2D hexagonal yttrium doped SnO$_2$ nanoplatelets for photocatalytic degradation

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Abstract
In this study, simple morphological and structural evolutions of two-dimensional hexagonal nanoplatelets were investigated. XRD analysis of SnO$_2$ and SnO$_2$:Y has revealed a tetragonal structure and photoluminescence spectra exhibited a visible emission broadband peak around 464 nm and 528 nm. The photoluminescence spectra of SnO$_2$:Y (7 wt.%) confirm the increased charge separation, which inhibits electron–hole recombination. Raman spectra validated the presence of oxygen vacancies in SnO$_2$:Y (7 wt.%) nanoplatelets. It has been shown that hexagonal SnO$_2$:Y (7 wt.%) nanoplatelets perform better in photocatalytic degradation than conventional spherical nanoparticles. EIS measurements were performed to investigate the charge carrier movement of SnO$_2$ and SnO$_2$:Y nanoparticles. Our study is the first to illustrate the two-dimensional morphology of SnO$_2$:Y (7 wt.%) hexagonal nanoplatelets and their application as a photocatalytic material.

Keywords SnO$_2$:Y · 2D hexagonal nanoplatelets · Photocatalytic degradation

Introduction
Morphology control is an important strategy for the development of functional nanomaterials such as promising transition metal oxide. Recently several techniques have been offered for waste water toxin elimination. It is critical to avoid ecological destruction by employing photocatalytic treatment to remove organic contaminants from effluent (Ali Baig et al. 2020). Semiconductor photocatalysts have been broadly utilized for environmentally friendly issues like hazardous effluent remedies and energy troubles using plentiful solar light, with low cost, minimal toxicity, recyclable, as well as the capability for enhancing multi-step electron transport movements (Xu et al. 2019).

Recently the efforts have made to develop semiconductor materials having specific size, surface area, morphology, optical, electrical and catalytic features have gained attentiveness in the zones of conservation, biosystems and energy tenders (Jayapandi et al. 2019; Gozde Aydoğdu Tig 2016). Photocatalysts (PCs) based on tin oxide (SnO$_2$) are a simple and cost-effective method for destroying and eliminating the organic contaminants (Vignesh et al. 2019). The yttrium ion is well suited for incorporation into SnO$_2$, since it has a comparable crystalline size as Sn$^{4+}$, resulting in high dispersion and enhanced electron–hole pair separation (Liu et al. 2007). SnO$_2$ morphology control is an important technique for fine-tuning and enhancing the material’s performance in photocatalytic applications. The different SnO$_2$ morphologies, i.e., 0D nanocubes (Khalid et al. 2018), nanopyramid (Kumaravelan et al. 2021), 1D nanotubes (Sadeghzadeh-Attar 2018), nanobelts by thermal evaporation (Li et al. 2016a), 2D nanosheets (Wan et al. 2018) and 2D nanoplatelets (NPLs) (Li et al. 2009; Wang and Xiao 2009). 2D NPLs and nanosheets exhibit novel chemical and physical features, including anisotropically quantum-confined photocarriers, a unified exposed crystal facet, and a specified atomic arrangement on the surface. The applications of reported 2D nanostructure especially for sensing properties
of SnO$_2$ NPLs (Li et al. 2009), porous SnO$_2$ NPLs as Photoelectrodes and Gas Sensors (Zhang et al. 2013) and 2D SnO$_2$ Nanosheets as an excellent sensing performance to Ethylene Glycol (Wan et al. 2018). SnO$_2$ and Fe$_3$O$_4$/SnO$_2$ were synthesized by microemulsion assisted co-precipitation method and its structural, electrical and magnetic properties have been studied (Mahfooz-ur-Rehman Waseem et al. 2021). Yttrium doped SnO$_2$ thin film (Li et al. 2016a; Lee et al. 2020) and Photodegradation activity of yttrium-doped SnO$_2$ nanoparticles against MB dye and their antibacterial effects (Ali Baig et al. 2020) have been reported.

In this work, we report the first 2D hexagonal NPLs through a simple co-precipitation synthetic route at an ambient temperature. There are several methods for synthesis of NPLs such as hydrothermal (Zhang et al. 2013) and thermal evaporation. Moreover, when irradiated with visible light, the 2D SnO$_2$:Y hexagonal NPLs serve as an efficient photocatalyst. Our work not only demonstrates an efficient method for obtaining high-quality NPLs, but also paves the way for future investigations of morphologically controlled materials with increased performance for a broad range of applications.

