Facile Carbonyl Sulfide (COS) Fixation into Novel COS-Storage Materials Towards Preparation of CdS Photocatalyst for CO2 Reduction and Promotion of Plant Growth

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**Supporting Information**

**Materials**

Cadmium nitrate was obtained from Tianjin Fengchuan Chemical Reagent Technology Co., Ltd. and analytical grade NH4HCO3 was bought from Tianjin Reagent Company (Tianjin, China). 99.9% COS used in the experiment was purchased from Shenzhen Jingu Gas Co., Ltd., China. The four plants used in this experiment were eggplant, tomato, pepper and cucumber. The plants were transplanted into flowerpots of 36 cm × 24 cm. And the soil came from the same place. Simultaneously, the same kind seedlings were purchased from the market. The chemical reagents used in the experiment are listed in Table S1.

**Characterizations of COSSMs**

The COSSMs were firstly characterized by Fourier transform infrared spectroscopy (FTIR), nuclear magnetic resonance (13C-NMR), X-ray photoelectron spectroscopy (XPS) and X-ray diffraction (XRD). The models, specifications and manufacturers of various types of instruments are shown in Table S2.

**Table captions**

**Table S1** Specification of chemical samples.

**Table S2** The models, specifications and manufacturers of various types of instruments.

**Table S3** The average growth of pepper at 30 d, 60d.

**Table S4** The average growth of eggplant at 30 d, 60d.

**Table S5** The average growth of tomato at 30 d, 60d.

**Table S6** The average growth of cucumber at 30 d, 60d.

**Table S7** Contrast results of eggplants blade at 30 d, 60d.

**Table S8** Contrast results of cucumbers blade at 30 d, 60d.

**Table S9** Contrast results of average stem diameters of pepper at 30 d, 60d.

**Table S10** The average wet weight of 4 plants.

**Table S11** The average dry weight of 4 plants.

**Table S12** The ratio of dry to wet weight of 4 plants.

**Table S13** Total nitrogen and pH in soil.

**Table S1**

|  |  |  |  |
| --- | --- | --- | --- |
| Chemical name | Source | Initial mass fraction purityb | Purification method |
| Ethylene glycol | Tianjin Yongsheng Fine Chemical Co., Ltd., China | ≥ 0.99 | Desiccationc and degasificationd |
| Diethylene glycol | Tianjin Guangfu Fine Chemical Research Institute, China | ≥ 0.98 | Desiccationc and  degasificationd |
| Triethylene glycol | Shanghai Macklin Fine Chemical, China | ≥ 0.99 | Desiccationc and  degasificationd |
| Tetraethylene glycol | Shanghai Macklin Fine Chemical, China | ≥ 0.99 | Desiccationc and  degasificationd |
| Polyethylene glycol 300 | Beijing Yili Fine Chemical Co., Ltd., China | ≥ 0.99 | Desiccationc and  degasificationd |
| Polyethylene glycol 400 | Beijing Yili Fine Chemical Co., Ltd., China | ≥ 0.99 | Desiccationc and  degasificationd |
| Dipropylene glycol | Shanghai Macklin Fine Chemical, China | ≥ 0.98 | Desiccationc and  degasificationd |
| 1,2-propanediol | Shanghai Macklin Fine Chemical, China | ≥ 0.99 | Desiccationc and  degasificationd |
| 1,3-butanediol | Shanghai Macklin Fine Chemical, China | ≥ 0.99 | Desiccationc and  degasificationd |
| Ethylenediamine | Tianjin Fuyu Fine Chemical Co., Ltd., China | ≥ 0.99 | Desiccationc and  degasificationd |
| 1,3-propanediamine | Shanghai Titan Scientific Co., Ltd., China | ≥ 0.99 | Desiccationc and  degasificationd |
| 1,6-hexanediamine | Shanghai Macklin Fine Chemical, China | ≥ 0.99 | Desiccationc and  degasificationd |
| Ethanol absolute | Tianjin Yongsheng Fine Chemical Co. Ltd., China | ≥ 0.995 | Desiccationc and degasificationd |
| Triethanolamine | Tianjin Yongsheng Fine Chemical Co., Ltd., China | ≥ 0.85 | Desiccationc and degasificationd |

a Chromatographic grade. b Declared by the supplier. c Molecular sieve type 4A. d Ultrasound.

