# Transparent photochromic Fe-doped $W_{18}O_{49}$ films with ultrahigh solar energy modulation for smart windows

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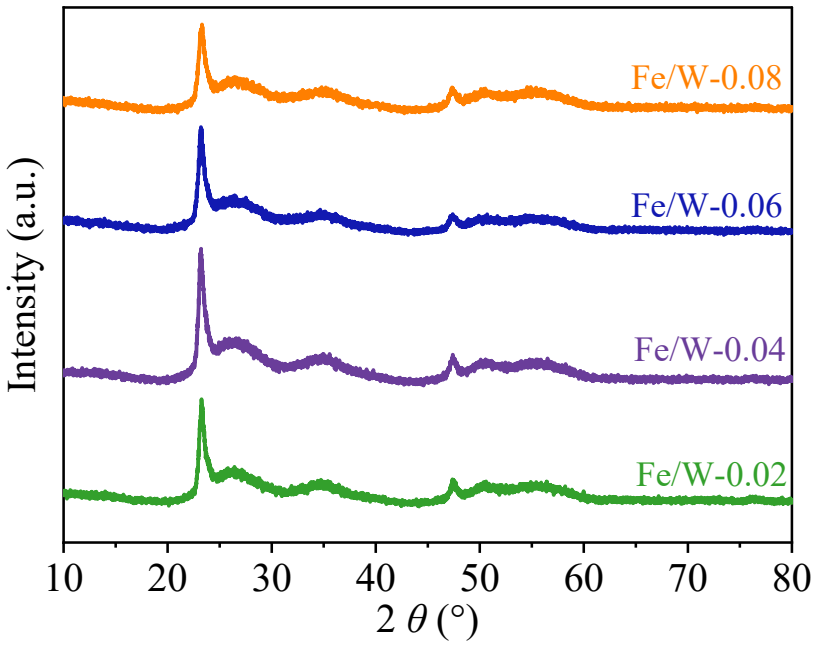


