Spectrally selective nanocoatings with synergistically enhanced photocatalytic and solar light modulation properties

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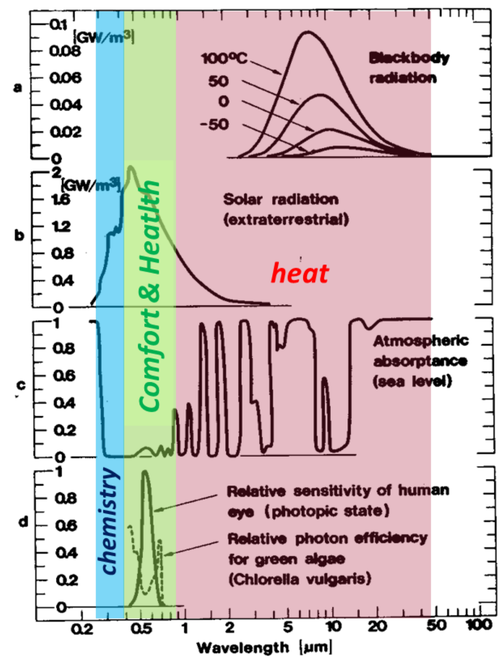
Abstract

Spectrally selective nanocoatings that exhibit **synergistically enhanced solar light modulation, luminous transmittance and catalytic properties** can be made by combining dielectric film stacks with complementary optical and structural properties. Here we show two case studies:

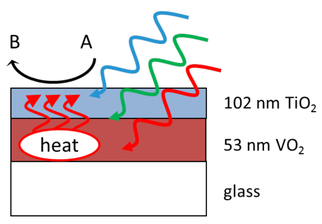
1)TiO_2/VO_2 luminous transparent bilayers that exhibits enhanced near-infrared light absorption and heats the TiO_2 film by up to ~ 30°C resulting in ~ 2-fold increase of the photocatalytic reaction rate. The TiO_2/VO_2 bilayer stack exhibits anti-reflective properties, and enhanced solar light modulation (~ 9%) compared to VO_2, and ~ 20 times% increased solar absorptance compared to TiO_2. In addition the TiO_2 chemically protects the VO_2 layer avoiding oxidation to vanadium pentoxide.

2)TiO_2/TiAlN solar absorber bilayers that yield an almost ~ 10-fold enhancement of the quantum yield for acetaldehyde removal (on par with state-of-the-art, heterojunction photocatalysts), and an associated temperature rise ~120 °C.

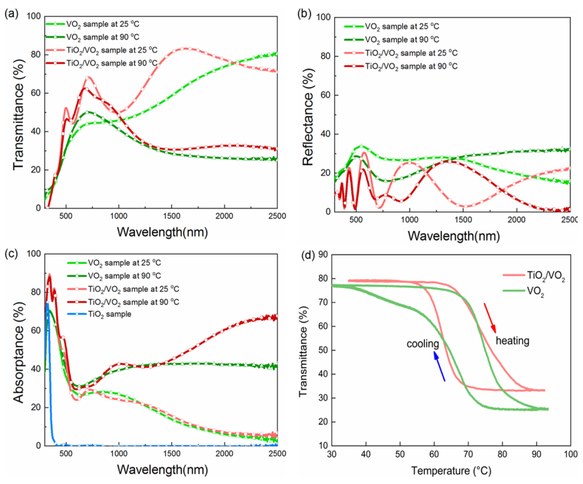
Light around us: Sun, heat, atmosphere and life



TiO_2/VO_2 luminous transparent bilayers

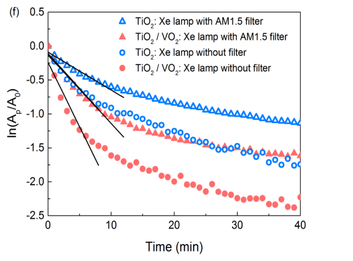


Optical properties



The TiO_2/VO_2 bilayer stack exhibits anti-reflective properties, enhanced solar modulation (~ 9%) compared to VO_2, and ~ 20 times% increased solar absorptance compared to TiO_2.