**Experimental techniques**

**Materials**

Tin chloride, Centyl trimethyl ammonium bromide (CTAB), Yttrium (III) acetate and ammonia solution supplied by Sigma-Aldrich were used to synthesize SnO$_2$ and SnO$_2$:Y nanoparticles. The chemicals employed for this work were not exposed to any other purification process. Double distilled water and ethanol is utilized as a solvent in the 2:1 for sample synthesis.

**Synthesis of SnO$_2$ and Y doped SnO$_2$**

10 gm of Tin chloride was dissolved in 90 ml of distilled water and ethanol, then allowed for stirring. The aqueous solution of CTAB (0.2 gm) was added for enhancing self-aggregation of nanoparticles. For precipitating ammonia solution was added drop by drop. The attained precipitate was cleaned with distilled water and ethanol to detach the remained impurities. The obtained SnO$_2$ nanoparticles (NPs) were annealed at 500$^\circ$ C at 2 h. The SnO$_2$:Y was synthesized by adding yttrium (III) acetate hydrate to the above stock solution.

**Characterization**

The morphology of the synthesized samples was probed with the Scanning electron microscope (SEM) (CAREL ZEISS, EVO 18). The structural analyses of the prepared samples were examined by XRD with the Bragg angles 10 $\leq 2\theta \leq 80$ through Cu target ($\text{K}\alpha = 1.5406 \text{Å}$). The Raman spectra were studied using an FT-Raman Spectrometer (Bruker RFS 27: Stand-alone). Fourier Transmission Infrared Spectrometer (FTIR-7600 Lambda Intelligent) was used to inspect vibrational studies. The absorption spectrum was investigated through the UV–Vis–NIR spectrophotometer (Lambda 35 model). The photoluminescence spectra were studied by using Spectrophotometer (Shimadzu RF-5301) with an excitation wavelength of 330 nm. Versastat MC- Metex was used to analyze the Electrochemical impedance spectroscopy (EIS) measurements. The fitting and equivalent circuits (CPE) of EIS spectra were generated by ZVIEW software.

**Evaluation of photocatalytic activities**

The photocatalytic activity of the synthesized samples was evaluated for degrading MB dye mixture. 10 mg of SnO$_2$ and SnO$_2$:Y were mixed in 100 mL of MB dye mixture. Visible light radiation was utilized as a light source. The dye mixture was sustained in dark for 30 min for confirming adsorption–desorption steadiness. The pH of the dye solution was 7. By utilizing a spectrophotometer (Perkin spectrophotometer Elmer LAMBDA-35), the apparent absorption intensity of the effluent including the irradiation period was also examined. The degradation efficacy (%) is reckoned by the consequent formulation.

\[
\text{Degradation Efficiency} = \left( \frac{C_0 - C}{C_0} \right) \times 100\% \tag{1}
\]

where $C_0$ and $C$ denote the dye mixture concentrations of the effluent at initial ($t=0$) and at time $t$, respectively.

**Results and discussions**

**Morphological and structural analysis**

The surface morphology of SnO$_2$, and SnO$_2$:Y NPs (3, 5 and 7 wt.%) are analyzed by SEM as shown in Fig. 1. Undoped SnO$_2$ reveals the spherical NPs and agglomerations of spherical NPs are augmented with increasing the dopant content (3 and 0.5 wt.%) shown in Fig. 1b, c. SnO$_2$:Y (7 wt.%) exhibits 2D platelet shape (Fig. 1d) and their surface is relatively soft, with no secondary nanostructures present. The doping content of Y affects the host SnO$_2$ and the obtained nanoplatelets are in the nanoscale region.

On the other hand, as a result of the high surface energy, the initial crystal grains combine in an orderly fashion to form layered SnO$_2$ by directed attachment growth. To limit the overall surface area, it may be argued that an emphasis should be placed on orderly attachment development in
the same horizontal plane (Wan et al. 2018). The SnO$_2$:Y (7 wt.%) nanoplatelets are reinforced by the addition of ligands that inhibit growth in other directions. Here, nanoplatelets are formed initially as a few seeds that grow longer the continued slow addition of precursors. At 500 °C, the production of two-dimensional SnO$_2$ nanoplatelets may be attributed to the template effect of their precursor (Wang and Xiao 2009).