**Table S2**

|  |  |  |  |
| --- | --- | --- | --- |
| Instrument name | Model | Specification and other | Manufacturer |
| FTIR | Nexus 670 | Resolution 1 cm-1,  ranging from (4000-400) cm-1 | Nicolet, USA |
| XPS | ESCLAB-250Xi | Resolution 0.5 *eV*  analysis area 200 to 600 *eV*, | Thermo-Fisher, USA |
| XRD | D / max-220/PC | Source of emission Cu Kα,  acceleration voltage 40 kV | Bruker, GER |
| Photocatalytic activity evaluation system | CEL-PAEM-D6 | GC-7920 | Zhongjiao Jinyuan Technology Co., Ltd., China |

**Table S3**

|  |  |  |  |
| --- | --- | --- | --- |
|  | Increment times of plant height | | |
|  | | 30 d | 60 d |
| Water | | 5.93 | 17.17 |
| NH4HCO3 | | 5.23 | 18.50 |
| EG-COSSM | | 7.40 | 20.43 |
| DEG-COSSM | | 8.97 | 18.37 |
| TeEG-COSSM | | 8.27 | 21.33 |
| PEG 300-COSSM | | 9.23 | 21.20 |
| PEG 400-COSSM | | 10.80 | 24.60 |
| PPD-COSSM | | 7.40 | 20.97 |
| TEG-COSSM | | 7.17 | 19.80 |
| DPG-COSSM | | 4.80 | 13.10 |

**Table S4**

|  |  |  |  |
| --- | --- | --- | --- |
|  | Increment times of plant height | | |
|  | | 30 d | 60 d |
| Water | | 4.70 | 17.50 |
| NH4HCO3 | | 4.30 | 19.40 |
| EG-COSSM | | 7.17 | 30.33 |
| DEG-COSSM | | 7.80 | 35.73 |
| TeEG-COSSM | | 5.67 | 21.40 |
| PEG 300-COSSM | | 4.70 | 24.07 |
| PEG 400-COSSM | | 5.00 | 21.33 |
| PPD-COSSM | | 7.07 | 26.37 |
| TEG-COSSM | | 4.83 | 26.27 |
| DPG-COSSM | | 4.93 | 26.53 |

**Table S5**

|  |  |  |  |
| --- | --- | --- | --- |
|  | Increment times of plant height | | |
|  | | 30 d | 60 d |
| Water | | 14.80 | 20.30 |
| NH4HCO3 | | 12.57 | 21.25 |
| EG-COSSM | | 14.30 | 27.10 |
| DEG-COSSM | | 16.73 | 28.53 |
| TeEG-COSSM | | 23.80 | 47.87 |
| PEG 300-COSSM | | 20.67 | 40.83 |
| PEG 400-COSSM | | 23.10 | 47.93 |
| PPD-COSSM | | 19.10 | 26.93 |
| TEG-COSSM | | 13.90 | 28.20 |
| DPG-COSSM | | 18.33 | 30.00 |

**Table S6**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | | Increment times of plant height | | | |
|  | 30 d | | | 60 d | |
| Water | | | 10.53 | | 50.23 |
| NH4HCO3 | | | 10.97 | | 52.73 |
| EG-COSSM | | | 13.70 | | 64.80 |
| DEG-COSSM | | | 23.60 | | 96.33 |
| TeEG-COSSM | | | 10.67 | | 54.37 |
| PEG300-COSSM | | | 14.20 | | 52.33 |
| PEG400-COSSM | | | 13.60 | | 61.37 |
| PPD-COSSM | | | 18.57 | | 58.07 |
| TEG-COSSM | | | 11.87 | | 45.60 |
| DPG-COSSM | | | 12.83 | | 47.57 |

**Table S7**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | | Length × Width of maximum leaf (Increment) (cm) | | | |
|  | 30 d | | | 60 d | |
| Water | | | 5.5 × 3.2 | | 12.6 × 7.6 |
| NH4HCO3 | | | 3.5 × 2.7 | | 12.4 × 7.9 |
| EG-COSSM | | | 4.0 × 2.8 | | 14.6 × 10.6 |
| DEG-COSSM | | | 4.7 × 2.7 | | 13.3 × 9.6 |
| TeEG-COSSM | | | 4.7 × 2.1 | | 13.9 × 8.0 |
| PEG 300-COSSM | | | 3.1 × 2.2 | | 13.1 × 8.8 |
| PEG 400-COSSM | | | 4.2× 3.5 | | 14.6 × 9.3 |
| PPD-COSSM | | | 4.4 × 2.1 | | 12.3 × 8.8 |
| TEG-COSSM | | | 3.5 × 3.0 | | 11.3 × 7.5 |
| DPG-COSSM | | | 3.0 × 2.1 | | 15.3 × 10.2 |

