (C343), Mercurochrome (MC), Methylene Blue (MB) and blended dye (BD) for red, magenta, yellow, orange, blue and orange colors, respectively were used for colorful approach whereas one blend as a typical case to enhance the efficiency. These dyes were chemoadsorbed over ZnO for making colorful DSSCs and devices was characterized for their various photovoltaic parameters.

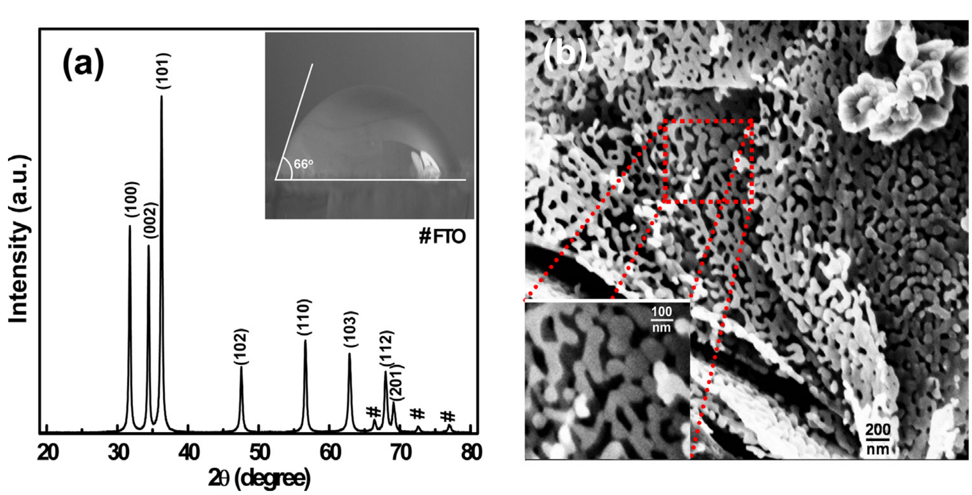

Fig. 1. (a) X-ray diffraction patterns of air annealed ZnO film grown by chemical bath deposition method. Inset shows the contact angle measurement done on ZnO. (b) Scanning electron microscopy (SEM) image from top-view showing petals consisted of interconnected nanoparticles with cactus-morphology. Inset shows magnified image with scale bar of 100 nm.