**Abstract**

Constructing heterojunction is an effective strategy to enhance photocatalytic performance of photocatalysts. Herein, we fabricated ZnTiO$_3$/Bi$_4$NbO$_8$Cl heterojunction with improved performance via a typical mechanical mixing method. The rhodamine (RhB) degradation rate over heterojunction is higher than that of individual ZnTiO$_3$ or Bi$_4$NbO$_8$Cl under Xenon-arc lamp irradiation. Combining ZnTiO$_3$ with Bi$_4$NbO$_8$Cl can inhibit the recombination of photo-excited carriers. The improved quantum efficiency was demonstrated by transient-photocurrent responses (PC), electrochemical impedance spectroscopy (EIS), photoluminescence (PL) spectra, and time-resolved PL (TRPL) spectra. This research may be valuable for photocatalysts in the industrial application.

**Keywords:** ZnTiO$_3$/Bi$_4$NbO$_8$Cl, Heterojunction, Photocatalysts, Photodegradation

**Introduction**

Photocatalysis has been attracting great interests in recent years, which already been applied in the fields of solar cells, water splitting, and water purification [1–4]. It has been reported that oxide based semiconductors are active photocatalysts [5], typified by TiO$_2$ [6, 7], ZnO [8], and so on. However, individual pristine ZnO or TiO$_2$ does not show gratifying photocatalytic performance. Specially, ZnTiO$_3$ shows better performance in perovskite-type oxides. ZnTiO$_3$ has been utilized in the fields of gas sensor and photocatalysis, etc. [9, 10]. However, the wide band gap of ZnTiO$_3$ (3.1 ~ 3.65 eV) [9–13] limits its utilization of solar energy. On the other hand, the high recombination rate of photo-generated charges is another limitation factor. It is necessary to take measures to enhance its photocatalytic performance. One feasible and convenient route is that coupling ZnTiO$_3$ with a type of narrow band gap semiconductor to form a heterojunction structure [14]. The narrow band gap semiconductor could behave as sensitizer to increase the light-harvesting ability and photocatalytic performance.

Bi$_4$NbO$_8$Cl, a promising candidate for increasing light-harvesting with several merits including narrow band gap (~ 2.38 eV), layered structure, appropriate potential of energy band [15–17], appears in the sight of researchers. Due to its low band gap energy and layered structure, this material could absorb light with a wavelength under 520 nm and benefit to charge transfer [18]. Some heterojunctions based on Bi$_4$NbO$_8$Cl have been prepared, such as Bi$_2$S$_3$/Bi$_4$NbO$_8$Cl [17] and g-C$_3$N$_4$/Bi$_4$NbO$_8$Cl [19]. Therefore, constructing ZnTiO$_3$/Bi$_4$NbO$_8$Cl heterojunction may be a useful measure to enhance photocatalytic performance.

In this study, we fabricate a series of ZnTiO$_3$/Bi$_4$NbO$_8$Cl heterojunction and evaluate the photocatalytic performance by RhB degradation under Xenon-arc lamp irradiation. Our results indicate that performance of the heterojunction is better than that of individual component. The formation of heterojunction could slow down the combination of electrons and holes, which leads to the enhanced degradation activity for RhB. The possible photocatalytic mechanism is discussed in details.

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Experimental
Materials
Bismuth oxide (Bi$_2$O$_3$), ethanol (C$_2$H$_5$OH), tetrabutyl titanate (C$_{16}$H$_{36}$O$_7$Ti), acetic acid (CH$_3$COOH), and zinc nitrate (Zn(NO$_3$)$_2$•6H$_2$O) were obtained from Sinopharm Chemical Reagent Co., Ltd; bismuth oxychloride (BiOCl) and niobium pentoxide (Nb$_2$O$_5$) were obtained from Energy Chemical (Shanghai, China). All of the reagents used in this work are analytical grade and without further purification.

Preparation of Bi$_4$NbO$_8$Cl
Bi$_4$NbO$_8$Cl was synthesized by ball mill mixing and solid state reaction methods. The mixing of materials was carried out in a planetary ball miller (Grinoer-BM4, China), equipped with corundum milling jar and corundum balls. Bi$_2$O$_3$ (18 g), BiOCl (12 g), and Nb$_2$O$_5$ (6 g) were weighted and mixed using ethanol (30 mL) as a dispersion solution in a milling jar, and fifty balls (10 mm diameters) were added and then ball milled for 2 h at 300 °C. After grinding, the mixed reagents were dried at 60 °C for 12 h and calcined at 600 °C (heating rate of 5 °C/min) in air for 10 h. Finally, the yellow powders of Bi$_4$NbO$_8$Cl were obtained.

