Supplementary information

Selective and efficient cleavage of C_{α} - C_{β} bond in lignin models and native lignin through S-scheme CeO₂/g-C₃N₄

heterojunction photocatalyst

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SI-1. Materials

Melamine, isopropyl alcohol (IPA), KHCO₃, HNO₃, ethylenediamine tetraacetic acid disodium salt (EDTA-2Na), acetonitrile (CH₃CN) and ethanol were obtained by Xilong chemical Co., Ltd. Ce(NO₃)₃·6H₂O, *p*-benzoquinone, 5,5-Dimethyl-1-pyrroline N-oxide (DMPO), silver nitrate, NaBD₄ and NaBH₄ were purchased from Macklin chemical Co., Ltd. All the chemicals were of analytical grade without further purification.

SI-2. General characterization of catalysts

X-ray diffractometer (XRD, Bruker D8 ADVANCE, Germany). XRD patterns were employed to analyze the crystal phase with Cu-K α radiation ($\lambda = 1.5406$ Å), and collected in the 2θ range of 5-80°.

Fourier transform infrared spectroscopy (FT-IR, Thermo NICOLET is5, USA). FT-IR was analyzed the functional groups with KBr as the reference sample.

Field-emission scanning electron microscopy (FESEM, TESCAN MAIA3 LMH, Czech Republic). The surface morphology of catalysts was observed by SEM, and the element composition was determined by energy dispersive spectroscopy (EDS, IXRF Systems Model 550i, USA).

Field emission transmission electron microscope (TEM, FEI Tecnai G2 F20, USA). Microstructure and lattice spacing was observed by TEM, and high-resolution transmission electron microscope (HETEM) was detected on the same instrument. The lattice spacing was calculated by GMS 3.

300 W Xenon-lamp (CEL-PF300-T8, Beijing Au-light, China). The Xenon-lamp was used in this work with full spectrum.

Gel permeation chromatography (GPC, Shimadzu RID 20A, Japan). GPC was analyzed the molecular weight of extracted lignin by using DMF as solvent.

X-ray photoelectron spectroscopy (XPS, Thermo ESCALAB 250Xi, USA). Chemical composition and states were measured by XPS with a monochromatic Al-K α source and spot size of 900 μ m. All experimental water for the synthesis and analysis was prepared by an ultrapure water machine.

UV-Vis diffuse reflectance spectroscopy (UV-Vis DRS, Persee TU1901, China). UV-Vis DRS spectra were record on the UV-Vis spectrophotometer equipped with an integrating sphere, and BaSO₄ was used as a reference.

Fluorescence spectrophotometer (PL, Hitachi F-4600, Japan). PL spectrum was recorded in the range of 300-600 nm with an excitation wavelength of 290 nm ($\lambda_{ex} = 290$ nm), and scan speed of 1200 nm/min.

Electron spin resonance (ESR, Bruker EMXPlus-10/12). ESR analysis were recorded

in the magnetic field intensity range of 3450-3560. DMPO-R* adduct conditions: 10 mg PTCN, 5 mg PP-ol, 2 mL CH₃CN, 40 μ L DMPO, 44.5 MHz of ¹⁴N a_{ISO}, 63.8 MHz of ¹H_{β} a_{ISO}. DMPO-•O₂⁻ adducts conditions: 10 mg PTCN, 1 mL H₂O, 40 μ L DMPO, 40.0 MHz of ¹⁴N a_{ISO}, 32.7 MHz of ¹H_{β} a_{ISO}, 3.3 MHz of ¹H_{γ} a_{ISO}.

Photoelectrochemical tests (i-t, EIS and M-S). Electrochemical workstation (Chenhua CHI 660E, China) was equipped with a standard three-electrode cell and 300 W Xe lamp. The details of the tests are as follows: the working electrodes were prepared by depositing the photocatalysts on the pre-cleaned indium-tin oxide (ITO) glasses (1 cm \times 4 cm), Pt sheet was used as counter electrode and Ag/AgCl electrode was used as reference electrode, and electrolyte was 0.2 M Na₂SO₄ solution. The photocurrent tests were carried out at an initial potential of 0.5 V with the dark/light conditions at 20 s intervals. Electrochemical impedance spectroscopy (EIS) curves were obtained through setting the frequency of 0.01-10⁵ Hz with the open circuit potential of 0.5 V. The Mott-Schottky curves were recorded at a frequency of 1K Hz and scanning the potential of -1.4 ~ -0.2 V.