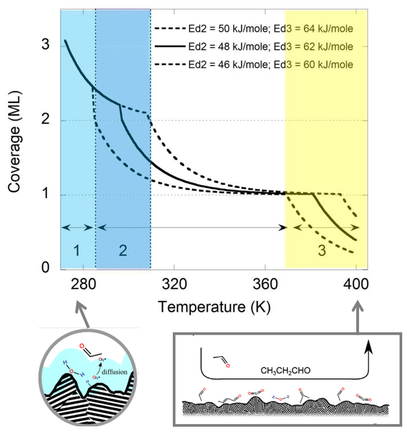
Photocatalytic properties



Quantum yield/ Temperature rise				
TiO_2	2.1 ± 0.2 / 0.8°C	1.5 ± 0.2 / 0.7 °C	0.50 ± 0.05 / 3.2°C	18 ± 2 / 0.2°C
TiO_2/VO_2	2.8 ± 0.3 / 17°C	2.5 ±0.3 / 18°C	0.93 ± 0.09 / 35°C	15 ±2 / 0.2

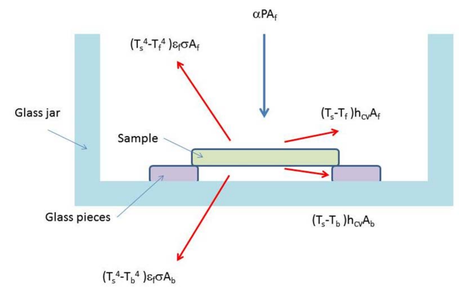
Effect of temperature

- Thermally enhanced reaction kinetics
- Desorption of water from the catalyst surface which otherwise acts as a diffusion barrier.



1. Multilayer builds up < 300 K
2. Bilayer 300 < T < 380 K
3. Submonolayer T > 380 K

Irradiation heating

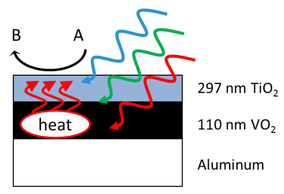


$$A_{source}P_{source} = (\varepsilon_f + \varepsilon_g)\sigma[(T_s + \Delta T_s)^4 - \tau_s^4] + 2h_c\Delta T_s + x\kappa\Delta T_s$$

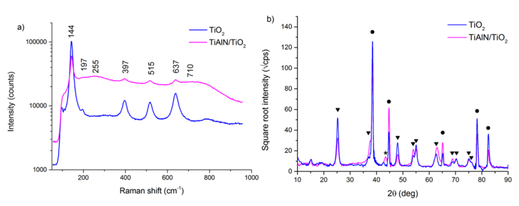
$$A_{source} = \frac{\int_{200}^{2500}[1 - T(\lambda) - R(\lambda)]\varphi_{source}\,d\lambda}{\int_{200}^{2500}\varphi_{source}\,d\lambda}$$

φ_{source} : irradiance spectrum.
P_{source}: illumination power (1700 W m^{-2} for simulated solar light, 4330 W m^{-2} for the unfiltered Xe lamp, and 7 W m^{-2} for the UV-LED)
ε_f : film's emissivity (0.84 for the TiO_2 film, 0.84 for the TiO_2/VO_2 bilayer sample at $\tau < \tau_c$, and 0.74 for the same sample at $\tau > \tau_c$)
ε_g: glass emissivity (0.84)
σ: Stefan-Boltzmann's constant,
h_c : heat-transfer coefficient due to convection (11 W m^{-2} K^{-1})
x=0.01: fraction of the sample area in contact with the sample holder
κ: is the heat conductivity of the glass substrate (1 W m^{-1} K^{-1}).
$\Delta\tau$: is the temperature rise in the film due to illumination and τ_s is the film temperature.