Preparation of ZnTiO$_3$
The sol-gel procedure was used to prepare ZnTiO$_3$ powder. In a typical synthesis, 34 mL of tetrabutyl titanate (0.1 mol) was dissolved in 35 mL of ethanol to form a solution A. Five milliliters of deionized water, 15 mL of acetic acid (CH$_3$COOH), and a certain amount of Zn(NO$_3$)$_2$•6H$_2$O were successively dissolved in 35 mL of ethanol to form a solution B. Then, the solution B was added dropwise to the solution A under magnetic stirring. A transparent sol was obtained after the addition of stirring for 30 min which formed a gel over a rest period of 24 h. The gel was dried at 105 °C for 12 h, and then the resulting product was calcined at 600 °C for 3 h at the heating rate of 2 °C/min to obtain the final ZnTiO$_3$ powders.

Preparation of ZnTiO$_3$/Bi$_4$NbO$_8$Cl heterojunction
In a typical experiment, 400 mg Bi$_4$NbO$_8$Cl and a certain amount of ZnTiO$_3$ (mass ratio of ZnTiO$_3$:Bi$_4$NbO$_8$Cl = 10%, 20%, 30%) were mixed and ground for 10 min, and then they were dispersed in 10 mL of ethanol, and followed by ultrasonic for 30 min. The resulting mixtures were dried at 60 °C for 12 h, and then calcined at 300 °C for 2 h. The as-fabricated samples were denoted as 10% BNZ, 20% BNZ, and 30% BNZ.

Characterization
X-ray powder diffraction (XRD) measurements were recorded with a D-max 2500 XRD spectrometer (Rigaku), and the scan ranges were 10–80° with 10°/min. The morphologies of the as prepared samples were characterized by the scanning electron microscopy (SEM, JSM-6700F, JEOL, Japan) and transmission electron microscopy (TEM, JEM-2100, JEOL, Japan). The energy dispersive spectroscopy and elemental mapping analysis were obtained with the X-ray spectrometer equipped on the scanning electron microscope. UV-vis diffuse reflectance spectra (UV-vis DRS) were obtained using an Agilent Technologies Cary 5000 spectrophotometer with an integrating sphere in which BaSO$_4$ powder was used as a reference. Photoluminescence (PL) and time-resolved transient PL decay spectra were recorded on Hitachi FL-4600 and Edinburgh FLS1000 fluorescence spectrophotometer with an excitation wavelength of 365 nm, respectively.

Photocatalytic experimental
The RhB photodegradation was examined as a model reaction to evaluate the photocatalytic performance of the samples. Fifty milligrams of photocatalyst was dispersed in 50 mL RhB solution (5 mg/L) into the quartz photo-reactor vessel. A 500 W Xenon-arc lamp that placed 15 cm away from the reactor was served as the light source. Initially, the mixture was kept in the dark for 30 min under the magnetic stirring to reach the adsorption-desorption equilibrium. Later, aliquots of suspension (4 mL) was sampled and centrifuged at the given intervals time of 30 min. The concentration of dye was analyzed by an Agilent Technologies Cary 5000 spectrophotometer.

For comparison, a certain amount of Bi$_4$NbO$_8$Cl and ZnTiO$_3$ (mass ratio of ZnTiO$_3$:Bi$_4$NbO$_8$Cl = 20%) were added directly into a quartz photo-reactor vessel to do photocatalytic activity evaluation experiment. The result of this sample was named as 20% BNZ-C (“C” means comparison).

The process of capture agent experiment is the same as that of photocatalytic activity evaluation just added respectively 40 µL isopropanol (IPA) as a hydroxyl radical scavenger, 0.005 g p-benzoquinone (BQ) as a superoxide radical scavenger, 0.0158 g ethylenediaminetetraacetic acid disodium salt (EDTA-2Na) as a hole trapping agent, and 0.078 g potassium bromate (KBrO$_3$) as an electron trapping agent.