SI-3. Extraction of lignin

Pine lignin was firstly extracted according to our previous reported ¹. 5 g of preground birch wood and 50 mL methanol containing 3 mL hydrochloric acid (37%) were added to a 100 mL flask. The mixture was refluxed for 12 h under stirring, and cooled to room temperature. Residue was removed by filtration and washed with adding small portions of methanol. The filtrate was concentrated to <10 mL by rotary evaporation and then poured into 100 mL of ice-cold water with vigorous stirring, obtaining a dark brown solid to precipitate. This lignin was collected by filtration, washed with water and dried overnight under vacuum at 60 °C. For wheat stalk lignin: 4 g wheat stalk power, 2 mmol of 1-(3-sulfobutyl) triethylammonium hydrogen sulfate and 80 mL solvent of the ethanol/water (v/v = 4/1) were added to a 250 mL stainless-steel autoclave (YZPR-250 (M), Yanzheng instrument Co., Ltd., China) equipped with mechanical agitation (300 rpm). After purging air with nitrogen three times and pressurizing to 1.0 MPa, the reactor was heated to 200 °C for 30 min. After that, the mixture was cooled to ambient temperature. Residue was removed by filtration and washed with water. Then 300 mL of water was added to the filtrate for precipitating lignin, which was eventually isolated and dried at 60 °C.

SI-4. Synthesis of lignin model compounds



A mixture of phenol (25 mmol, 4.98 g) and K_2CO_3 (37.5 mmol, 5.183 g) was dissolved in acetone (60 mL) under stirring at room temperature for 30 min. Then 2bromoacetophenone (30 mmol, 2.82 g) was added to the mixture solution under N_2 atmosphere and stirred at reflux temperature for 6 h, and then cooled to room temperature. The suspension was collected by filtration and washed with acetone and concentrated under reduced pressure. The crude residue was purified by recrystallization with ethanol to give a white solid 2-phenoxy-1-phenylethanone (82%).

2-Phenoxy-1-phenylethanone (PP-one) ¹H NMR (500 MHz, DMSO-*d*₂): δ = 8.06-8.03 (m, 2 H), 7.74–7.70 (m, 1 H), 7.61–7.57 (t, 2 H), 7.32-7.28 (m, 2 H), 6.99-6.94 (m, 3 H), 5.60 (s, 2 H).



¹H NMR spectra of 2-phenoxy-1-phenylethanone.



NaBH₄ (1.42 g, 37.32 mmol) was slowly added to the solution of 2-phenoxy-1phenylethanone (4 g, 18.66 mmol) in THF: H₂O (4:1, 50 mL) and stirred at room temperature for 6 h. The reaction was quenched by excess of diluted HCl solution. The coarse product was separated and the aqueous layer was extracted with ethyl acetate. The organic phase was thoroughly washed with NaCl aqueous solution, dried with MgSO₄, the residue solid was purified by column chromatography to give product 2phenoxy-1-phenylethanol as a white powder (97%). The detailed ¹H NMR data of PPol, PP-one and other lignin models were recorded in our previously reported ².

2-Phenoxy-1-phenylethanol (PP-ol) ¹H NMR (500 MHz, DMSO-*d*₂): δ = 7.48-7.46 (d, *J*= 10, 2 H), 7.39-7.35 (t, 2 H), 7.31-7.26 (m, 3 H), 6.95-6.91 (m, 3 H), 5.68-5.67 (d, *J*=5, 1 H), 4.95-4.91 (m, 1 H), 4.02-4.01 (d, *J*=5, 2 H).



¹H NMR spectra of 2-phenoxy-1-phenylethanol.

2-(2-Methoxyphenoxy)-1-phenylethanol (PP-ol-MeO) ¹H NMR (500 MHz, DMSO*d*₂): δ = 7.47-7.45 (d, *J*=12, 2 H), 7.37-7.35 (dd, 2 H), 7.29-7.27 (t, 1 H), 6.97-6.95 (m,

2 H), 6.91-6.84 (m, 2 H), 5.62-5.59 (t, 1 H), 4.95-4,92 (m, 1 H), 4.02-3.96 (m, 2 H), 3.75 (s, 3 H), 3.38-3.35 (d, *J*=18, 1 H).