**Table S8**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | | Length × Width of maximum leaf  (Increment)  (cm) | | | |
|  | 30 d | | | 60 d | |
| Water | | | 4.4 × 4.1 | | 9.0 × 10.8 |
| NH4HCO3 | | | 3.2× 3.6 | | 9.1× 11.7 |
| EG-COSSM | | | 3.7 × 5.7 | | 9.4× 12.5 |
| DEG-COSSM | | | 4.8 × 5.9 | | 9.5 × 13.5 |
| TeEG-COSSM | | | 4.6 × 5.3 | | 10.0 × 13.9 |
| PEG 300-COSSM | | | 4.9 × 5.5 | | 10.5 × 13.3 |
| PEG 400-COSSM | | | 3.4 × 4.1 | | 9.5 × 12.5 |
| PPD-COSSM | | | 5.8 × 6.7 | | 9.7 × 12.8 |
| TEG-COSSM | | | 3.7 × 3.8 | | 10.5 × 13.3 |
| DPG-COSSM | | | 3.5 × 3.3 | | 10.0 × 12.5 |

**Table S9**

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Average stem diameters (cm) | | | | | | | | |
|  | Pepper | | Eggplant | | Tomato | | Cucumber | |
| Water | | 0.40 | | 0.47 | | 0.50 | | 0.43 |
| NH4HCO3 | | 0.47 | | 0.50 | | 0.50 | | 0.47 |
| EG-COSSM | | 0.53 | | 0.57 | | 0.63 | | 0.50 |
| DEG-COSSM | | 0.63 | | 0.63 | | 0.57 | | 0.63 |
| TeEG-COSSM | | 0.53 | | 0.53 | | 0.63 | | 0.50 |
| PEG 300-COSSM | | 0.60 | | 0.43 | | 0.60 | | 0.50 |
| PEG 400-COSSM | | 0.63 | | 0.50 | | 0.73 | | 0.60 |
| PPD-COSSM | | 0.57 | | 0.50 | | 0.67 | | 0.50 |
| TEG-COSSM | | 0.53 | | 0.50 | | 0.67 | | 0.53 |
| DPG-COSSM | | 0.50 | | 0.57 | | 0.73 | | 0.57 |

\*Data in the same column followed by different lowercase letters stand for significant difference.

**Table S10**

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Average wet weight (g) | | | | | | | | |
|  | Pepper | | Eggplant | | Tomato | | Cucumber | |
| Water | | 1.5633 | | 6.2569 | | 2.5079 | | 0.8712 |
| NH4HCO3 | | 1.4748 | | 5.5784 | | 2.5514 | | 1.7534 |
| EG-COSSM | | 4.0634 | | 10.3957 | | 5.8551 | | 2.3448 |
| DEG-COSSM | | 5.5116 | | 15.4564 | | 3.5527 | | 3.2034 |
| TeEG-COSSM | | 6.9768 | | 8.9860 | | 5.8014 | | 2.5756 |
| PEG 300-COSSM | | 4.6177 | | 12.2286 | | 3.8061 | | 2.3793 |
| PEG 400-COSSM | | 3.3975 | | 8.0535 | | 8.6271 | | 2.5996 |
| PPD-COSSM | | 3.9121 | | 20.5926 | | 2.9318 | | 2.9713 |
| TEG-COSSM | | 4.8748 | | 7.9178 | | 4.0811 | | 2.5179 |
| DPG-COSSM | | 2.6442 | | 14.4775 | | 6.2420 | | 1.7859 |

**Table S11**

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Average dry weight (cm) | | | | | | | | |
|  | Pepper | | Eggplant | | Tomato | | Cucumber | |
| Water | | 1.3369 | | 5.2611 | | 1.8280 | | 0.5214 |
| NH4HCO3 | | 1.2829 | | 4.8055 | | 1.6697 | | 0.7209 |
| EG-COSSM | | 2.3484 | | 4.6776 | | 3.1102 | | 0.6404 |
| DEG-COSSM | | 2.4115 | | 6.4756 | | 1.8361 | | 0.8609 |
| TeEG-COSSM | | 2.9578 | | 3.6689 | | 2.8529 | | 0.6038 |
| PEG 300-COSSM | | 2.2941 | | 4.2265 | | 1.5057 | | 0.5259 |
| PEG 400-COSSM | | 2.2931 | | 3.6278 | | 4.1892 | | 0.5685 |
| PPD-COSSM | | 1.8639 | | 6.6392 | | 1.3847 | | 0.7697 |
| TEG-COSSM | | 2.4766 | | 3.5486 | | 2.1611 | | 0.5982 |
| DPG-COSSM | | 1.3674 | | 5.8255 | | 2.3567 | | 0.4638 |