Electrochemical measurements
The photoelectrochemical properties were measured on a CHI760E electrochemical system (Shanghai Chenhua, China) in a standard three electrode with the catalyst-deposited FTO glass, Pt plate, and Ag/AgCl electrode as the photoanode, counter electrode, and reference electrode, respectively. Meanwhile, 0.5 M Na$_2$SO$_4$ was used as the electrolyte solution. Transient photocurrent
measurements were carried out using a 500 W Xe lamp as a light source. The Mott-Schottky measurement was performed at frequency of 1000 Hz. The working photoanodes were prepared as follows: 30-mg sample, 300 μL mixture solution of chitosan (1% wt%), and acetic acid (1% wt%) were mixed by stirring for 20 min to make a suspension. Then, the mixture above was added dropwise onto an FTO glass (3 × 1 cm) and dried at 40 °C.

Results and discussion

The crystal structure of the samples could be detected from XRD results [20], as shown in Fig. 1a. The characteristic diffraction peaks at 23.7°, 26.0°, 29.6°, 32.6°, 46.7°, and 56.3° could be indexed to the (112), (114), (116), (020), (220), and (316) planes of the bare Bi₄NbO₈Cl (JCPDS card 84-0843). The crystal planes (220), (311), (400), (422), (511), and (440) have a good correspondence with the cubic perovskite ZnTiO₃ structure (space group R-3 with cell constant a = b = c = 0.841 nm, JCPDS card 39-0190). The XRD patterns of BNZ samples are similar to that of the Bi₄NbO₈Cl, and the intensity of the reflection diffraction peak at 35.4° for ZnTiO₃ increased with the addition of ZnTiO₃ content. Moreover, the signals associated with Zn, Ti, Bi, Nb, O, and Cl are observed from the EDX mapping images (Fig. 1d) of ZnTiO₃/Bi₄NbO₈Cl heterojunction.

The morphology of ZnTiO₃, Bi₄NbO₈Cl, and BNZ samples are investigated by SEM. Figure 1b shows that ZnTiO₃ sample is micron-scale irregular blocks structure. Pristine Bi₄NbO₈Cl products are composed with irregular ellipsoid particles in which shows stacked structure due to the particles clump together, seen from Fig. 1c. As for 20% BNZ compound (Fig. 1d), it can be found that ZnTiO₃ are crushed and attached on the surface of the Bi₄NbO₈Cl after grinding, ultrasonic mixing, and calcination treatment.

Figure 2 displays the TEM and HRTEM images of the 20% BNZ sample, and the fast Fourier transform (FFT) pattern and inverse FFT (IFFT) image of corresponding select areas. It can be clearly observed that there is a close interface contact between the ZnTiO₃ blocks and Bi₄NbO₈Cl blocks (Fig. 2a). Marked with red wireframe in Fig. 2b, the measured lattice fringe of 0.375 nm is corresponded to Bi₄NbO₈Cl (112) crystal plane, and its corresponding FFT and IFFT is displayed in Fig. 2c. As shown in Fig. 2b, the measured lattice fringes of 0.301 nm and 0.293 nm are matched well with Bi₄NbO₈Cl (116) crystal plane (green areas) and ZnTiO₃ (311) crystal plane (orange areas), and their FFT and IFFT images are shown in Fig. 2d and Fig. 2e, respectively. The HRTEM analysis suggests that Bi₄NbO₈Cl and ZnTiO₃ are well combined.

The photocatalytic performance of pristine Bi₄NbO₈Cl, ZnTiO₃, and BNZ heterojunctions were evaluated by the degradation of RhB dye aqueous solution under Xenon-arc lamp irradiation. As shown in Fig. 3a, the adsorption...
rate of RhB for all samples are 0–11% in dark. After exposure to light for 5 h, the degradation rate over the bare Bi$_4$NbO$_8$Cl and ZnTiO$_3$ are 89% and 61%, respectively. Moreover, the BNZ composites display improved photocatalytic activity, and the dye removal efficiency is increased with the increase of ZnTiO$_3$ contents at first, and then the photodegradation performance has a slight decrease when the ZnTiO$_3$ content increased from 20 wt% to 30 wt%. The 20% BNZ composite displays the highest photocatalytic activity with a degradation rate of almost 100%. As for the 20% BNZ-C, the RhB removal rate over it is 81% after 5 h reaction. Twenty percent BNZ showed higher photocatalytic performance due to efficient separation of carriers after heterojunction formation.

