



# Efficient photocatalytic degradation of gas-phase formaldehyde by Pt/TiO<sub>2</sub> nanowires in a continuous flow reactor

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ABSTRACT: Herein, we investigated the photocatalytic degradation of gas-phase formaldehyde (HCHO) on Pt deposited TiO<sub>2</sub> nanowires (Pt/TiO<sub>2</sub>NW) at continuous flow. Formaldehyde is decomposed into CO<sub>2</sub> and H<sub>2</sub>O in a homemade tube reactor under the LED irradiation. The reactor can monitor online various parameters such as formaldehyde concentration, light intensity, humidity, and temperature. The results indicated that the formaldehyde degradation rate of Pt/TiO<sub>2</sub>NW increased at continuous flow compared with TiO<sub>2</sub> nanowires. Under ultraviolet and visible LED light irradiation, the stable time of degrading low-concentration formaldehyde by Pt/TiO<sub>2</sub>NW was 5.6 times that of TiO<sub>2</sub>NW. Higher ambient humidity facilitates the formaldehyde degradation of Pt/TiO<sub>2</sub>NW by increasing the hydroxyl radical ( $\cdot$ OH) and superoxide radical ( $\cdot$ O<sub>2</sub><sup>-</sup>

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KEYWORDS: TiO<sub>2</sub> nanowires; Pt nanoparticle; photocatalysis; formaldehyde.

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# 1. Introduction

In recent years, a large number of volatile organic compounds (VOC) have been used in decoration materials and furniture production, which polluted severely the in-door air on which humans depend. Volatile organic compounds include formaldehyde (HCHO), NOx, SO<sub>2</sub>, CO<sub>2</sub> and a series of toxic and harmful substances.[1-4] Among these pollutants, formaldehyde is one of the most widely used organic substances and the main source of air pollution.[3,5] Formaldehyde is a highly toxic substance and has been listed as a suspected carcinogen for humans by the International Cancer Research Center (IAPC). Excessive formaldehyde intake can cause symptoms of cough, chest stuffiness, dizziness, and even leukemia and chromosomal mutations, which would seriously jeopardize the human health.[6] The conventional methods for removing formaldehyde include adsorption purification, biodegradation, thermal catalysis, photocatalysis, HCHO capture and so on. [7-13] Of the several methods for removing formaldehyde in in-door environments, the most economical and convenient method is photocatalytic degradation of formaldehyde. The advantages included high removal efficiency, wide application range, simple equipment operation and no secondary pollutant. Therefore, photocatalytic technology has attracted tremendous attention in the application of eliminating formaldehyde.

The principle of photocatalytic oxidation is that when the energy of incident light is greater than the band gap of catalysts, the valence band electrons are excited to the conduction band to generate photo-generated electron-hole pairs, and the charge is transferred between the electron-hole pair and the adsorbant (reactant) on the semiconductor surface. Then occurs the photo-oxidation reaction. Semiconductor photocatalysts commonly used included ZnO, CeO<sub>2</sub>, g-C<sub>3</sub>N<sub>4</sub>, MnO<sub>2</sub>, TiO<sub>2</sub> and Bi<sub>2</sub>O<sub>3</sub>, and various composites of these compounds.[10, 12, 14-17] TiO<sub>2</sub>, as the most classic semiconductor photocatalysts, was widely used in polluted air purification due to its stable Accepted Manuscrip

