Supporting Information

for

# Facile synthesis of recyclable Pd-rGO/CNT/CaFe<sub>2</sub>O<sub>4</sub> nanocomposite with high multifunctional photocatalytic activities under visible light irradiation

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## Experimental

## Materials and methods

Unless otherwise stated, all solvents and reagents were purchased from commercial sources and used as received without further purification. Fourier transform infrared (FTIR) spectra were recorded with a Bruker Tensor 27 spectrometer, using a KBr pellet at room temperature. X-ray diffraction (XRD) analysis was carried out by an Inel Equinox 3000 diffractometer under Cu K $\alpha$  radiation. The Raman spectra (wavelength 532 nm) were recorded via an Upright Raman microscope with DPSSVD: YAG type of laser excitation. Room temperature magnetization characteristic of the synthesized samples was investigated with vibrating sample magnetometer (VSM) technique (Lake Shore Model 7400, Japan). ASAP 2020 surface area analyzer was employed to evaluate of BET Surface area.

The UV-Vis spectra were recorded by a Varian Cary 100 BIO Spectrophotometer. The <sup>1</sup>HNMR spectra were recorded at room temperature with a Bruker FT-NMR 400 MHz spectrometer in CDCl<sub>3</sub>. Gas chromatography (GC) analysis was performed by using Hewlett-Packard HP 6890N equipped with a capillary column 19091J-236 HP-5, 5% phenyl methyl siloxane capillary column, an FID detector and nitrogen as a gas carrier. The percent of Palladium loaded on the catalyst were determined by using an ICP-OES 730-ES Varian instrument.

The morphologies of prepared samples were investigated by the field emission scanning electron microscope (FESEM) and energy disperse X-ray (EDX) mapping (TESCAN MIRA II). The Photoluminescence (PL) spectra were collected on CARY ECLIPSE.

The data of Ultraviolet-visible (UV-Vis) diffuse-reflectance spectra (DRS) were collected using an AvaSpec-2048-TEC UV-Vis-NIR spectrometer.

The electrochemical impedance spectroscopy (EIS) measurements were done using an Autolab potentiostat/galvanostat apparatus. Three electrode cell assembly was employed where Pt wire and Ag/AgCl (saturated KCl) were employed as a counter and reference electrodes respectively. Also, an aqueous solution of Na<sub>2</sub>SO<sub>4</sub> (0.5 M) was used as an electrolyte. Fluorine-doped Tin oxide (FTO) substrates were employed as working electrodes. In order to fabricate the working electrode, 30 mg synthesized photocatalyst was added in the 1 mL of ethanol and ultrasonicated for preparing uniform dispersion of the sample and the obtained mixture was sprayed on a  $1 \times 1$  cm<sup>2</sup> area of FTO substrate which was allowed to dry in a furnace at 400 °C for 1 h. These tests were carried out at room temperature (25 °C) with a 500 W xenon lamp source equipped with AM 1.5G filter.

#### Additional characterization data

Fig. S1 shows the FT-IR spectra of F-MWCNT, Pd-rGO/CNT, and Pd-rGO/CNT/CaFe<sub>2</sub>O<sub>4</sub> nanocomposites. The major peaks corresponding to the functionalities of F-MWCNT (Fig. S1a) located at 1710 cm<sup>-1</sup> (C=O stretching vibration from the carboxylic and carbonyl groups), 1580

cm<sup>-1</sup> (C=C stretching band), 2898 and 2830 cm<sup>-1</sup> (CH<sub>2</sub> stretching bands), 1214 (C-OH stretching vibration for the hydroxyl groups), 1047 cm<sup>-1</sup> (C-O stretching band) and 3404 cm<sup>-1</sup> (stretching vibrations of O–H). Due to the highly negative surface charge of GO and FMWCNT from the ionization of oxygen functionalities and the electrostatic repulsion force among the GO sheets and FMWCNT in water (a polar solvent), these functional groups are suitable to the generation of a stable GO and FMWCNT colloidal suspension. It should be noticed that after the preparation of Pd-rGO/CNT nanocomposite, these oxygen functionalities were remarkably decreased because of the defunctionalization of FMWCNT during the process (Fig. S1b).<sup>1</sup> The peak at 881 cm<sup>-1</sup> can be attributed to Fe-O-H bending vibrations and the peaks at 487 cm<sup>-1</sup> can be assigned to the stretching vibration of the metal-oxygen bonds such as Ca-O and Fe-O (Fig. S1c).<sup>2</sup>