The effective growth of SnO$_2$ and SnO$_2$:Y NPs is validated over EDAX spectrum and which is demonstrated in Fig. 2a–d. This confirms the NPs mostly comprise of Sn, O, and Y and also the nonexistence of any impurities. A described elemental composition and weight % are presented the inset of Fig. 2. The amount of Y$^{3+}$ ion showed on EDAX spectrum, which is reliable with the amount included in the synthesis step.

The XRD pattern of SnO$_2$ and SnO$_2$:Y NPs are displayed in Fig. 3. It exhibits a distinct diffraction peak, and which is indexed as the rutile tetragonal structure of SnO$_2$ with JCPDS card no. 88–0287. The positions of the diffraction peaks ($2\theta = 26.6^\circ$, 33.9$^\circ$, 37.9$^\circ$, 51.8$^\circ$, 54.9$^\circ$, 57.7$^\circ$, 61.9$^\circ$, and 64.9$^\circ$) matched with the crystal plane ((110), (101), (200), (211), (220), (310), (112), and (301), respectively) (Li et al. 2016b). The absence of impurities indicates that yttrium element doping had no effect on the crystal structures. By compared with XRD of pure SnO$_2$, the diffraction peaks of SnO$_2$:Y lattice planes slightly shift to the low-angle (shown by dash vertical line) due to the replacement of Y$^{3+}$ ions (radius 89 pm) with Sn$^{4+}$ (radius 69 pm) and which validates that the Y$^{3+}$ ions have been doped into the SnO$_2$ lattices. The crystallite size is determined by Scherrer’s equation, and it is found to be 17 nm for SnO$_2$, and 18.2, 20, and 22 nm for 3, 5, and 7 wt.% Y doped SnO$_2$ NPs.

**Vibrational analysis**

FTIR is an effective device for identifying the functional groups and the kinds of chemical bonds. Figure 4 shows the FTIR spectra of SnO$_2$, and SnO$_2$:Y NPs. The absorption band at 3437–3434 cm$^{-1}$ and 1637–1627 cm$^{-1}$ for SnO$_2$, and SnO$_2$:Y NPs is known as stretching and bending mode of OH groups related to the adsorbed/re-adsorbed water over the SnO$_2$ surface. The peak observed at 2941–2935 and 2853 cm$^{-1}$ indicates the antisymmetric (d$^-$) and symmetric (d$^+$) CH$_2$ stretches of hydrocarbon chains of the CTAB (Campbell et al. 2004). The band
detected at 1395–1383 cm\(^{-1}\) was due to the C-H deformation vibration. The FTIR spectra bands at 1106–1044 cm\(^{-1}\) are ascribed to C–O–C vibration mode. The strong apex observed at 558–539 cm\(^{-1}\) and 635–620 cm\(^{-1}\) accord to the metal–oxygen for antisymmetric and symmetric vibration of O–Sn–O and Sn–O lattice stretching wave modes (Ali Baig...
et al. 2020; Mahfooz-ur-Rehman Waseem et al. 2021). When dopant concentration is increased the peak observed at 558 and 635 cm\(^{-1}\) for undoped SnO\(_2\) is shifted to 539 cm\(^{-1}\) and 620 cm\(^{-1}\), respectively, for SnO\(_2\):Y. It validates incorporation of dopant ion into the SnO\(_2\). In addition, the absorption processes were not noticed further, confirming the coherent dispersion of dopant ions and indicating the precision of the synthesized samples. Furthermore, the shifts to lower wavenumber for Y doped SnO\(_2\) may be interpreted via the dissimilarity in the bond length or strength of Sn\(^{4+}\) and O\(^{2-}\) bond (Phukan et al. 2017). The strong bands associated with OH groups in the synthesized samples designate the SnO\(_2\), and SnO\(_2\):Y NPs may accomplish higher photocatalytic activity and it inhibits the recombining of electron–hole pairs (Suganthi and Pushpanathan 2019).