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chemical properties, high catalytic activity, easy preparation and non-toxic. [10, 18-20] Titanium dioxide is irradiated by ultraviolet light to generate electron-hole pairs. The electron-hole pairs react with oxygen and water in the surrounding air to generate  $\cdot$ OH and  $\cdot$ O<sub>2</sub>. Both of them have strong oxidizing ability to oxidize and decompose formaldehyde into CO<sub>2</sub> and H<sub>2</sub>O. However, as a wide bandgap semiconductor, titanium dioxide only responds in the ultraviolet (UV) region and has a small surface area, which limits the wider application of  $TiO_2$  under visible light. Commercially available P25 titanium dioxide has a very limited photocatalytic activity to degrade formaldehyde. Recently, a high performance TiO<sub>2</sub> nanowires (TiO<sub>2</sub>NW) photocatalyst was successfully prepared by hydrothermal method to decompose gaseous formaldehyde into CO<sub>2</sub> and H<sub>2</sub>O in a homemade tube reactor without secondary pollution under UV irradiation.[10] TiO<sub>2</sub>NW was synthesized by hydrothermal method to increase specific surface area and surface active sites to improve its photocatalytic efficiency and enhance visible light response. Moreover, researchers found that noble metals (Pt, Au, Ag, Pd, Rh, and Ru) loading further improved the photocatalytic performance. [20-28] Among them, Pt supported on TiO<sub>2</sub> can improve quantum efficiency and enhance photocatalytic activity with Pt loading not exceeding 0.2 wt%. Therefore, it can be predicted that the photocatalytic oxidation performance of TiO<sub>2</sub> nanowires could be improved further by depositing Pt nanoparticles.

Herein,  $Pt/TiO_2$  nanowires were prepared and the photocatalytic degradation of gas-phase formaldehyde was studied in a self-made reactor. The photocatalytic degradation of lowconcentration formaldehyde at gas-phase flowing was monitored in real time and the effects of light intensity, air humidity and formaldehyde concentration were investigated.

## 2. Experimental

# 2.1 Reagents

Titanium (IV) oxide (Aeroxide<sup>TM</sup> P25), chloroplatinic acid solution (H<sub>2</sub>PtCl<sub>6</sub>, 8 wt% in water), sodium hydroxide (NaOH, 98%), hydrochloric acid solution (HCl, 1 M) were purchased from Sinopharm Chemical Reagent Co. Ltd. All chemicals were analytical grade and used without further purification. Deionized water was utilized throughout this study.

2.2 Synthesis of TiO<sub>2</sub> nanowires

3 g of titanium (IV) oxide (Aeroxide<sup>TM</sup> P25) was dispersed in 300 mL of a 10 M NaOH solution under ultrasonic stirring, and the mixture was transferred to a 500 mL hydrothermal autoclave heated continuously at 165 °C for 48 h. The white precipitate obtained from the autoclave was washed with HCl solution to pH neutral. Then, Na<sup>+</sup> was replaced with 600 mL of a 0.1 M HCl solution for 24 h. Finally, the precipitate was dried to obtain a white titanate solid powder. The titanate powder was annealed at 700 °C for 90 min, with a heating rate was 3 °C/min to obtain TiO<sub>2</sub> nanowires, labeled as TiO<sub>2</sub>NW.

2.3 Preparation of Pt/TiO2 nanowires

Pt deposited TiO<sub>2</sub> was prepared by a photodeposition method. Three portions of the abovementioned white titanate powder (0.5 g) were dispersed in 30 mL deionized water ultrasonically, and adding 0.075 wt%, 0.1 wt%, and 0.125 wt% H<sub>2</sub>PtCl<sub>6</sub> (ratio of H<sub>2</sub>PtCl<sub>6</sub> to titanate) under stirring, respectively. The mixtures were irradiated with a 500 W Xe lamp with a light intensity of 100 mW/cm<sup>2</sup> for 30 min under continuous magnetic stirring. After being centrifuged and dried at 80 °C,

the sample was annealed at 700 °C for 90 min with heating rate of 3 °C/min. The resulting samples were denoted as 75 PT, 100 PT, and 125 PT, respectively.