Fig. S2 exhibits the XRD pattern of GO, F-MWCNT, and Pd-rGO/CNT/CaFe<sub>2</sub>O<sub>4</sub> nanocomposites. The XRD pattern of GO shows diffraction peak at  $2\theta$ ~10.0 that is related to the (002) plane that vividly demonstrates the oxidation of graphite affecting its crystal structure and  $2\theta$ ~41.5 that is corresponded to the (001) planes (Fig. S2a).<sup>3</sup> The characteristic peaks at  $2\theta$ ~26.1° and  $2\theta$ ~43° for the F-MWCNT can be assigned to the (002) plane and (100) plane, respectively (Fig. S2-b).<sup>4</sup> In the XRD pattern of Pd rGO/CNT/CaFe<sub>2</sub>O<sub>4</sub> in Fig. S2c, two diffraction peaks also appear at 24.7° and 42°. Compared with F-MWCNT the diffraction peak which is related to (002) plane is slightly shifted towards lower diffraction angle for Pd-rGO/CNT/CaFe<sub>2</sub>O<sub>4</sub> which is corresponded to the interaction between graphene and carbon nanotubes. Because of the low Pd loading on rGO/CNT nanocomposite, no Pd diffraction peaks were observed. The characteristic peaks of CaFe<sub>2</sub>O<sub>4</sub> at  $2\theta$ ~30.2°, 38°, and 63° which are related to the (320), (031) and (170) planes respectively, also indicates the presence of CaFe<sub>2</sub>O<sub>4</sub> nanoparticles in the prepared Pd-rGO/CNT/CaFe<sub>2</sub>O<sub>4</sub> nanocomposite.<sup>2-4</sup>

Raman scattering spectra were employed to further study the structural changes of carbonous materials. As shown in Fig. S3, Raman spectra of the GO, F-MWCNT and Pd-rGO/CNT/CaFe<sub>2</sub>O<sub>4</sub> (carbon materials) exhibited three well-known bands called D, G and 2D bands. In the Raman scattering spectra of the carbon materials, the D band which observed at~1340-1365 cm<sup>-1</sup> is attributed to the defect or disorder mode results from edge configurations in the sheets of graphene where the configuration of the planar sheet defects.<sup>5</sup> The G band at~1560-1590 cm<sup>-1</sup> is corresponded to the tangential stretching of the C-C bonds, indicating the graphitization of carbonaceous materials and the 2D band at ~2640-2660 cm<sup>-1</sup> indicates a second-order overtone that appears in-plane vibration of the graphitic structure. Also, the ID/IG is another important parameter to investigate defect densities and disorder degree in the sheets of graphene. The results of Raman spectroscopy are collected in Table S1. As shown in this Table, the intensity ratio of the D to G bands (disorder parameter) for Pd-rGO/CNT/CaFe<sub>2</sub>O<sub>4</sub> nanocomposite is remarkably larger than those for GO and F-MWCNT. The increase in the ID/IG value can indicate a decrease in the size of the sp<sup>2</sup> domains results from a decrease in sizes of graphitic domains. These defects can make the bands of Pd-rGO/CNT/CaFe<sub>2</sub>O<sub>4</sub> nanocomposite shifted to a lower

frequency. In the other hand, two peaks at~494 and 566 cm<sup>-1</sup> can correspond to the presence of  $CaFe_2O_4$  nanoparticles in the prepared nanocomposite.<sup>2-6</sup>