**Raman studies**

Raman spectroscopy gives the details about the structural composition and defects of the doped samples. Figure 5 shows the Raman spectra of SnO\(_2\) and SnO\(_2\):Y (7 wt.\%) samples at 200–4000 cm\(^{-1}\), and their inset figure represents the 200–800 cm\(^{-1}\) wavenumber range. Bulk crystalline SnO\(_2\) with a tetragonal rutile structure (P4\(_2\)/mm space group) demonstrates four Raman active peaks caused by zone center vibrations such as \(A_{1g}\) (634 cm\(^{-1}\)), \(B_{2g}\) (773 cm\(^{-1}\)), and \(E_g\) (473 cm\(^{-1}\)) (Karmaoui et al. 2018). The peaks observed at 627–633, 467, and 477 and 800–810 cm\(^{-1}\) can be allocated to \(A_{1g}\) (symmetric Sn–O stretching), \(B_{2g}\) (asymmetric Sn–O stretching), and \(E_g\) (translational) modes of typical rutile-type for SnO\(_2\) and SnO\(_2\):Y (7 wt.% ) samples (Reddy et al. 2016; Sohn et al. 2005). For highly crystalline materials, the spectra are governed by the strong \(A_{1g}\) mode that becomes broadened and shift to a lower wavenumber (627–633 cm\(^{-1}\)).

The \(B_{2g}\) and \(E_g\) peaks consistent with the vibrational excitations in the density of states function \(g(\omega)\) (Karmaoui et al. 2018). The \(E_g\) (467–477 cm\(^{-1}\)) mode attributed to the vibration of oxygen in the oxygen plane (Srinivas et al. 2005) for prepared sample while the other modes \(A_{1g}\) (633 cm\(^{-1}\)) and \(B_{2g}\) (776 cm\(^{-1}\)) due to the expansion and contraction of the vibrating mode of Sn–O bonds. In addition, a weak peak originated by a typical IR-active \(A_{2u}\) LO mode could be detected as a surface mode appear at 560 cm\(^{-1}\) (Reddy et al. 2016). The high intense Raman peak slightly shifted toward the higher wavenumber side and are 477, 633, and 810 cm\(^{-1}\) for SnO\(_2\):Y (7 wt.% ) nanoplatelets. Owing to the misalliance of ionic radius of Y and Sn, the inclusion of Y distorts the lattice structure of SnO\(_2\) by inserting into interstitial site. Entering of Y\(^{3+}\) into the SnO\(_2\) matrix creates oxygen vacancies. The creation of these oxygen vacancies shifted the Raman peak to the higher wavenumber side (Dhanalakshmi et al. 2017). The widening and shifting of Raman active modes are attributable to the existence of oxygen vacancies (lattice defects) and which is arisen through the shift of oxide ions on its normal lattice (Dhanalakshmi et al. 2017).

**Optical studies**

Figure 6a shows the UV-DRS spectra of SnO\(_2\), and SnO\(_2\):Y NPs. Undoped SnO\(_2\) exhibits a strong peak at ~289 nm, while SnO\(_2\):Y (3 wt.\%, 5 wt.\%, and 7 wt.\%) reveals the absorption peak at ~292, 295, and 305 nm, respectively. As compared to the Undoped SnO\(_2\) the absorption edges of SnO\(_2\):Y is red shifted increasingly. Whereas the dopants and defects are existed, further extrinsic electronic points may well reside in the Energy gap \(E_g\) of the SnO\(_2\). Furthermore, the optical property is enriched henceforth the Y doped SnO\(_2\) comprises into the visible light region because of the incorporation of Y dopants into SnO\(_2\) lattice. Additionally, the red shifted optical absorption superiority of Y doped SnO\(_2\) to the lesser energy level.

The absorption is proportional to reflectance, then the absorption coefficient (\(\alpha\)) is replaced by \(F(R)\). The band gap is calculated by Tau’s plot. The obtained band gap is 3.77, 3.67, 3.58, and 3.46 eV for 0%, 3 wt.%, 5 wt.%, and 7 wt.% doped SnO\(_2\) correspondingly as shown in Fig. 6b and it is found that the \(E_g\) of the SnO\(_2\):Y sample decreases. The \(E_g\) of SnO\(_2\) NPs is found to be higher than the bulk SnO\(_2\) (3.6 eV) due to the quantum confinement and their absorption edges showed a red shift with an increase in the dopant concentration because of following causes; SnO\(_2\) is a degenerate semiconductor, and its Fermi level remains within the conduction band (CB). Since \(E_g\) is correlated to the excitation of the electrons from the valance band (VB) to Fermi level (Babar et al. 2011). It suggests that the Fermi level moving toward the lowest of CB of the semiconductor owing to the reduction in the carrier concentration precedes narrowing the \(E_g\).
through the replacement by $Y^{3+}$ ions on several $Sn^{4+}$ ions in the lattice. Moreover, the decrease in energy $E_g$ may be due to the spin-exchange interactions. The shift of $E_g$ by Y ion doping may be ascribed to the Moss-Burstein (MB) effect.