### 2.4 Characterization

The samples were characterized with a Shimadzu XRD7000 X-ray diffractometer (XRD), Zeiss Libra200FE transmission electron microscope (TEM), field emission scanning electron microscope (FESEM, JSM-7800F10100), X-ray photoelectron spectroscopy (XPS) (VGESCALAB 250 spectrometer), UV-Vis spectrophotometer (Agilent Cary 5000), photoluminescence spectrum (PL) (Hitachi F-7000), electron paramagnetic resonance (EPR) spectrometer (Bruker EMXnano), and nitrogen adsorption-desorption isotherms (Quadrasorbevo 2QDS-MP-30). Electrochemical tests were performed on an AUTOLAB workstation (model PGSTAT 302N) using a three-electrode system at room temperature. An FTO conductive glass film with an area of 2 cm<sup>2</sup> was used as the working electrode, the electrolyte was a 0.5 M Na<sub>2</sub>SO<sub>4</sub> solution, the light source was a 500 W xenon lamp, the wavelength range was 250-780 nm, and the light intensity was 110 mW/cm<sup>2</sup>.

# 2.5 Photocatalytic degradation of formaldehyde

The photocatalytic degradation of gas formaldehyde was performed at room temperature using a home-made reactor at continuous flow, as shown in Figure S1. 10 mg catalyst was filled into  $\phi$ 3 mm quartz tube, and the two ends are blocked by a small amount of asbestos. Prior to the degradation reaction, the formaldehyde flow rate was well controlled to achieve an adsorption-desorption equilibrium. The surface of the quartz tube is irradiated with a set of LED lamp. The efficiency of photocatalytic degradation of formaldehyde was calculated by comparing the change in formaldehyde concentration after passing through a quartz tube. The formaldehyde

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concentration before and after the photocatalytic reaction was monitored the formaldehyde sensor (Dart Sensor Ltd, UK). The formaldehyde degradation rate was calculated according to the following equation:

Degradation rate  $\eta = (C_t - C_0)/C_0$ 

Where  $C_0$  is the equilibrium concentration of HCHO at adsorption-desorption equilibrium, and  $C_t$  is the HCHO concentration at reaction time t.

## 3. Results and discussion

Figure 1 shows the XRD patterns of TiO<sub>2</sub>, 75 Pt/TiO<sub>2</sub>, 100 Pt/TiO<sub>2</sub>, and 125 Pt/TiO<sub>2</sub>. The main diffraction peaks of TiO<sub>2</sub> are located at 25.3 °, 37.0 °, 37.7 °, 38.6 °, 48.1 °, 53.9 °, 55.1 °, 62.2 °, and 62.7 °, corresponding to the (101), (103), (004), (112), (200), (105), (211), (213), and (204) crystal planes of anatase phase (JCPDS 99-0008). The diffraction peaks of 75 Pt/TiO<sub>2</sub> at 26.7 ° and 43.1 ° correspond to the characteristic planes (110) and (210) of the rutile phase (JCPDS 21-1276), respectively. The diffraction peak at 20 at 62.7 ° corresponds to the (002) crystal plane of the rutile phase, overlapped with the (204) plane of the anatase phase. For 100 Pt/TiO<sub>2</sub>, the diffraction peak at 20 of 35.5 ° is related to the characteristic plane (101) of the rutile phase. Upon loading 0.1 wt% Pt, the non-stable crystal plane (101) in the rutile phase was exposed. XRD pattern shows that there appears rutile phase in TiO<sub>2</sub> nanowires for 75 Pt/TiO<sub>2</sub>, 100 Pt/TiO<sub>2</sub>, 125 Pt/TiO<sub>2</sub> after loading Pt. 75 Pt/TiO<sub>2</sub> exposed the rutile (110) plane, while 100 Pt/TiO<sub>2</sub> exposed the (101) crystal plane, which is less stable than (110), causing more oxygen vacancy defects.

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Figure 1 XRD patterns of TiO<sub>2</sub> and Pt/TiO<sub>2</sub> nanowires. R, A, and B represent rutile, anatase, and brookite, respectively.