**Fig. S1** XRD patterns of Fe/W-0.02, Fe/W-0.04, Fe/W-0.06 and Fe/W-0.08 nanoparticles.

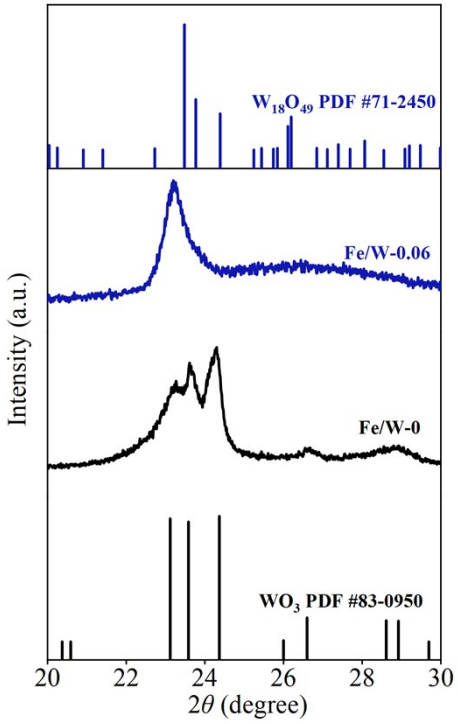


**Fig. S2** XRD patterns of Fe/W-0.06 and Fe/W-0 nanoparticles.

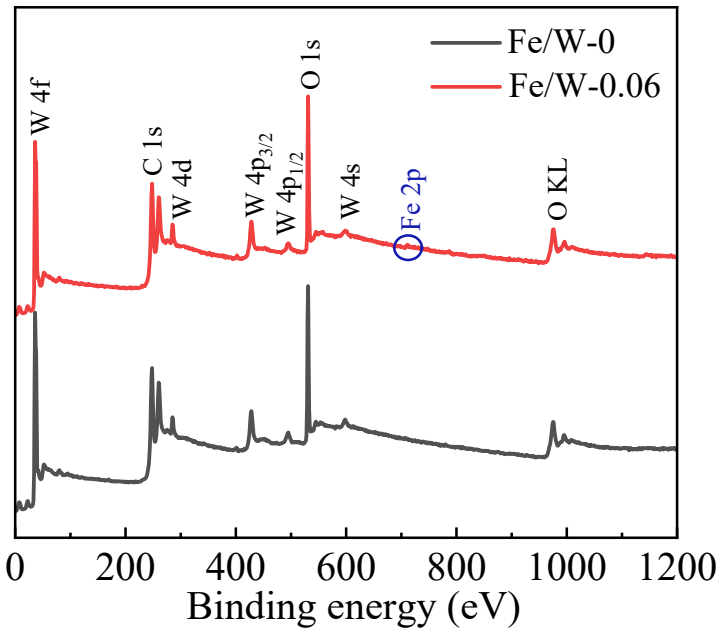


**Fig. S3** Survey XPS spectra of Fe/W-0 and Fe/W-0.06 nanoparticles.

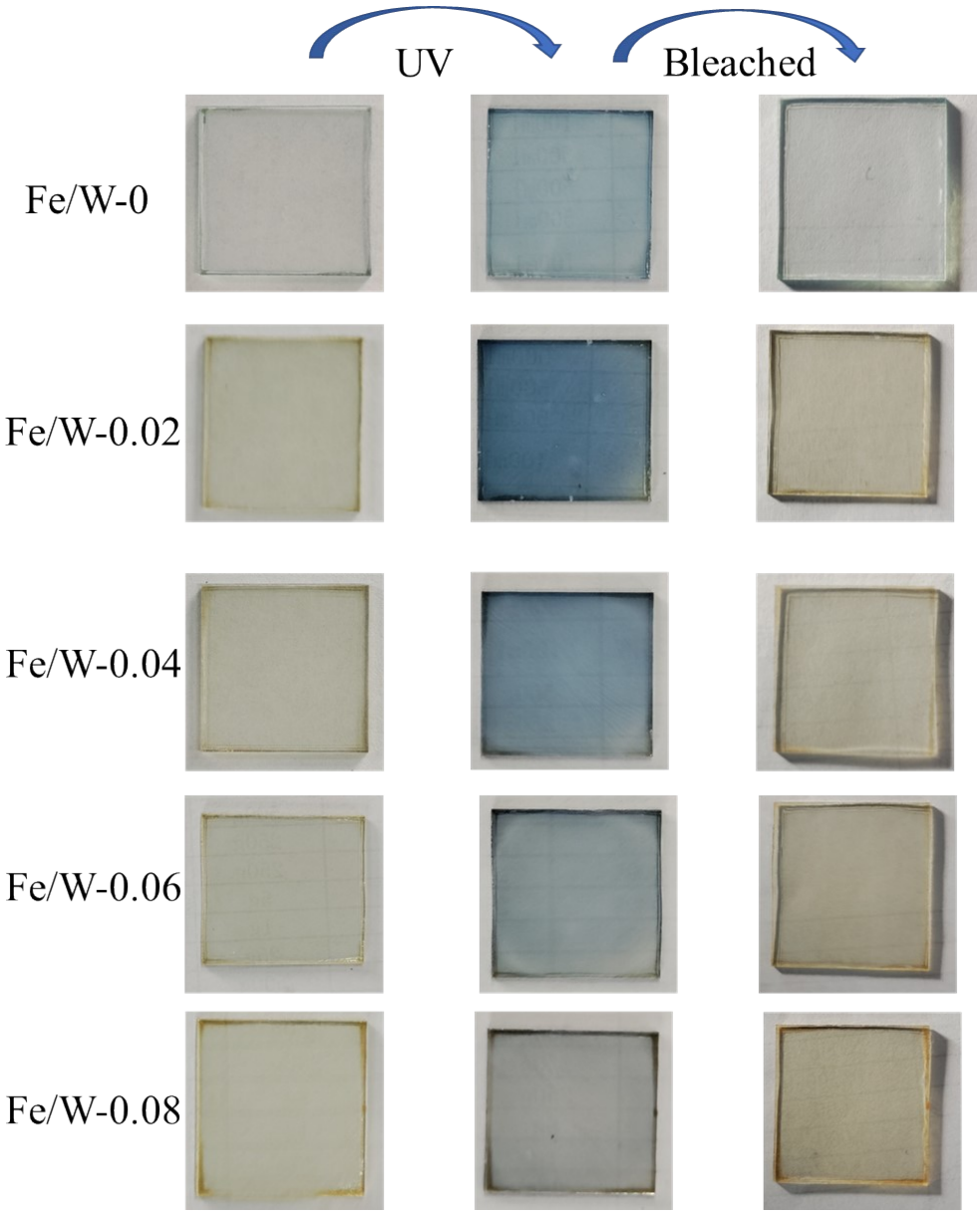