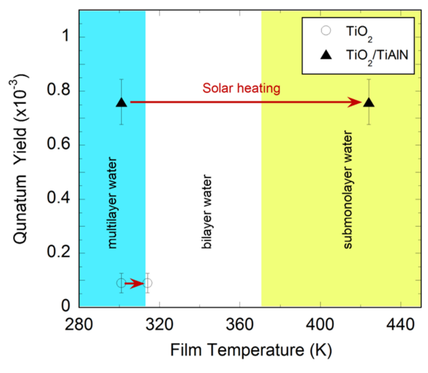
TiO_2/TiAlN solar absorber bilayers



Bilayer structure



Photocatalytic properties



Optical properties

Film	Solar absorptance α_{sol}	Thermal emittance $\varepsilon(373\ \mathrm{K})$
TiO_2	0.32	0.06
TiO_2/TiAlN	0.71	0.07
TiAlN	0.72	0.06

Solar absorption heats the film by ~120 °C. An accompanying increase of the quantum yield for acetaldehyde photodegradation of about 10 times is found

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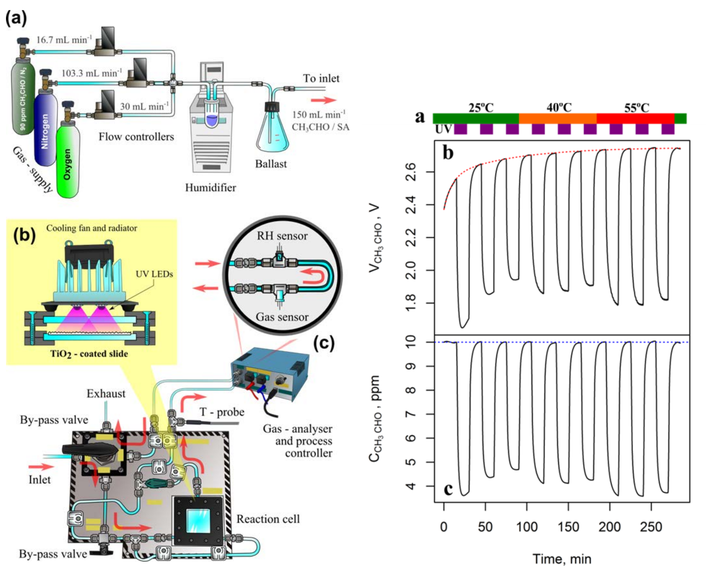
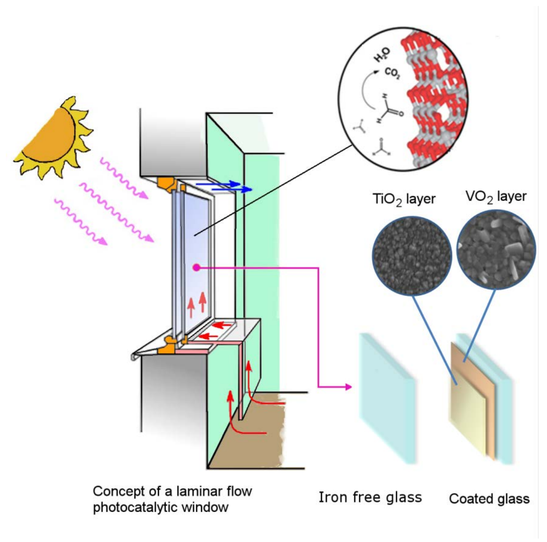
An indoor air cleaning window



Concept of indoor air cleaning window



- Double pane window setup with iron free glass. One pane is coated on the inside with a 50 x 50 mm (001) oriented TiO_2 film
- 365 nm LED array (13 mW cm^{-2})
- T and RH control
- 1-pass air cleaning of acetaldehyde

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