Figures 2(a-d) show the FESEM images of TiO<sub>2</sub>NW, 75 Pt/TiO<sub>2</sub>, 100 Pt/TiO<sub>2</sub>, and 125 Pt/TiO<sub>2</sub>. It shows that the nanowires have a diameter of 30-80 nm and a length of more than 5  $\mu$ m. The loading of Pt has no effect on the morphology of TiO<sub>2</sub> nanowires. Figures 2 (e-f) are TEM images of 100 Pt/TiO<sub>2</sub>. The high-resolution TEM lattice fringe pattern shows that the crystal plane spacing is 0.35 nm, which corresponds to the (101) crystal plane of the anatase phase TiO<sub>2</sub>. [10, 23-25] Figure 2(f) shows that Pt nanoparticles uniformly distributed on the nanowires, indicating that Pt/TiO<sub>2</sub> was prepared successfully. The TEM-EDS mapping in Figure 2(g) further confirmed that the Pt nanoparticle supported on TiO<sub>2</sub> nanowires.

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Figure 2 SEM images of TiO<sub>2</sub> (a), 75 Pt/TiO<sub>2</sub> (b), 100 Pt/TiO<sub>2</sub> (c), and 125 Pt/TiO<sub>2</sub> (d). TEM images with different magnifications (e-f) of 100 Pt/TiO<sub>2</sub>. (g) STEM image and corresponding EDS mapping profiles for Ti, O, and Pt.



Figure 3 XPS spectra of Ti 2p (a), O 1s (b), and Pt 4f (c) for TiO<sub>2</sub> and 100Pt/TiO<sub>2</sub>.

The oxidation state and surface chemical composition of the sample were analyzed by XPS, as shown in Figure 3. The high-resolution Ti 2p spectra show two symmetrical peaks, located at 459.3 and 465.1 eV, respectively, which can be ascribed to the spin splitting orbits of Ti  $2p_{3/2}$  and  $2p_{1/2}$ . The XPS spectrum of O 1s can be fitted as three peaks at binding energies of 529.6, 531.1, and 532.1 eV, corresponding to the oxygen atoms in Ti-O and the adsorbed oxygen and adsorbed water. The atomic ration of Ti/O is close to the chemostoichiometry of 1:2 of TiO2. The binding energies

of TiO<sub>2</sub> and 100PT are similar, which is a typical feature of coordination between Ti (IV) and O atoms. The high-resolution spectrum of Pt 4f shows two symmetrical peaks located at 73.9 and 77.9 eV, respectively, corresponding to spin-split of Pt4f<sub>7/2</sub> and 4f<sub>5/2</sub>. The results showed that the single surface mass of Pt was successfully loaded on the sample surface, indicating that Pt was successfully loaded onto TiO<sub>2</sub> by photodeposition. [26-28] The atomic ration of Pt/TiO<sub>2</sub> is about 0.05%. Thus, the weight ration of Pt to TiO<sub>2</sub> is closed to 0.1 wt%.

Figure 4(a) shows UV-vis diffusion reflectance spectroscopy. The absorption edge is 389 nm for  $TiO_2$  and Pt/TiO\_2, and the band gap value is 3.18 eV, indicating that the band gap remains unchanged upon Pt loading. The absorption intensity is improved from UV to visible light range after Pt deposition. The enhanced absorption of Pt/TiO<sub>2</sub> indicated that Pt loading facilitates the photocatalytic activity. Figure 4(b) shows PL spectra of  $TiO_2$  and Pt/TiO<sub>2</sub> with the excitation wavelength of 290 nm. It shows the fluorescence quenching phenomenon with PL intensity: 100 PT<75 PT<125 PT<TiO<sub>2</sub>. The loading of noble metal Pt facilitates the separation of electron-hole pairs.



Figure 4 UV-vis spectra (a) and PL spectra (b) for TiO<sub>2</sub> and Pt/TiO<sub>2</sub>.