**Table S12**

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| dry to wet weight ratio | | | | | | | | |
|  | Pepper | | Eggplant | | Tomato | | Cucumber | |
| Water | | 85.52% | | 84.08% | | 72.89% | | 59.85% |
| NH4HCO3 | | 86.99% | | 86.14% | | 65.44% | | 41.11% |
| EG-COSSM | | 57.79% | | 45.00% | | 53.12% | | 27.31% |
| DEG-COSSM | | 43.75% | | 41.90% | | 51.68% | | 26.87% |
| TeEG-COSSM | | 42.39% | | 40.83% | | 49.18% | | 23.44% |
| PEG 300-COSSM | | 49.68% | | 34.56% | | 39.56% | | 22.10% |
| PEG 400-COSSM | | 67.49% | | 45.05% | | 48.56% | | 21.87% |
| PPD-COSSM | | 47.64% | | 32.24% | | 47.23% | | 25.90% |
| TEG-COSSM | | 50.80% | | 44.82% | | 52.95% | | 23.76% |
| DPG-COSSM | | 51.71% | | 40.24% | | 37.76% | | 25.97% |

**Table S13**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Test items | | | | | |
|  | Total nitrogen (g/kg) | | | Total sulfur ( g/kg) | pH |
| Water | | 0.64 | 0.99 | | 8.94 |
| NH4HCO3 | | 0.67 | 0.69 | | 8.92 |
| EG-COSSM | | 0.62 | 0.66 | | 9.09 |
| DEG-COSSM | | 0.54 | 0.68 | | 9.00 |
| TeEG-COSSM | | 0.56 | 0.48 | | 8.91 |
| PEG 300-COSSM | | 0.66 | 0.52 | | 9.07 |
| PEG 400-COSSM | | 0.64 | 0.63 | | 9.13 |
| PPD-COSSM | | 0.50 | 0.63 | | 8.99 |
| TEG-COSSM | | 0.71 | 0.78 | | 8.85 |
| DPG-COSSM | | 0.56 | 0.69 | | 9.00 |

\*The measure standard of total nitrogen, total sulfur and pH depend on NY/T 53-1987, barium sulfate turbidimetry and NY/T 1121.2-2006.

**Figure captions**

**Figure S1** The photocatalytic apparatus for CO2 reduction to CH4 and CO.

**Figure S****2** XPS spectra of an overview and C(1s) ,O(1s), N(1s), and S(2p) of COSSMs.

**Figure S3** XPS full spectra of CdS NPs prepared under three conditions, and the high-resolution spectra of Cd(3d) and S(2p).

**Figure S4** Average growth of the experimental and control plants at 60 d.

**Figure S5** Comparison of leaves color of eggplant and cucumber plants.

**Figure S6** Fruits of the experimental group and the control group of 4 plants.

**Figure S7** Growth of 4 plants at 0 d, 30 d and 60 d.



**Figure S1**





 

  

 

  

































**Figure S2**

 

cubic phase

  

mixed phase



hexagonal phase

**Figure S3**



**Figure S4**



**15.5 cm**

**8.3 cm**

**12.5 cm**

**7.8 cm**

**13.7 cm**

**9.0 cm**

DEG-COSSM H2O NH4HCO3

**Eggplant**



**13.0 cm**

**8.0 cm**

**9.2 cm**

**8.0 cm**

**10.7 cm**

**10.5 cm**

PPD-COSSM H2O NH4HCO3

**Cucumber**

**Figure S5**



PEG 400-COSSM Water NH4HCO3 DEG-COSSMWater NH4HCO3

**pepper eggplant**



TeEG -COSSM Water NH4HCO3 TeEG-COSSMWater NH4HCO3

**tomato cucumber**

**Figure S6**

** **

**36.0 cm**

**41.7 cm**

DEG-COSSM

PEG 400-COSSM

** **

**22.0 cm**

**24.0 cm**

Water

Water

** **

**30.0 cm**

**23.5 cm**

NH4HCO3

NH4HCO3

**0 d 30 d 60 d 0 d 30 d 60 d**

**eggplant**

**pepper**

** **

**64.0 cm**

**117.0 cm**

DEG-COSSM

TeEG-COSSM

** **

**28.0 cm**

**49.0 cm**

Water

Water

** **

**21.0 cm**

**55.0 cm**

NH4HCO3

NH4HCO3

**0 d 30 d 60 d 0 d 30 d 60 d**

**cucumber**

**tomato**

**Figure S7**