¹H NMR spectra of 2-(2-methoxyphenoxy)-1-phenylethanol.

2-(2-Methoxyphenoxy)-1-(2-methoxyphenyl)ethanol (MeO-PP-ol-MeO) ¹H NMR (600 MHz, DMSO-*d*₂): δ = 7.53-7.51 (d, *J*= 10, 1 H), 7.29-7.26 (dd, 1 H), 7.00-6.95 (m, 4 H), 6.90-6.84 (m, 2 H), 5.26-5.24 (dd, 1 H), 3.99-3.97 (dd, 1H), 3.81 (s, 3 H), 3.76 (s, 3 H), 3.36 (s, 2 H).



¹H NMR spectra of 2-(2-methoxyphenoxy)-1-(2-methoxyphenyl)ethanol.



1,2-diphenylethanol was prepared as follows. Diphenylethanone (0.98 g, 5 mmol) was added into a THF/water solvent (25 mL, v/v = 4/1). NaBH₄ (0.76 g, 20 mmol) was added in one portion and stirred at room temperature for 2 h. Then, an excess of saturated NH₄Cl aqueous solution (15 mL) was added. The crude product was extracted with ethyl acetate (3 × 20 mL). The combined organic extracts were dried over anhydrous Na₂SO₄. The organic solvent was concentrated in vacuo and the obtained solid was dried at 60 °C overnight.

1,2-diphenylethanol (DP-ol) ¹H NMR (500 MHz, DMSO-*d*₂): δ = 7.33-7.28 (d, *J* = 6.7, 4 H), 7.25-7.20 (m, 3 H), 7.17-7.14 (dt, *J* = 8, 3 H), 5.28 (s, 1 H), 4.77-4.74 (t, *J* = 6.6, 1 H), 2.95-2.85 (m, 2 H).



¹H NMR spectra of 1,2-diphenylethanol.



NaBD₄ (0.197 g, 4.72 mmol) was slowly added to the THF: H_2O (4:1, 10 mL) solution with 2-phenoxy-1-phenylethanone (0.5 g, 2.36 mmol) and stirred at room temperature for 12 h. The reaction was quenched by excess of diluted HCl solution. The coarse product was separated and the aqueous layer was extracted with ethyl acetate. The organic phase was thoroughly washed with NaCl aqueous solution, dried with MgSO₄, then filtered and concentrated in a vacuum to give a white powder (2-phenoxy-1-phenylethanol-1-d, PP-ol'-D) pure to be used without further purification (93%).

2-phenoxy-1-phenylethanol-1-d (PP-ol'-D) ¹H NMR (500 MHz, DMSO-*d*₂): δ = 7.85-7.84 (d, *J* = 7.2 Hz, 2 H), 7.75-7.72 (t, *J* = 7.5 Hz, 2 H), 7.68-7.63 (m, 3 H), 7.31-7.28 (d, *J* = 8.0 Hz, 3 H), 6.03 (s, 1 H), 4.39 (s, 2 H).



¹H NMR spectra of 2-phenoxy-1-phenylethanol-1-d.



2-Phenoxy-1-phenylethanone (0.5 g, 2.36 mmol) and anhydrous K_2CO_3 (0.138, 1 mmol) was added to round-buttom flask along with D_2O . The flask was sealed and stirred for 60 h at 100 °C in an oil bath. The solid was washed with H_2O to remove the residue of K_2CO_3 and dried at 60 °C to obtain a slight yellow solid. Subsequently, the slight yellow solid (0.22 g, 1.03 mmol) and NaBH₄ (0.076 g, 2.00 mmol) was dissolved in THF: H_2O (4:1, 10 mL) solution and stirred at room temperature for 12 h. The reaction was quenched by excess of diluted HCl solution. The coarse product was separated and the aqueous layer was extracted with ethyl acetate. The organic phase was thoroughly washed with NaCl aqueous solution, dried with MgSO₄, then filtered and concentrated in a vacuum to obtain 2-phenoxy-1-phenylethanol-2,2-d2 (PP-ol''-D).

2-phenoxy-1-phenylethanol-2,2-d2 (PP-ol''-D) ¹H NMR (500 MHz, DMSO-*d*₂): δ = 8.10-8.08 (d, *J* = 7.6 Hz, 2 H), 7.77-7.74 (t, *J* = 7.4 Hz, 1 H), 7.65-7.62 (t, *J* = 7.7 Hz, 2 H), 7.36-7.33 (m, 2 H), 7.03-6.99 (dd, 3 H), 5.63-5.61 (d, *J* = 7.6, 1 H), 4.93-4.92 (d, *J* = 7.2, 1 H).