Figure 5(a) shows the instant photocurrent response, all of which exhibit fast photocurrent responses. The photocurrent test after 5 cycles tends to be stable, there is no significant decrease in the last 5 cycles, and it has good repeatability. It shows that TiO<sub>2</sub> and Pt/TiO<sub>2</sub> exhibit high stability under ultraviolet light. At the same bias voltage, the stable photocurrent value of a 100 PT electrode is three times that of a  $TiO_2$  electrode, which means that 100 PT can generate more photoelectrons and achieve effective separation of electron-hole pairs. [29] Pt load is conducive to improving the instant photocurrent response, and is beneficial to the generation and regeneration of electron-hole pairs. 100 PT has the highest photocurrent response. The electrochemical impedance spectroscopy (EIS) of TiO<sub>2</sub> nanowires is shown in Figure 5(b). As the Pt load increases, the arc radius of the electrode decreases, indicating that the interface charge transfer resistance of the working electrode is reduced, which can effectively promote the transport and separation of photo-generated carriers in the photocatalytic reaction. That indicated that the load of Pt is beneficial to the charge migration, thereby improving photocatalytic efficiency. Figures 5(c) and (d) show the Mott-Schottky curves of TiO<sub>2</sub> and 100 PT at 1000 Hz. The tangent slope of curves is positive, indicating that  $TiO_2$  is a typical n-type semiconductor. The intercept of the tangent and abscissa of the MS curves represents the flat band potential. The flat band potentials of  $TiO_2$  and 100 Pt/TiO<sub>2</sub> are -1.057 and -1.116 V, respectively. The conduction band positions are approximately -1.06 eV and -1.12 eV, respectively. That shows the negative shift of the conduction band position after Pt loaded TiO2, and the band gap value of 3.18 eV determined by the UV-vis spectrum. The positions of the valence bands are calculated to +2.12 eV and +2.06 eV, respectively.

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The negative shift of the valence band is more conducive to the production of the more oxidative  $\cdot O_2^2$ , which is beneficial to the occurrence of photocatalytic oxidation reactions.

Figure 5 Transient photocurrents (a) and EIS (b) spectra of TiO<sub>2</sub> and Pt/TiO<sub>2</sub>. Mott-Schottky plots of TiO<sub>2</sub> (c) and 100 PT (d).

The photocatalytic oxidation of formaldehyde was carried out on a home-made reactor with a quartz tube filled with 10 mg photocatalyst under the 420 nm LED irradiation with light intensity of 6 W at the environmental temperature of 19 °C. The formaldehyde concentration was set to 0.5 mg/m<sup>3</sup>, and the flow rate at 50 mL/min. The ambient humidity was fixed at 80%. The inlet and

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outlet of formaldehyde were monitored to determine the degradation rate. Figure 6(a) shows the degradation performance of four catalysts. After the adsorption equilibrium is reached, the light was turned on to degrade the formaldehyde. The outlet concentration of formaldehyde gradually decreased to 0, indicating all catalysts can degrade the formaldehyde completely in a short time interval. However, the outlet formaldehyde concentration rises a little after a period of degradation and eventually reaches the equilibrium saturation. The degradation equilibrium of formaldehyde is 0.06, 0.09, 0.02, and 0.08 mg/m<sup>3</sup> for TiO<sub>2</sub>NW, 75Pt/TiO<sub>2</sub>, 100Pt/TiO<sub>2</sub>, and 125Pt/TiO<sub>2</sub>, respectively. Accordingly, the degradation rate is 88%, 82%, 99%, 84% for TiO<sub>2</sub>NW, 75Pt/TiO<sub>2</sub>, 100Pt/TiO<sub>2</sub>, and 125Pt/TiO<sub>2</sub>, respectively. Figure 6(b) shows the detailed diagram of the corresponding degradation performance. The time taken to decompose formaldehyde completely is 4.98, 3.92, 4.45, and 3.58 min for TiO<sub>2</sub>, 75 PT, 100 PT, and 125 PT, respectively. The degradation rate of formaldehyde increases after loading Pt nanoparticles on TiO<sub>2</sub> nanowires, and 100Pt/TiO<sub>2</sub> takes only 4.45 min, being slightly shorter than 4.98 min of TiO<sub>2</sub>. Figure 6(c) shows the details of the stable time of formaldehyde degradation. There exists a stable time period before the outlet concentration begin to increase and eventually reaches the equilibrium. The stable time was 16.20, 19.57, 90.89, 29.62 min, for TiO<sub>2</sub>, 75 PT, 100 PT, 125 PT 100 PT, respectively. For 100 Pt, the stable time was about 5.6 times that of  $TiO_2$ . Figure 6(d) shows the cycle stability test of 100 PT degradation of formaldehyde. The formaldehyde degradation under 420 nm UV (6 W) light has been tested at first, and the degradation equilibrium has finally been reached so that the formaldehyde degradation test under this condition cannot reach a 100% degradation. By turning on the strong ultraviolet (11.2 W) at 420 nm, the formaldehyde can reach 100% degradation. After 50 cycles in 50 hours, the photocatalytic performance of formaldehyde degradation did not decrease, indicating that the 100PT photocatalyst is very stable, and can be used continuously.