The recyclability of the photocatalysts is also an important aspect in their practical application. The cyclic experiments of removing RhB dye were carried out under the same conditions to investigate the recyclability of 20% BNZ samples, as shown in Fig. 3b. After four repeated experiments, the photocatalytic activity just presents a slight decrease, indicating that the 20% BNZ is a stable photocatalyst for the degradation of RhB. Figure 3c shows the changes in UV-vis absorption spectra of RhB by 20% BNZ, with the irradiation time increased, the intensity of characteristic peak is decreased. In addition, the position of absorption peak shifted from 554 to 499 nm during photocatalytic reaction. This blue shift of absorption maximum is caused by the N-deethylation of RhB [21–23].

To clarify the main active species responsible for RhB degradation by 20% BNZ composite, the trapping experiments were carried out. The ethylenediaminetetraacetic acid disodium salt (EDTA-2Na), potassium bromate (KBrO$_3$), benzoquinone (BQ), and isopropanol (IPA) act as the scavengers of hole (h$^+$), electron (e$^-$), superoxide radical (•O$_2^-$), and hydroxyl radical (•OH), respectively. As shown in Fig. 3d, the photodegradation rate is affected seriously and decreased by the addition EDTA into the photocatalytic reaction system, and the photocatalytic activity is inhibited slightly when BQ or IPA is added. Hence, the h$^+$ was the main dominant reactive species, and the •O$_2^-$ or •OH participated in the degradation process of RhB in 20% BNZ system.

As shown in Fig. 4a, transient-photocurrent responses of as-prepared photocatalysts were measured under the light irradiation with intermittent on-off cycles to evaluate the production and migration of photogenerated carriers. The higher intensity of photocurrent, the stronger generating ability of photogenerated carriers [24, 25]. The photocurrent density is higher in the light than that in the dark, and displays a typical on-off cycle mode. The photocurrent response intensities obey the follow order: 20% BNZ > 30% BNZ > 10% BNZ > Bi$_4$NbO$_8$Cl > ZnTiO$_3$. It means that the photogenerated carriers’ production ability of 20% BNZ is the best. The obviously enhanced photocurrent density of 20% BNZ sample could be attributed to the intimated contact in the heterojunction, which benefits to the charge generation, separation, and transfer. Moreover, the electrochemical impedance spectroscopy (EIS) was employed to study the ability of the interfacial charge transfer of catalysts. The smaller arc radius of EIS Nyquist plots becomes, the
smaller charge transfer resistance is [26]. From the results (Fig. 4b), it can be observed that the 20% BNZ exhibited the smallest semi-circular arc, which indicated that 20% BNZ possesses smaller transfer resistance, and the charge carriers process is very fast in comparison with others as-prepared samples. In order to investigate the recombination behaviors of photogenerated carriers, the PL spectra (Fig. 4c) with the excited wavelength of 365 nm at room temperature were obtained [27]. Compared to bare Bi$_4$NbO$_8$Cl, the PL intensity of the as-prepared 20% BNZ is weaker, indicating a lower recombination rate of photogenerated carriers. These results imply that the introduction of ZnTiO$_3$ could effectively inhibit the recombination of photo-generated electrons (e$^-$) and holes (h$^+$). As shown in Fig. 4d, time-resolved PL spectra could provide the information about lifetime of photo-excited carriers. The time-resolved PL decay curves of samples were fitted by Eq. (1):

$$I(t) = A_1e^{\frac{-t}{\tau_1}} + A_2e^{\frac{-t}{\tau_2}}$$  

(1)

Where $\tau_1$ and $\tau_2$ are the fast decay constant (shorter lifetime) and slower decay constant (long lifetime), respectively. $A_1$ and $A_2$ are the corresponding amplitudes. The average lifetime was calculated through Eq. (2) [17]:

$$\tau = \frac{A_1\tau_1^2 + A_2\tau_2^2}{A_1\tau_1 + A_2\tau_2}$$  

(2)

The average lifetime of 20% BNZ is shorter than that of Bi$_4$NbO$_8$Cl ($\tau_{BNB} = 3.66$ ns and $\tau_{20\%BNZ} = 2.72$ ns). The $\tau$ value is decreased from 3.66 to 2.72 after modifying ZnTiO$_3$, indicating the formation of heterojunction could improve the transfer efficiency of carriers and promote the separation of photogenerated electrons and holes [28–30].