¹H NMR spectra of 2-phenoxy-1-phenylethanol-2,2-d2.

SI-5. Calculation of the conversion of lignin model compounds and yield of products



Sample	Regression equation	R ²
Benzaldehyde	y = 6744.28035x + 0.28261	0.99999
Benzoic acid	y = 2600.09739x + 3.90435	0.99998
Phenyl formate	y = 2144.62509x + 25.24855	0.99991
PP-one	y = 2404.85978x + 7.46237	0.99995
PP-ol	y = 1587.28035x + 11.65194	0.99956
2-methoxybenzaldenhyde	y = 1766.6713x + 41.29565	0.99998
Guaiacol	y = 7778.76522x + 194.78261	0.99966
2-(2-methoxyphenoxy)-1-phenylethanol	y = 3915.74609x + 32.71304	0.99999
1-(2-methoxyphenyl)-2-phenoxyethanol	y = 3919.27652x + 104.37826	0.99988
2-(2-methoxyphenoxy)-1-(2-	$y = 5060.45012y \pm 78.46507$	0.00077
methoxyphenyl)ethanol	y = 3900.43913x + 78.40397	0.999//

 Table S1. The fitting results of standard curves of samples by HPLC.



Figure S1. (a) N_2 absorption-desorption isotherms and (b) pore size distribution of g-C₃N₄, CeO₂ and 30% CeO₂/g-C₃N₄.



Figure S2. XPS survey spectra of CeO_2 , $g-C_3N_4$ and 30% $CeO_2/g-C_3N_4$.

Catalyst	Resistance (ohm)		
BCN	57.56		
CeO ₂	58.99		
$g-C_3N_4$	51.42		
15% CeO ₂ /g-C ₃ N ₄	33.58		
30% CeO ₂ /g-C ₃ N ₄	22.91		
50% CeO ₂ /g-C ₃ N ₄	45.69		

Table S2. The resistances of the relevant catalysts calculated by ZSimpWin software.



Figure S3. The Kubelka-Munk function plots of (a) $g-C_3N_4$ and (b) CeO₂, the Mott-Schottky plots (c) $g-C_3N_4$ and (d) CeO₂, the band energy structure for $g-C_3N_4$ and CeO₂.



Figure S4. (a) GC-MS spectrum and (b) corresponding MS spectra of cleavage samples of β -O-4 models over 30% CeO₂/g-C₃N₄.

Under the standard reaction conditions, PP-ol was mainly converted into benzaldehyde, phenyl formate and by-product PP-one, respectively. Meanhwile, benzaldehyde and phenyl formate could be partially oxidized to benzoic acid and phenol.

C	PP-ol	P1 +	P2) + 🕻	P3	^{)H} + (P4
Variation from the standard		Conv.	$\underbrace{\text{Yield (\%)}}_{\alpha} \text{C}_{\alpha} \text{-} \text{C}_{\beta} \text{ bor}$				C_{α} - C_{β} bond
Entry	conditions	(%)	P1	P2	P3	P4	cleavage selectivity (%) ^b
1	No light source	0	0	0	0	0	-
2	No catalyst	0	0	0	0	0	-
3	BCN as catalyst	45.7	15.9	7.8	2.7	7.6	77.6
4	Stand conditions	~100	65.0	46.3	17.6	4.5	96.7
5	CH ₂ Cl ₂ as the solvent	17.1	6	0.3	-	2.3	73.3
6	H ₂ O as the solvent	36.1	17.5	9.8	3.5	12.6	71.0
7	Ethanol as the solvent	12.6	7.7	2.4	4.2	0.8	94.7

Table S3. Optimization of the reaction conditions^a

^{*a*}Standard reaction conditions: PP-ol (5 mg), photocatalyst (5 mg), CH₃CN (5 mL), 300 W Xe-lamp, air, 4 h, room temperature. ^{*b*}Yield of **P1-P4** (%) = moles of product/moles of PP-ol × 100. ^{*c*} C_{α}-C_{β} bond cleavage selectivity (%) = molar ratio of (**P1** + **P2** + **P3**) and (**P1** + **P2** + **P3** + **P4**) × 100 in product distribution.