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Figure 6 Degradation performance of flowing gas-phase formaldehyde (a-c). The stability test of  $100Pt/TiO_2$  (d). CH1, inlet formaldehyde concentration fixed at 0.5 mg/m<sup>3</sup>; CH2, outlet formaldehyde concentration.

The photocatalytic degradation of formaldehyde under different humidity was carried out under irradiation using the 365 nm LED light with an intensity of 1.8 W. Figure 7(a-b) shows the photocatalytic degradation of formaldehyde at the humidity of 80%, while Figure 7(a'-b') shows the measurements at the humidity of 60%. At ambient humidity of 80%, the time required for

formaldehyde degradation of 100 PT is 10.63 min. As the humidity decreases to 60%, the time required for the degradation 100 PT is 43.4 min. Under the ambient humidity of 80%, the stable degradation lasts for more than 50 h, while the stable time decreased to 40 h at ambient humidity of 60%, indicating that humidity increase facilitates the continuous and stable degradation of low-concentration formaldehyde. Properly increasing the humidity is beneficial to the degradation of formaldehyde gas and can improve the stability of the material's continuous degradation of low concentration of formaldehyde. The blank test and the photocatalytic degradation for P25 were shown in Figure 7(a) as reference.



Figure 7 Effect of humidity on the formaldehyde degradation. (a-b) humidity at 80%, (a'-b') humidity of 60%.

Figure 8 shows the degradation performance of four catalysts with inlet concentration of 1.0 mg/m<sup>3</sup>. After the adsorption equilibrium is reached, the light is turned on to degrade the formaldehyde. The outlet concentration of formaldehyde gradually decreased. However, the outlet formaldehyde concentration rises a little after a period of degradation and eventually reaches the equilibrium saturation. he degradation rate is 88%, 86%, 92%, 87% for TiO<sub>2</sub>NW, 75Pt/TiO<sub>2</sub>, 100Pt/TiO<sub>2</sub>, and 125Pt/TiO<sub>2</sub>, respectively. The results show that the degradation rate is related to the formaldehyde concentration. The catalysts decompose formaldehyde partially at higher inlet concentration.



Figure 8 Degradation performance of flowing gas-phase formaldehyde. CH1, inlet formaldehyde concentration fixed at 1.0 mg/m<sup>3</sup>; CH2, outlet foamaldehyde concentration.