The magnetic properties of the prepared samples were investigated at room temperature by a vibrating sample magnetometer. The obtained results showed that  $M_s$  (saturation magnetization) for CaFe<sub>2</sub>O<sub>4</sub> and Pd-rGO/CNT/CaFe<sub>2</sub>O<sub>4</sub> are 30.2 and 11.2 emu/g, respectively. Note that the value of Ms for Pd-rGO/CNT/CaFe<sub>2</sub>O<sub>4</sub> nanocomposite is a little lower than that of the rGO/CNT/CaFe<sub>2</sub>O<sub>4</sub> nanocomposite, which is due to the presence of Pd nanoparticles.<sup>7</sup> In conclusion, the Pd-rGO/CNT/CaFe<sub>2</sub>O<sub>4</sub> nanocomposite can be quickly separated from the system via an external magnetic field (Fig. S4).

In order to investigate the electrochemical behavior of the samples, electrochemical impedance spectroscopy (EIS) measurement was employed. Fig. S5 illustrates the impedance spectra as Nyquist plots for CaFe<sub>2</sub>O<sub>4</sub> and Pd-rGO/CNT/CaFe<sub>2</sub>O<sub>4</sub> nanocomposite. It can be seen that Pd-rGO/CNT/CaFe<sub>2</sub>O<sub>4</sub> nanocomposite has a smaller diameter of the semicircle that was attributed to the less charge-transfer resistance (Rct), whereas CaFe<sub>2</sub>O<sub>4</sub> have the larger Rct. This result shows higher effectiveness of charge transfer between the electrode and the electrolyte as well as more effective separation of photogenerated electron-hole pairs.

Photoluminescence (PL) exhibits useful information that can investigate the charge carrier immigration and transfer. The intensity of the PL signal provides helpful information on the photogenerated electron-hole recombination rate. Fig. S6 illustrates the PL spectra of  $CaFe_2O_4$  and Pd-rGO/CNT/CaFe\_2O\_4 nanocomposite recorded at an excitation wavelength of 420 nm. The CaFe\_2O\_4 nanoparticles vividly showed a strong PL intensity, whereas the PL intensity of Pd-rGO/CNT/CaFe\_2O\_4 was remarkably reduced. This result can be attributed to the presence of F-MWCNT, rGO, and Pd. The presence of these materials can reduce the recombination rate of photoinduced electron-hole pairs.

## Photocatalytic activity measurement

The photodegradation experiments of methylene blue (MB) as a dangerous pigment under visible light illumination was conducted with a 250-W mercury lamp. In order to block the UV irradiation, a cut off filter ( $\geq$  420 nm) was employed. The degradation progress was carried out in a 150 mL photoreactor at room temperature (25 °C ± 2 °C). The distance between the lamp and photoreactor level was kept at 50 cm and the focused intensity on the reactor was calculated as 85.272 µW.cm<sup>-2</sup>. The emission wavelength of the light source (250-W mercury lamp) with the UV cut-off filter is illustrated in Fig. S7. In each experiment, a certain amount of synthesized photocatalysts (1-5 g/L) was added to 50 mL of the desired concentration of MB aqueous solutions (4-20 mg/L) at various times of irradiation (30-120 min) according to experiments designed using Design Expert 7.0.0 Software and illumination under uninterrupted stirring. Before visible light irradiation, it is worthwhile noting that the above photocatalyst solution containing the dyes was stirred under dark for 1 h to ensure that adsorption-desorption equilibrium between the catalyst

and reactant. At 15 min illumination time intervals, 5 mL of the reaction solution was collected and the absorbance of the solution at the wavelength of 662 nm was investigated. For the next test, the synthesized catalysts were collected via an external magnetic field and dried at 70 °C. In order to investigate the photodegradation efficiency and photodegradation kinetics of the dyes Eqs. (1) And (2) were employed, respectively.<sup>8</sup>

$$n = \frac{C_0 - C_t}{C_0} \times 100$$

$$ln \frac{C_0}{C} = K_{app} \times t$$
(2)

In which  $C_0$  and  $C_t$  are the concentration of the initial and final dye in aqueous solution (mg.L<sup>-1</sup>) after irradiation time. K<sub>app</sub> is the first-order reaction rate constant (min<sup>-1</sup>) and t is illumination time (min).