**Fig. S4** The photographs of Fe/W-0~0.08 films from bleached to colored to bleached state.

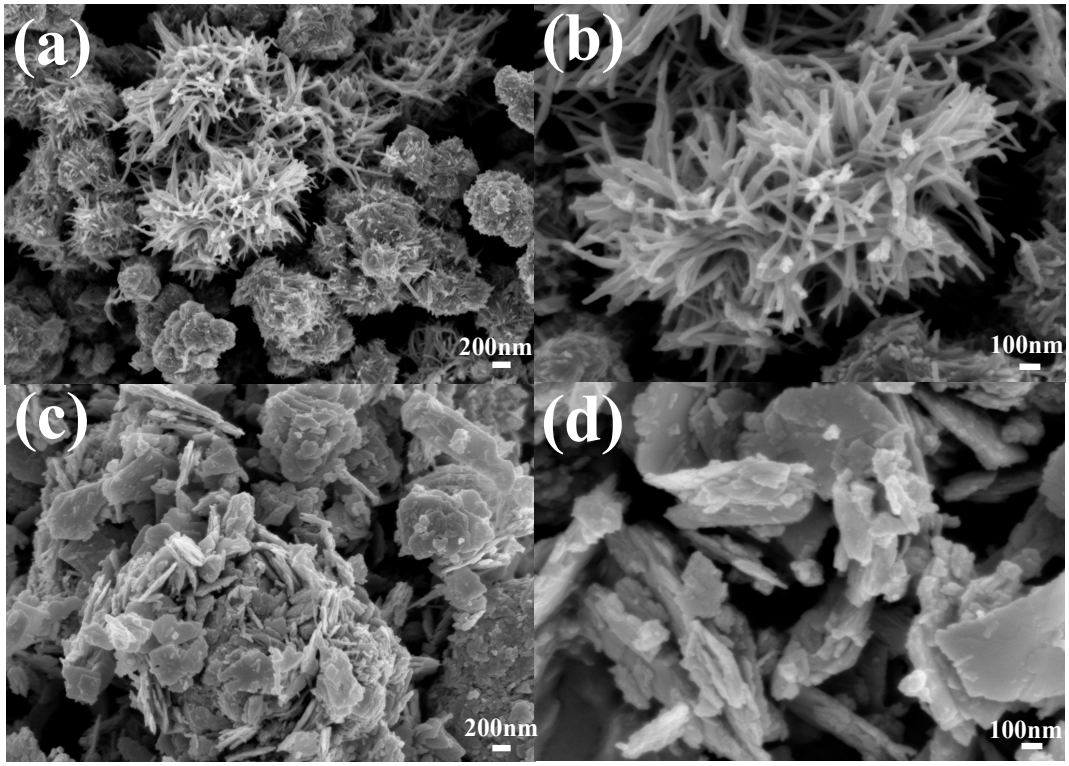


**Fig. S5** SEM image (a) and partial enlargement (b) of Fe/W-0 particles. SEM image (c) and partial enlargement (d) of Fe/W-0.06 particles.