Figure S5. HPLC chromatograms for photocatalytic conversion of PP-ol by using 30% $CeO_2/g-C_3N_4$.



Figure S6. (a) XRD patterns, (b) FT-IR spectra and (c) SEM image of reused 30% $CeO_2/g-C_3N_4$.



Figure S7. High-resolution XPS spectra of (a) C 1s, (b) N 1s, (c) O 1s and (d) Ce 3d for fresh and reused 30% CeO₂/g-C₃N₄.

Catalyst	Conv (%)	Time (h)	Vield of the mai	n products (%)	Ref
Cataryst					nej.
U-Nb ₂ O ₅	94	18	48		3
mpg-C ₃ N ₄	96	10	51 SI	5° C 30	4
Mo ₁₃₂	9.0	6	0.2		5
PDI, TBACI	>99	48	он 70	o to 74	6
DEG CN	>99	10	64.7	1 1 1 1 1 1 1 1 1 1	7
PTP-dq•Cl	99	5	С ⁰ 45	6°) 38	8
p-CN/P-PDI-3	>99	3	59 S	101111111111111	9
30% CeO ₂ /g-C ₃ N ₄	~100	4	65.0 est.0	6°) 46.3	This study

Table S4. Comparison of performance between PTCN and some typical photocatalytic systems for PP-ol.

Substrate	Conv. (%)	Time (h)	Yield of main products (%)
OH OH PP-ol-MeO	99	4	⁹ 35.5 ⁹ 35.5 3.1 ^{11.} 7
MeO-PP-ol-MeO	97.8	5	29.6 2.7 но 9.4
DP-ol	~100	4	

Table S5. Photocatalytic cleavage of C_{α} - C_{β} bonds in different substrates.

Entry	Types of lignin	M_w (Da)	M_n (Da)	PDI (M_w/M_n)
1	Pine lignin	3294	2750	1.20
2	Wheat straw lignin	1495	921	1.62
3	Pine lignin after photoreaction	584	481	1.17
4	Wheat straw lignin after photoreaction	648	614	1.06

Table S6. The average molecular weight of lignin products before and after photocatalytic reaction.



Figure S8. The GPC analysis of (a) pine lignin and (b) wheat stalk lignin before and after photocatalytic reaction. Samples for GPC analysis were dissolved by DMF for 24 h at room temperature.



Figure S9. The GC-MS analysis for photocatalytic depolymerization of (a) pine lignin and (b) wheat stalk lignin. Reaction condition: 50 mg of lignin, 50 mg of 30% $CeO_2/g-C_3N_4$, 50 mL of CH₃CN, air, 10 h, 1 mg of anthracene, 300 W Xe-lamp.

Entre	Retention time	Aromatic	D1	Peak area share	Content
Entry	(min)	monomers	Peak area	(%)	(mg)
Internal standard	32.26		82005652	-	1
1	24.750		1388244	1.3	0.017
2	25.070	у- О- О- О- О- О- О- О- О- О-	1184863	1.1	0.014
4	25.755		5331567	5.2	0.065
5	26.782	К	2929104	2.8	0.036
6	26.906	но С Он	987620	1.0	0.012
7	27.128	но сулан	1331649	1.3	0.016
8	27.715		3047976	3.0	0.037
9	28.287	Ţ	2120830	2.1	0.026
10	31.068	\sim	744585	0.7	0.009
11	31.700	ноон	624379	0.6	0.008
12	33.722		4389290	4.3	0.054
13	34.017	~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~	44020281	42.7	0.537
14	35.284		16641579	16.1	0.203
15	36.511		7572135	7.3	0.092

 Table S7. GC-MS analysis of pine lignin depolymerization products

16	38.589	но-С	8182095	7.9	0.100
17	38.805	но-	2656410	2.6	0.032

Entry	Retention time	Aromatic	Peak area	Peak area	Content (mg)
Internal standard	32.26		82005510	-	1
1	22.856	с он	3614020	6.2	0.044
2	25.071	»−< →− o H o ·	2127885	3.5	0.026
3	25.466		734422	1.3	0.009
4	25.753	-о-сон	2797904	4.8	0.034
5	26.924	но	1407011	2.4	0.017
6	27.396	~~~~~~	3854335	6.6	0.047
7	28.128		1905686	3.2	0.023
8	35.182	С	20808368	35.4	0.254
9	35.348	$\neg \langle \cdot \rangle \sim \langle \circ \rangle \circ \rangle \sim \langle \circ \rangle \circ \rangle \circ \rangle \circ \langle \circ \rangle \circ \rangle \circ \rangle \circ \rangle \circ \rangle \circ$	3208678	5.5	0.039
10	35.710	но С	7437369	12.7	0.091
11	38.524		4411891	7.5	0.054