The chemical oxygen demand (COD) that is an empiric laboratory assay, mentions the amount of oxidant consumed when the water is digested by a strong oxidizing agent. A known amount of water sample is oxidized by adding  $K_2Cr_2O_7$  (0.25 N) as a strong oxidant under acidic condition (H<sub>2</sub>SO<sub>4</sub>) and using AgSO<sub>4</sub> as a catalyst. The interferences caused via the presence of the chloride can be overcome markedly, though not completely, by complexing with HgSO<sub>4</sub> before the refluxing procedure. During the digestion (150 °C, during 1h), the organic carbon material in the sample is oxidized with the dichromate ion (Cr<sub>2</sub>O<sub>7</sub><sup>2-</sup>). The dichromate readily gives up O<sub>2</sub> to bond with carbon atoms to generate CO<sub>2</sub> and the oxygen transaction from Cr<sub>2</sub>O<sub>7</sub><sup>2-</sup> to CO<sub>2</sub> reduces the dichromate ion to the chromium ion (Cr<sup>3+</sup>). The amount of Cr<sup>3+</sup> is determined after oxidization is completed. After oxidation, the amount of excess K<sub>2</sub>Cr<sub>2</sub>O<sub>7</sub> must be determined in order to ensure that the amount of Cr<sup>3+</sup> can be measured right. So, the excess K<sub>2</sub>Cr<sub>2</sub>O<sub>7</sub> is titrated with 0.1N FAS (ferrous ammonium sulfate) in the presence of ferrion as an indicator until all of the excess K<sub>2</sub>Cr<sub>2</sub>O<sub>7</sub> has been reduced to Cr<sup>3+</sup>.

In order to examine the role of the active species, the effects of some radical scavengers on the photodegradation process were investigated (Benzoquinone (BZQ) as the superoxide radical  $(O_2^{-})$  scavenger, KI as the hole (h<sup>+</sup>) scavenger and tert-butyl alcohol (t-BuOH) as the hydroxyl radical ('OH) scavenger.

#### Experimental design for the photodegradation process

The response surface methodology (RSM) is one of the affordable methods to optimize certain processes. It can reduce the number of designed experiments needed to study the effects of operating factors.<sup>9</sup> The RSM based on Box–Behnken Design (BBD) was utilized in order to estimate the effects of operating key factors such as catalyst dosage, initial dye concentration and the irradiation time on the photodegradation process. For this target, the design Expert 7.0.0

software was employed for experimental design to investigate the gained results. Note that several pre - tests were carried out in order to reach the domain values of operating factors.

# **Optimizing effective parameters on photodegradation performance**

The efficiency of photodegradation system is dependent on various factors such as light intensity, irradiation time, initial pollutant concentration, the dosage of the catalyst, flow rate, reactor configuration, etc.<sup>10</sup> These various factors make it difficult to design an experiment with the respect of all these parameters. Therefore, the key three factors including catalyst dosage (A), dye concentration (B) irradiation time (C) and their binary interactions, are modeled by the RSM technique. The domains of factor variation in BBD are depicted in Table S2.

## Fitting of the process model

The final equation in terms of coded factors for the degradation rate of MB (X) is shown in Eqs. (3), where A, B, and C are independent process variables namely catalyst dosage, initial dye concentration and irradiation time, respectively.

Χ

$$= 98.00 + 1.25A - 3.50B + 9.25C + 1.75AB - 0.25AC + 1.25BC - 22.62A^{2}$$

$$C^{2}$$
(3)

Based on the ANOVA calculation, the significance of coefficients is defined by F and P values (Table S3). The regressions for the degradation rate of MB are statistically significant as it is obvious from the F values with a little probability value (P < 0.0001). A good agreement between the predicted response values with the observed values over the chosen range of independent variables is illustrated in Fig S8. A great number of the response points are located in a narrow range and the standard deviation is 1.98 between the predicted and experimental results. In addition, the R<sup>2</sup> value is 0.995 that this value is in good agreement with the adjusted R<sup>2</sup> (0.99). These results show a high dependence and correlation between the predicted and observed values of responses. Adequate precision is 35.19 that shows the significance of the model for the degradation process of MB due to this value is greater than 4.<sup>11</sup> Fig. S9 shows a straight line that it confirms the normality of the data. In fact, the validity of ANOVA is investigated via the normal distribution of residuals from the normal probability plot (NPP).