Typically, the photoluminescence (PL) emission spectra are utilized for investigating electron–hole evolutions over semiconductor surfaces and therefore resolve the surface defect in the samples. The PL emission spectra of $SnO_2$ and $SnO_2:Y$ NPs are revealed in Fig. 6c under an excitation wavelength of ~320 nm. The blue and green emission peak is observed at 464 nm and 528 nm in all synthesized samples. The blue emission peak exhibits the shallower trapped states within energy gap, enormous oxygen vacancies and surface defects in the prepared samples (Kumar et al. 2019). At 433 nm, the band is ascribed to defect centers inside the energy gap and in-plane oxygen vacancies (Luo et al. 2006). The higher oxygen vacancies are the most prevalent defect in nanocrystalline metallic oxides that serve as luminous centers. $SnO_2$ emits light at 540 nm, which is caused by structural defects such as Sn interstitials (Shajira et al. 2014).

The PL spectra of Y doping results suggest that the decrease in the $E_g$ of $SnO_2$ and endorse photo-response ability, creating numerous active positions inside the $SnO_2$ among VB and CB by $Y^{3+}$ ion exchange. This shows that the larger separation of the photoexcited electron–hole recombination has weak peak intensity, which grades in the realization of reactive surface interiors instigated via additional $Y^{3+}$ for enhancing photodegradation efficiency.

**Impedance measurement**

Figures 7 and 8 show the Nyquist plot of $SnO_2$ and $SnO_2:Y$ NPs and their equivalent circuit is shown in Fig. 7. A semicircle and a straight line are shown in these figures (low-frequency region). The radius of the arc denotes the higher frequency zone, and the value of the charge transfer resistance corresponds to this region ($R_{ct}$). The semicircle radius of the Nyquist cross-section is proportional to the interface charge migration, which is dependent on the prepared sample’s charge separation efficiency. The 7 wt.%
Y doped SnO$_2$ exhibits a smaller semicircle in the higher frequency zone, indicating that the doped electrode has a reduced charge transfer resistance (Suthakaran et al. 2020). The charge transfer resistance (Rct) of SnO$_2$, SnO$_2$:Y (3 wt.%), SnO$_2$:Y (5 wt.%), and SnO$_2$:Y (7 wt.%) nanoparticles is 46816, 37156, 29177, and 12146 Ohm, respectively. These values are lower than those previously reported for La doped SnO$_2$ (Jayapandi et al. 2017). In comparison with SnO$_2$, the arc radius of SnO$_2$:Y (7 wt.%) nanoplatelets is lowest, which results in a smallest charge transfer resistance. Because the presence of yttrium in SnO$_2$ enhances charge carrier movement.
Photocatalytic degradation

The SnO$_2$ and SnO$_2$:Y NPs were utilized as photocatalysts for degradation of MB dye under visible light source. Figure 9a–d shows the absorption spectrum of an aqueous MB dye solution in the presence of photocatalysts. As seen in Fig. 9, it shows the characteristic absorption peak intensity of MB (664 nm) that is effectively lowered with illumination duration due to the degradation process. For SnO$_2$:Y (7 wt.%) hexagonal NPLs, the distinctive MB absorption peak was reduced after 120 min of irradiation. This indicates that hexagonal SnO$_2$:Y (7 wt.%) NPLs have higher photocatalytic activity than other samples. Additionally, when Y$^{3+}$ is added to SnO$_2$, the degradation efficiency is increased further in comparison with the dye molecules evaluated. The presence of a large number of Y$^{3+}$ ions inside the structure creates an oxygen vacancy, which prevents electron and hole recombination, hence increasing photocatalytic efficiency.