Diffuse reflectance spectra (DRS) of Bi$_4$NbO$_8$Cl, ZnTiO$_3$, and 20% BNZ were measured in the range of 300–800 nm to study their optical property. As shown in Fig. 5a, it can be found that the absorption edge of ZnTiO$_3$ is 375 nm, and Bi$_4$NbO$_8$Cl has an intense absorption band with a steep absorption edge at about 505 nm. In addition, the absorption edge 20% BNZ is about 510 nm. Besides, the band gap energy ($E_g$) of the semiconductors can be calculated by Tauc’s equation, 

$$(\alpha hv)^n = A(hv - E_g)$$

where $E_g$, $A$, $\alpha$, $h$, and $v$ are the band gap, absorption constant, absorption coefficient, Planck’s constant, and light frequency, respectively [31]. In addition, $n$ represents a direct-transition material ($n = 2$) or an indirect-transition material ($n = 1/2$). As we all know, both Bi$_4$NbO$_8$Cl and ZnTiO$_3$ are indirect-transition semiconductor, thus $n$ equals to 4. As shown in Fig. 5b, the band gap values of as-prepared
Bi$_4$NbO$_8$Cl, ZnTiO$_3$, and 20% BNZ samples are 2.33 eV, 3.10 eV, and 2.31 eV, respectively.

Conduction band (CB) potential and valance band (VB) potential are the utmost important factors to understand the heterojunction formation and electron transfer mechanism of nanocomposites. It is known that the bottom of the CB is close to the flat band position; thus, Mott–Schottky tests were carried out to estimate the flat band potential ($E_{fb}$) of samples [32]. Corresponding flat band potential of the electrode were obtained from the M–S plots employing the following Eqs. (3) and (4) [31, 33]:

For an n-type semiconductor

$$\frac{1}{C^2} = \frac{2}{\varepsilon \varepsilon_0 ND} \left( E - E_{fb} - \frac{KT}{e} \right)$$

(3)

For an p-type semiconductor

$$\frac{1}{C^2} = \frac{2}{\varepsilon \varepsilon_0 NA} \left( E - E_{fb} - \frac{KT}{e} \right)$$

(4)

where the $\varepsilon$, $\varepsilon_0$, $e$, $C$, $E$, $E_{fb}$, $K$, $T$, $N_D$, and $N_A$ represent the dielectric constant of materials, permittivity of free space, electron charge, capacitance, energy, flat band potential, Boltzmann constant, temperature, and donor and acceptor concentrations, respectively.

![Fig. 5](image-url) **Fig. 5** a DRS spectra of ZnTiO$_3$, Bi$_4$NbO$_8$Cl, and 20% BNZ sample. b Tacus’s curves of ZnTiO$_3$, Bi$_4$NbO$_8$Cl, and 20% BNZ sample. c Mott–Schottky curves of ZnTiO$_3$ and Bi$_4$NbO$_8$Cl.
space, charge of electron \((1.60 \times 10^{-19} \text{ C})\), capacitance of the space charge region, applied to the potential, flat band potential, Boltzmann constant, absolute temperature, donor, and acceptor density, respectively. As shown in Fig. 5c, all the plots display positive slopes, which confirmed clearly that as-prepared samples act as n-type semiconductor behavior [34, 35]. The flat band potential can be measured from the intersection of linear potential curve up to the X-axis at point \(1/C^2 = 0\), and can convert to normalized hydrogen electrode scale (NHE) according the formula (5) [36]:

\[
E(\text{NHE}) = E(\text{Ag}/\text{AgCl}) + 0.197V
\]  

(5)

According to M-S results, the flat band potential for Bi\(_4\)NbO\(_8\)Cl and ZnTiO\(_3\) is \(-0.60\) eV and \(-0.40\) eV (vs. Ag/AgCl), respectively. Accordingly, \(E_{\text{CB}}\) of Bi\(_4\)NbO\(_8\)Cl and ZnTiO\(_3\) is \(-0.403\) eV and \(-0.203\) eV, respectively. Thus, the \(E_{\text{VB}}\) of Bi\(_4\)NbO\(_8\)Cl is 1.927 eV, and \(E_{\text{VB}}\) of ZnTiO\(_3\) is 2.897 eV.