The interaction between the catalyst dosage and the initial dye concentration on the degradation rate of MB was depicted in Fig. S10a (irradiation time = 75 min). As the concentration of dye increases, the amount of adsorbed dye on the active surface of the synthesized catalyst increases and the generation of 'OH radicals enhances. So the photodegradation efficiency of dye increases with enhancing the initial dye concentration up to 12 mg/ L, while the obtained results show a steady decrease in the degradation rate of dye with increasing the MB concentration up to 20 mg/ L. One of the main reason for this issue is that increasing the dye concentration makes the solution more impermeable to the visible light irradiation. The limited active site onto the catalyst dosage increases from 1 to 3 g/ L, the degradation rate of MB increases. It can be originated from enhancing more available photocatalytic active sites on the surface of Pd-rGO/CNT/CaFe<sub>2</sub>O<sub>4</sub> (40%) nanocomposite which perform as an anchorage for the dye but further raising the dosage of

the catalyst up to 5 g/L has a negative effect on the degradation rate of the dye. This issue can be caused by enhancing the scattering and turbidity effects, so the light penetration into the solution can be limited. Fig. S10b shows the joint effects of catalyst dosage and irradiation time on the degradation rate of MB. As observed, the addition of the dosage of the catalyst is not effective on the photocatalytic performance at low irradiation time. The results exhibit that the dosage of photocatalyst at high irradiation time leads to a significant effect on the degradation rate of the dye. Fig. S10c shows the interaction between initial dye concentration and irradiation time on the degradation rate of the dye. It is found that a low initial concentration of MB and high irradiation time are necessary to reach the highest degradation rate of the dye. In conclusion, the interactions between the operating key parameters can play an important role in the photocatalyst activity.

Note that the Pd-rGO/CNT/CaFe<sub>2</sub>O<sub>4</sub> (40%) nanocomposite with the highest removal efficiency of MB and the value of  $K_{app}$  was selected. The optimum parameters for the MB degradation process using the Pd-rGO/CNT/CaFe<sub>2</sub>O<sub>4</sub> (40%) nanocomposite were 3.04 g/ L for catalyst dosage, 11.75 mg/ L for MB concentration and 75.44 min for the time of irradiation. To study the accuracy of the gained results of the model under optimum conditions, the proposed experiment was performed and good agreement was observed between the mean experimental responses (98.5%) and optimum calculated responses (98.78%).

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Fig. S1. FT-IR spectra of (a) F-MWCNT (b) Pd-rGO/CNT (c) Pd-rGO/CNT/CaFe<sub>2</sub>O<sub>4</sub> (40%).

![](_page_8_Figure_0.jpeg)

Fig. S2. XRD patterns of (a) GO (b) F-MWCNT (c) Pd-rGO/CNT/CaFe<sub>2</sub>O<sub>4</sub> (40%).

![](_page_9_Figure_0.jpeg)

Fig. S3. Raman spectra of (a) GO, (b) F-MWCNT, (c) Pd-rGO/CNT/CaFe<sub>2</sub>O<sub>4</sub> (40%).

![](_page_10_Figure_0.jpeg)

**Fig.S4.** Magnetization curve of CaFe<sub>2</sub>O<sub>4</sub>, rGO/CNT/CaFe<sub>2</sub>O<sub>4</sub> (40%), Pd-rGO/CNT/CaFe<sub>2</sub>O<sub>4</sub> (40%).