In order to explore the photocatalytic mechanism of formaldehyde degradation by TiO<sub>2</sub> and Pt/TiO<sub>2</sub>, 5,5-dimethyl-1-pyrroline N-oxide (DMPO) was used as active species trapping agent to detect radicals over photocatalysts under visible light irradiation, as shown in Figure 9. Under dark and visible light conditions, absolute methanol was used as solvent to test the DMAP $-\cdot$ O<sub>2</sub><sup>-</sup> of TiO<sub>2</sub> and Pt/TiO<sub>2</sub>, respectively. Figure 9(a) showed that both TiO<sub>2</sub>-methanal and TiO<sub>2</sub>-water had no characteristic EPR signals in the dark state, and the DMAP $-\cdot$ O<sub>2</sub><sup>-</sup> (superoxide radicals) and DMPO $-\cdot$ OH (hydroxyl radicals) characteristic peaks appeared under visible light irradiation. As

shown in Figure 9(b), the DMAP– $\cdot$ O<sub>2</sub><sup>-</sup> and DMPO– $\cdot$ OH characteristic peaks for Pt/TiO<sub>2</sub> appeared under visible light conditions, respectively. There was no characteristic signal under dark conditions. DMAP– $\cdot$ O<sub>2</sub><sup>-</sup> and DMPO– $\cdot$ OH characteristic peak was generated under visible light irradiation, indicating that  $\cdot$ O<sub>2</sub><sup>-</sup> and  $\cdot$ OH active species were generated by the interaction of photoinduced electrons and holes. The EPR experiments showed that hydroxyl radical ( $\cdot$ OH) and superoxide radical ( $\cdot$ O<sub>2</sub><sup>-</sup>) were the main reactive oxygen species (ROS) involved in the photocatalysis. The reactive oxygen species (ROS) were generated through the interaction of photoinduced charge carriers with H<sub>2</sub>O and O<sub>2</sub> adsorbed on the catalyst surface. Under visible light irradiation, the photoinduced electrons are trapped by O<sub>2</sub> to yield  $\cdot$ O<sub>2</sub><sup>-</sup>, and  $\cdot$ O<sub>2</sub><sup>-</sup> react with water to form –OH. HCHO is then oxidized into formate species with the surface –OH. Holes in VB directly oxidize –OH and/or water to produce  $\cdot$ OH. Subsequently, the formate is further oxidized to CO<sub>2</sub> and H<sub>2</sub>O by  $\cdot$ OH. [30, 31]



Figure 9 EPR spectra in methanol dispersion for DMPO  $\cdot O_2^-$  and aqueous dispersion for DMPO  $\cdot OH$  for TiO<sub>2</sub> (a) and 100PT (b) in the dark and under visible light irradiation ( $\lambda$ > 420 nm).

#### 4. Conclusion

In summary, the loading of Pt nanoparticles on TiO<sub>2</sub> nanowires promoted the photocatalytic degradation of gas-phase HCHO at low concentrations. Under visible light irradiation, the outlet concentration of formaldehyde decreased exponentially to zero, and maintained for a certain time interval, then reached the degradation equilibrium at the inlet concentration of formaldehyde fixed at 0.5 mg/m<sup>3</sup>. 100 Pt/TiO<sub>2</sub> maintained the 100% formaldehyde degradation for the longest time, and the highest equilibrium formaldehyde degradation rate among all catalysts. The photocatalytic performance of formaldehyde degradation did not show any observable decrease for undergoing 50 degradation cycles, indicating that the 100 Pt/TiO<sub>2</sub> photocatalyst is very stable. The degradation rate of HCHO increases with increasing ambient humidity by increasing the hydroxyl radical ( $\cdot$ O<sub>2</sub><sup>-</sup>). The experimental results show that a small amount of Pt nanoparticles loaded on titanium dioxide is conducive to the degradation of low-concentration formaldehyde, and appropriately increasing the ambient humidity is beneficial to the degradation of formaldehyde.

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## **Author Contributions**

The manuscript was written through contributions of all authors. All authors have given approval to the final version of the manuscript.

# Conflicts of interest

The authors declare no competing financial interest.

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The photocatalytic oxidation mechanism of formaldehyde degradation.