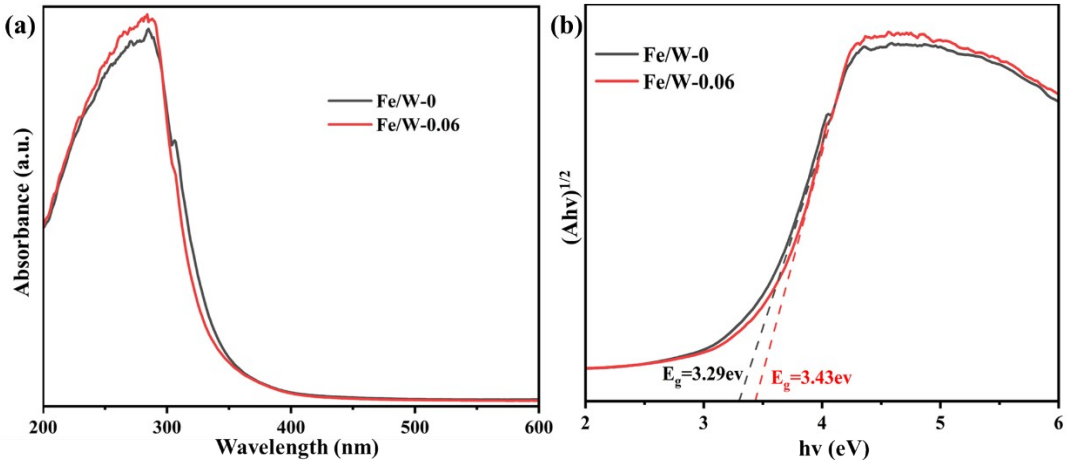


**Fig. S6** (a) UV-Vis absorption spectra of Fe/W-0 and Fe/W-0.06 particles, (b) the corresponding optical band gap. The optical bandgap *E*g was derived from equation $(\alpha hv)^m = A(hv - E_g)$, where the exponent *m* here was identified as 1/2 for indirect-allowed optical transition. By linear fitting the plot of $(\alpha h\upsilon)^{1/2}$ depend on hυ, $E_g$ was obtained from the intercept of fitted line with x axis.


**Fig. S7** Photographs of Fe/W-0.06 bilayer film during the bleaching process at 15 °C in the dark.

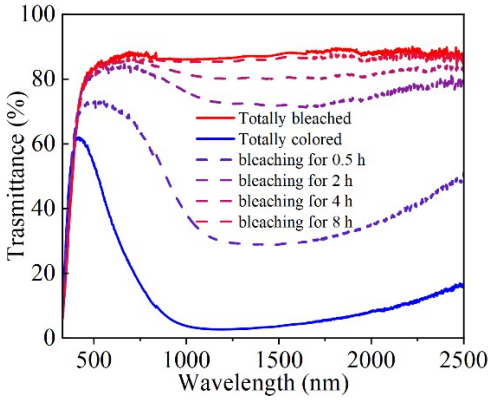


**Fig. S8** Transmittance spectra of Fe/W-0.06 bilayer film during the bleaching process at 15 °C in the dark.

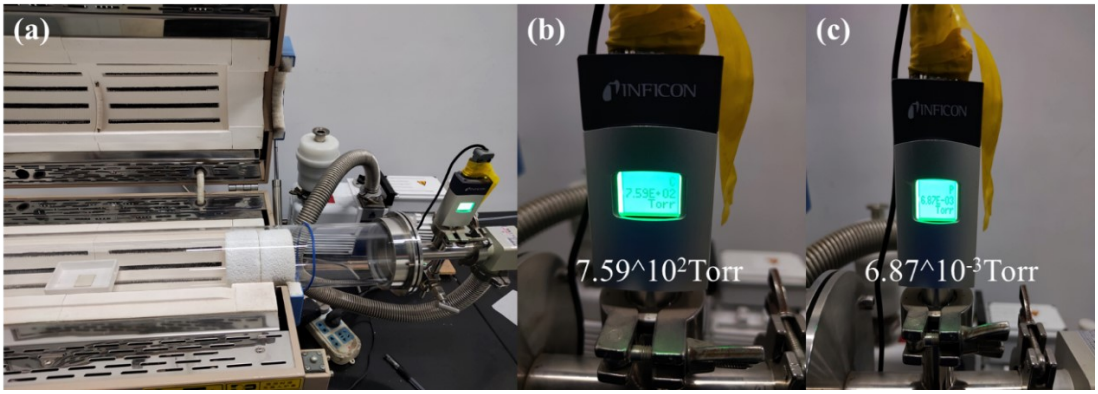


**Fig. S9** (a) Photograph of the experimental set up. The pressure in the tube furnace (b) before and (c) after evacuation (the coloring and bleaching process were taken under this condition).