![](_page_11_Figure_0.jpeg)

**Fig. S5.** EIS Nyquist plots of CaFe<sub>2</sub>O<sub>4</sub>, Pd-rGO/CNT/CaFe<sub>2</sub>O<sub>4</sub> (40%).

![](_page_12_Figure_0.jpeg)

**Fig. S6.** Photoluminescence spectra with an excitation of a diode laser (wavelength 420 nm) of (a) CaFe<sub>2</sub>O<sub>4</sub>, (b) Pd-rGO/CNT/CaFe<sub>2</sub>O<sub>4</sub> (40%).

![](_page_13_Figure_0.jpeg)

**Fig. S7.** Spectrum distribution of the Visible light source provided by a 250-W mercury lamp with a UV cut off filter (visible light ≥420 nm).

![](_page_14_Figure_0.jpeg)

Fig. S8. Predicted values of the response against observed values for Pd-rGO/CNT/CaFe<sub>2</sub>O<sub>4</sub> (40%) nanocomposite.

![](_page_15_Figure_0.jpeg)

Fig. S9. Normal probability plot of residuals for Pd-rGO/CNT/CaFe<sub>2</sub>O<sub>4</sub> (40%) nanocomposite.

![](_page_16_Figure_0.jpeg)

Fig. S10. Response surface showing the interaction effects of the various factors on the photodegradation of MB using the Pd-rGO/CNT/CaFe<sub>2</sub>O<sub>4</sub> (40%) nanocomposite. (a) Catalyst dosage and dye concentration, (b) irradiation time and catalyst dosage, (c) dye concentration and irradiation time.

![](_page_17_Figure_0.jpeg)

**Fig. S11.** The degradation efficiency for MB (12 mg/L) removal in the process of prepared samples under visible light irradiation.

![](_page_18_Figure_0.jpeg)

**Fig. S12.** Linear-log plot for the photocatalytic degradation of MB in the presence of CaFe<sub>2</sub>O<sub>4</sub>, rGO/CaFe<sub>2</sub>O<sub>4</sub> (30%), rGO/CaFe<sub>2</sub>O<sub>4</sub> (40%), rGO/CaFe<sub>2</sub>O<sub>4</sub> (50%), rGO/CNT/CaFe<sub>2</sub>O<sub>4</sub> (30%), rGO/CNT/CaFe<sub>2</sub>O<sub>4</sub> (40%), rGO/CNT/CaFe<sub>2</sub>O<sub>4</sub> (50%), Pd-rGO/CNT/CaFe<sub>2</sub>O<sub>4</sub> (40%).

![](_page_19_Figure_0.jpeg)

**Fig. S13.** The degradation rate constant of the prepared photocatalysts for the photocatalytic degradation of MB under visible light irradiation.

![](_page_20_Figure_0.jpeg)

**Fig. S14.** COD analysis of the degraded MB solution (Initial dye concentration: 12 mg/L, Irradiation time: 75 min).

![](_page_21_Figure_0.jpeg)

Fig. S15. Effect of various scavengers on the degradation of MB by Pd-rGO/CNT/CaFe<sub>2</sub>O<sub>4</sub> (40%) under the optimized conditions.

![](_page_22_Figure_0.jpeg)

**Fig. S16.** Recycling studies of the Pd-rGO/CNT/CaFe<sub>2</sub>O<sub>4</sub> (40%) catalyst for the photodegradation of MB solution.

Sample	D	G	2D	ID/IG
GO	1355	1582	2650	0.91
F-MWCNT	1361	1585	2658	1.01
Pd-rGO/CNT/CaFe <sub>2</sub> O <sub>4</sub>	1343	1568	2646	1.55

Table. S1. Detailed Raman features of GO, F-MWCNT and Pd-rGO/CNT/CaFe $_2O_4$ 

Variable	Symbol	Coded factor level			
		-1	0	+1	
Catalyst dosage (g/L)	А	1	2.5	5	
MB concentration (mg/ L)	В	4	12	20	
Irradiation time (min)	С	30	75	120	

Table. S2. Factors and levels used in the BBD.