The specific BET surface areas of the Bi\(_4\)NbO\(_8\)Cl, ZnTiO\(_3\), and 20% BNZ are shown in Table 1. The \(S_{\text{BET}}\) of 20% BNZ is 0.87 m\(^2\)/g more than \(S_{\text{BET}}\) of Bi\(_4\)NbO\(_8\)Cl. It can be seen from Table 1 that the \(S_{\text{BET}}\) of ZnTiO\(_3\) is 5.34 m\(^2\)/g. The increased \(S_{\text{BET}}\) of 20% BNZ is due to the introduction of ZnTiO\(_3\). The ability to use light of ZnTiO\(_3\) is weak owing to its wide band gap. Therefore, the increased \(S_{\text{BET}}\) may not provide many effective active sites. In contrast, ZnTiO\(_3\) may cover the active sites of Bi\(_4\)NbO\(_8\)Cl surface or becomes new recombination centers of electrons and holes. Thus, the increased \(S_{\text{BET}}\) of 20% BNZ may only provide a slight impact for enhanced photocatalytic performance. The improved performance is mainly due to the formation of heterojunction.

To explain the enhanced photocatalytic performance, a possible photocatalytic mechanism is proposed in Scheme 1. Under Xenon-arc lamp irradiation, the electrons (\(e^-\)) are generated in Bi\(_4\)NbO\(_8\)Cl, and they transfer from VB to CB leaving corresponding holes (\(h^+\)) on VB. Meanwhile, the same process takes place in ZnTiO\(_3\). Through a comparison of energy band potential between Bi\(_4\)NbO\(_8\)Cl and ZnTiO\(_3\), \(E_{\text{CB}}\) (Bi\(_4\)NbO\(_8\)Cl) is more negative than \(E_{\text{CB}}\) (ZnTiO\(_3\)), and \(E_{\text{VB}}\) (Bi\(_4\)NbO\(_8\)Cl) is more positive than \(E_{\text{VB}}\) (ZnTiO\(_3\)). Therefore, they can form a type-II heterojunction. Because of the internal electric field, \(e^-\) on CB of Bi\(_4\)NbO\(_8\)Cl is transferred to CB of ZnTiO\(_3\), and \(h^+\) on VB of ZnTiO\(_3\) is transferred to VB of Bi\(_4\)NbO\(_8\)Cl, realizing the separation of photo-excited \(e^-\)-\(h^+\) pairs, which leads to the enhancement of performance. Because 20% BNZ has a high positive potential of VB, so its holes have high oxidative capacity. Therefore, holes on VB can directly oxidize organic pollutants like RhB. However, excessive ratio of ZnTiO\(_3\) in BNZ heterojunction will cover the active sites of Bi\(_4\)NbO\(_8\)Cl surface, decreasing its light-harvesting ability. Moreover, excessive ratio of ZnTiO\(_3\) may become new recombination centers of electrons and holes. Hence, the quantity of ZnTiO\(_3\) has an optimum value in heterojunction.

### Conclusions

In this work, the ZnTiO\(_3\)/Bi\(_4\)NbO\(_8\)Cl heterojunction catalyst was prepared successfully via a typical mechanical mixing method. The heterojunction exhibits enhanced photocatalytic performance in comparison with individual ZnTiO\(_3\) or Bi\(_4\)NbO\(_8\)Cl under Xenon-arc lamp irradiation. Specially, 20% ZnTiO\(_3\)/Bi\(_4\)NbO\(_8\)Cl heterojunction has the best performance. This report may inspire the development of heterojunction structure in catalyst modification and application.

### Abbreviations

BNZ: ZnTiO\(_3\)/Bi\(_4\)NbO\(_8\)Cl; BNZ-C: ZnTiO\(_3\)/Bi\(_4\)NbO\(_8\)Cl-Comparison; \(S_{\text{BET}}\): Specific BET surface areas; PL: Photoluminescence; CB: Conduction band; VB: Valence band

### Acknowledgements

Not applicable

### Authors’ contributions

QX and GZ conceived and designed the experiments and were major contributors in performing the analysis with constructive discussions. GZ performed the experiments, analyzed the data, and wrote the manuscript.

| Catalyst code | BET surface area (\(S_{\text{BET}}\)) (m\(^2\)/g) |
|---------------|-----------------------------------|
| Bi\(_4\)NbO\(_8\)Cl | 1.36 |
| ZnTiO\(_3\) | 5.34 |
| 20% BNZ | 2.23 |

**Table 1** Specific BET surface areas parameters of the Bi\(_4\)NbO\(_8\)Cl, ZnTiO\(_3\), and 20% BNZ samples
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