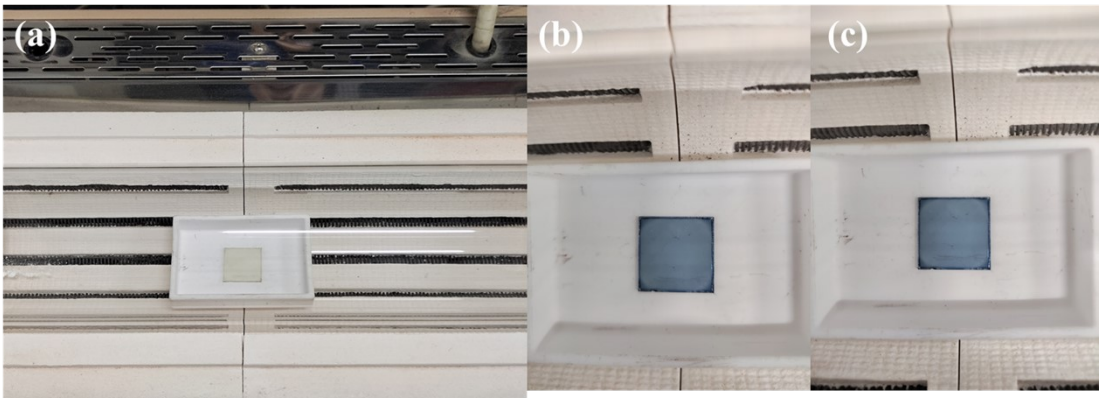


**Fig. S10** Photographs of Fe/W-0.06 bilayer films: (a) totally bleached, (b) totally colored and (c) the colored film after leaving in a vacuum tube furnace at room temperature in the dark for 8 h.

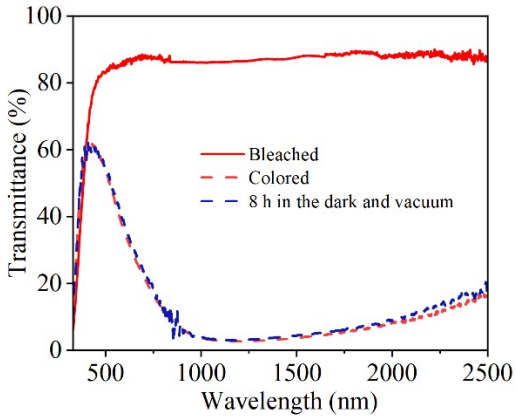


**Fig. S11** Transmittance spectra of Fe/W-0.06 bilayer film in the totally bleached and colored state, and the totally colored film after leaving in a vacuum tube furnace at room temperature in the dark for 8 h.

**Table S1** Optical properties of films with different doping $Fe^{3+}$ concentration.

| Fe/W (at.%) | $T_{sol}$ (%) | | $T_{lum}$ (%) | | $\Delta T_{sol}$ (%) |
|---|---|---|---|---|---|
| | Bleached state | Colored state | Bleached state | Colored state | |
| 0 | 83.0 | 45.5 | 87.3 | 67.8 | 37.5 |
| 2 | 84.4 | 35.6 | 88.0 | 46.7 | 48.8 |
| 4 | 85.1 | 41.1 | 87.5 | 57.0 | 44.0 |
| 6 | 84.3 | 42.6 | 87.2 | 58.3 | 41.8 |
| 8 | 84.9 | 53.6 | 87.2 | 69.6 | 31.3 |
| 6 (bilayer) | 79.9 | 19.7 | 82.9 | 34.9 | 60.2 |

**Table S2** The transmittance of films with different doping $Fe^{3+}$ concentrations at 1200 nm during the bleaching process.

| Fe/W (at.%) | Transmittance (%) | | | | | |
|---|---|---|---|---|---|---|
| | Colored state | B-5min | B-10min | B-20min | B-30min | Initial state |
| 0 | 17.95 | 42.46 | 50.43 | 62.26 | 67.09 | 81.41 |
| 2 | 20.83 | 48.85 | 60.29 | 67.80 | 71.43 | 82.81 |
| 4 | 20.13 | 66.07 | 74.70 | 79.98 | 80.44 | 85.49 |
| 6 | 21.74 | 75.39 | 81.51 | 84.16 | 84.88 | 85.56 |
| 8 | 30.59 | 82.25 | 83.89 | 84.76 | 84.85 | 86.04 |

**Table S3** Comparison between the Fe/W-0.06 bilayer film and some best reported photochromic materials in terms of photochromic performance.

| Materials | Irradiation conditions | Coloring process | Bleaching process | $\Delta T$ | Ref. |
|---|---|---|---|---|---|
| $WO_3$/PVA | 365 nm, 8 W | 5 min | Air/dark, 3 d | ~30% | [1] |
| $WO_{3-x}/Ta_2O_5$ | 365 nm, 8 W | 10 s | – | 28% at 1200 nm | [2] |
| Zn/W-0.04 | 365 nm, 5 W | <1 min | – | 47.18% | [3] |
| $WO_3$, $TiO_2$ and $SiO_2$ | 15 min, sunlight, | - | air/dark, ~2 days | 41% ($T_{vis}$) | [4] |
| Cu-$WO_3$ | 90 min, 365 nm | - | air/dark, ~3h | - | [5] |
| Fe/W-0.06 | 365 nm, 5 W | <1 min | <20 min at 80 ℃ | 60% | This work |

## References


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