Table S8. GC-MS analysis of wheat stalk lignin depolymerization products

12	43.087	$+ \bigcirc {}^{\sim} \rightarrow {}^{\sim}$	6428545	10.9	0.078
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The yield of aromatic monomers detected by GC-MS from pine lignin (wt%) = (0.017 + 0.014 + 0.065 + 0.036 + 0.012 + 0.016 + 0.037 + 0.026 + 0.009 + 0.008 + 0.054 + 0.537 + 0.203 + 0.092 + 0.100 + 0.032) / 50 × 100 = 2.678 wt%.

The yield of aromatic monomers detected by GC-MS from wheat stalk lignin (%) = $(0.044 + 0.026 + 0.009 + 0.034 + 0.017 + 0.047 + 0.023 + 0.254 + 0.039 + 0.091 + 0.054 + 0.078) / 50 \times 100 = 1.432$ wt%.

In order to obtain the yields of detectable aromatic monomers after the photocatalytic reaction, GC-MS analysis was used to assess. Anthracene (1 mg) was used as an internal standard to calculate the content of each depolymerized product. The content of product was obtained by using the following equation: f = (As / ms) / (Ar / mr), where the f, As, ms, Ar, mr are the calibration factor, peak area of the internal standard, content of internal standard, peak area of product and content of product, respectively. The calibration factor was 1. After reaction, the yields of aromatic monomers detected by GC-MS from the depolymerization of pine lignin and wheat stalk lignin were 2.678 wt% and 1.432 wt%, respectively (**Table S7-8**). These results indicated that the natural lignin could be depolymerized to aromatic monomers during the photocatalytic reaction.



Figure S10. Mass spectra of photocatalytic reaction PP-ol''-D. Reaction conditions: PP-ol''-D (5 mg), 30% CeO₂/g-C₃N₄ (5 mg), air, 1 h, CH₃CN (5 mL), room temperature.



Figure S11. Mass spectra of photocatalytic reaction PP-ol'-D. Reaction conditions: PP-ol'-D (5 mg), 30% CeO₂/g-C₃N₄ (5 mg), air, 1 h, CH₃CN (5 mL), room temperature.

Reference

- X. Liu, Z. Jiang, X. Cao, Z. Shen, W. Zhao, F. Wang, M. Cui and C. Liang, Green Chemistry, 2024, 26, 1935-1948.
- X. Liu, Z. Jiang, X. Cao, Z. Shen, W. Zhao, F. Wang, M. Cui and C. Liang, ACS Sustainable Chemistry & Engineering, 2023, 11, 14947–14959.
- H. Chen, D. Hong, K. Wan, J. Wang, B. Niu, Y. Zhang and D. Long, *Chinese Chemical Letters*, 2022, 33, 4357-4362.
- H. Liu, H. Li, J. Lu, S. Zeng, M. Wang, N. Luo, S. Xu and F. Wang, ACS Catalysis, 2018, 8, 4761-4771.
- 5. H. J. Lee and E. S. Cho, *ACS Sustainable Chemistry & Engineering*, 2023, **11**, 7624-7632.
- P. Li, R. Liu, Z. Zhao, W. Yang, F. Niu, L. Tian and K. Hu, ACS Sustainable Chemistry & Engineering, 2024, 12, 10-17.
- D. Liang, J. Wu, C. Xie, J. Wen, Y. Lyu, Z. Sofer, J. Zheng and S. Wang, *Applied Catalysis B: Environmental*, 2022, 317, 121690.
- C. H. Rao, H. R. Wei, X. L. Miao, M. Z. Jia, X. R. Yao, X. Y. Zheng and J. Zhang, *Green Chemistry*, 2023, 25, 3974-3981.
- 9. X. Xu, S. Dai, S. Xu, Q. Zhu and Y. Li, *Angewandte Chemie-International Edition*, 2023, **63**, e202309066.