Photocatalytic mechanism

Electrons in the valence band (VB) are stimulated into the conduction band (CB) when they absorb enough photon energy to generate holes. In CB, electrons produced during photosynthesis may interact with neighboring O$_2$ to generate a superoxide anion (O$_2^-$). Similarly, the holes react with hydrogen molecules in H$_2$O to form hydroxyl radicals (OH$^-$). O$_2^-$ and OH$^-$ participate in the decomposition of dye molecules. These O$_2$ and OH$^-$ can efficiently react with dye molecules and create carbon dioxide and water (Yakout 2021). However, the wide bandgap of SnO$_2$ and easy recombination of charge carriers determines the photocatalytic efficiency of SnO$_2$. Therefore, SnO$_2$ shows a relatively low efficiency. Scheme 1 displays the Photocatalytic mechanisms of prepared SnO$_2$:Y NPLs. Yttrium doped SnO$_2$ photocatalyst alters the rapidity of photodegradation and systematic path of waste products. The improvement in photocatalytic activity was primarily due to the creation of oxygen vacancies and the improvement in effective electron mobility. When the Sn$^{4+}$ ions are replaced with Y$^{3+}$, an oxygen vacancy will

![Fig. 9 Absorbance spectra of MB dye in the presence of a undoped, b 3 wt.%, c 5 wt.% and d 7 wt.% Y doped SnO$_2$ nanoparticles](image-url)
occur in SnO₂. Oxygen vacancy on surfaces can increase O₂ adsorption and function as a center for capturing photoinduced electrons through photocatalytic reaction activities. Oxygen vacancies delay the recombination of electron–hole pairs and also enhanced photocatalytic processes (Sadeghza-deh-Attar 2018).

Furthermore, nanoplatelet 2D structure with lower bandgap energy of SnO₂:Y (7 wt.%) has higher photocatalytic degradation compared with spherical morphology. Since 2D SnO₂:Y (7 wt.%) NPLs possess a high percentage of surface atoms, superior free-charge mobilities, and a short distance to surface catalytic sites. It shows that the 2D morphology can greatly promote their performances in photocatalytic reactions (Voiry et al. 2018; Su et al. 2018). Such a drastically improved photocatalytic performance of SnO₂:Y (7 wt.%) NPLs was likely due to the anisotropically confined charge carries and their in-plane long diffusion length for the NPLs as compared to undoped and Y doped SnO₂ spherical NPs. The surface morphology and bandgap have a significant effect on the photocatalytic efficiency of SnO₂:Y (7 wt.%) semiconductors.

The rate of degradation of the dye solution is calculated based on pseudo-first-order kinetics and tested using the Langmuir–Hinshelwood model and given by the relation \( k = \ln \left( \frac{C_0}{C} \right) / t \) where \( C_0 \) and \( C \) represent the concentration of the dye solution at initial \( (t_0) \) and time \( t \) and \( k \) times are the so-called first-order velocity constant (Suganthi and Pushpanathan 2019). The relationship between the natural logarithm of \( C_0/C \) and irradiation time \( (t) \) for SnO₂ and SnO₂:Y is shown in Fig. 10a, b. The evaluated degradation efficiency (%) of SnO₂, the rate constant \( (k) \) and regression coefficient \( (R^2) \) are presented in Table 1. The high \( R^2 \) value obtained, indicates that the prepared catalyst has good first-stage pseudo-model kinetics. The correlation value is almost 1 showing the best adsorption rate (Adeyemi et al. 2019). These outcomes validated that SnO₂:Y (7 wt.%) was successfully synthesized by Y as a dopant which has a better photocatalytic performance than other samples. Various reported photocatalytic activity of doped SnO₂ photocatalysts are listed in Table 2.
Conclusion

The enhanced photocatalytic activity of SnO$_2$:Y (7 wt.%) hexagonal nanoplatelets are attributed to increased optical absorption, effective charge separation of photogenerated charge carriers, and reduced electron–hole recombination. The change in weight percentage of Y in SnO$_2$ matrix brings out a change in crystallite size along with the bandgap. The change in the Raman intensity along with the peak shift in SnO$_2$:Y (7 wt.%) confirms the generation of oxygen vacancies. 7 wt.% doped SnO$_2$ decreased the bandgap and the replacement of Y$^{3+}$ with Sn$^{4+}$ ions enhance the oxygen vacancies on the surfaces which can increase O$_2$ adsorption and function as a center for capturing photo-induced electrons through photocatalytic reaction activities. The presence of defects and mechanism of charge carrier recombination is confirmed by photoluminescence spectra. Moreover, the electrochemical performance of the SnO$_2$:Y (7 wt.%) NPLs validates the higher charge separation efficiency. Our demonstrated simple co-precipitation methodology for the synthesis of SnO$_2$:Y (7 wt.%) 2D hexagonal nanoplatelets have environmental applications for the degradation of MB dye solution.

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Declaration

Conflict of interest

On behalf of all authors, the corresponding author states that there is no conflict of interest.

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