Source	Sum of	Degree of	Mean Square	F Value	p-value (Prob > F)	
	Squares	Ireedom				
Model	6416.44	9	712.94	181.48	< 0.0001	significant
A-Cat	12.5	1	12.5	3.18	0.1176	
B-MB	98	1	98	24.95	0.0016	
C-Time	684.5	1	684.5	174.24	< 0.0001	
AB	12.25	1	12.25	3.12	0.1208	
AC	0.25	1	0.25	0.064	0.8081	
BC	6.25	1	6.25	1.59	0.2476	
A <sup>2</sup>	2155.33	1	2155.33	548.63	< 0.0001	
<b>B</b> <sup>2</sup>	1163.75	1	1163.75	296.23	< 0.0001	
<b>C</b> <sup>2</sup>	1705.33	1	1705.33	434.08	< 0.0001	
Residual	27.5	7	3.93			
Lack of Fit	22.5	3	7.5	6	0.0581	not significant
Pure Error	5	4	1.25			-
Cor Total	6443.94	16				

**Table. S3.** Analysis of variance (ANOVA) for the BBD using Pd-rGO/CNT/CaFe2O4 (40%)nanocomposite.

![](_page_26_Figure_0.jpeg)

## Table S4. <sup>1</sup>H NMR data of Cinnamate derivatives

![](_page_27_Figure_0.jpeg)

# Table S5. <sup>1</sup>H NMR data of Stylbene derivatives

![](_page_28_Figure_0.jpeg)

**Fig S17.** <sup>1</sup>H NMR spectra of Methyl cinnamate

![](_page_29_Figure_0.jpeg)

Fig S18. <sup>1</sup>H NMR spectra of Methyl (E)-3-(p-tolyl)acrylate

![](_page_30_Figure_0.jpeg)

Fig S19. <sup>1</sup>H NMR spectra of Methyl (E)-3-(4-methoxyphenyl)acrylate

![](_page_31_Figure_0.jpeg)

Fig S20. <sup>1</sup>H NMR spectra of Methyl (E)-3-(4-acetylphenyl)acrylate

![](_page_32_Figure_0.jpeg)

**Fig S21.** <sup>1</sup>H NMR spectra of Butyl cinnamate

![](_page_33_Figure_0.jpeg)

Fig S22. <sup>1</sup>H NMR spectra of Butyl (E)-3-(p-tolyl)acrylate

![](_page_34_Figure_0.jpeg)

Fig S23. <sup>1</sup>H NMR spectra of Butyl (E)-3-(4-methoxyphenyl)acrylate

![](_page_35_Figure_0.jpeg)

Fig S24. <sup>1</sup>H NMR spectra of Butyl (E)-3-(4-acetylphenyl)acrylate

![](_page_36_Picture_0.jpeg)

![](_page_36_Figure_1.jpeg)

**Fig S25.** <sup>1</sup>H NMR spectra of (E)-stylbene

![](_page_37_Figure_0.jpeg)

Fig S26. <sup>1</sup>H NMR spectra of (E)-1-methyl-4-styrylbenzene

![](_page_38_Figure_0.jpeg)

Fig S27. <sup>1</sup>H NMR spectra of (E)-1-methoxy-4-styrylbenzene

![](_page_39_Figure_0.jpeg)

Fig S28. <sup>1</sup>H NMR spectra of (E)-1-(4-styrylphenyl)ethan-1-one

![](_page_40_Figure_0.jpeg)

**Fig S29.** <sup>1</sup>H NMR spectra of (E)-1-chloro-4-styrylbenzene

![](_page_41_Figure_0.jpeg)

Fig S30. <sup>1</sup>H NMR spectra of (E)-1-chloro-4-(4-methylstyryl)benzene

![](_page_42_Figure_0.jpeg)

**Fig S31.** <sup>1</sup>H NMR spectra of (E)-1-chloro-4-(4-methoxystyryl)benzene

![](_page_43_Figure_0.jpeg)

Fig S32. <sup>1</sup>H NMR spectra of (E)-1-(4-(4-chlorostyryl)phenyl)ethan-1-one