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Supporting Information

Inkjet Printing of Vanadium Dioxide Nanoparticles for Smart Windows

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Experimental Section

Preparation of VO_2 nanoparticles: All reagents were purchased from Aladdin chemical reagent corporation and used without further purification. VO_2 nanoparticles were prepared via a one-step hydrothermal method. In a typical procedure, 2.34g NH_4VO_3 and 1.40 g $N_2H_4 \cdot HCl$ were dispersed in 70 mL deionized water. The suspension was stirred for 30 min and then transferred to a 100 mL Teflon-lined stainless-steel autoclave. The autoclave was maintained at 280 °C for 24 h and then air-cooled to room temperature.

Ink formulation: The inks were prepared in the following way: in brief, 8 g VO_2 nanoparticles as-prepared were dispersed in 120 g mixed solvent containing 25 wt.% butyl ethanoate and 75 wt.% dimethylbenzene with an ultrasonic probe for 30 min before milling. Then 0.4 g dispersant DISPERBYK-110 and 24 g fluorocarbon resin were added into the obtained VO_2 dispersion. Full dispersion was realized by milling on a high energy bead mill for 10 hours with the aid of 0.8 mm diameter zirconia beads. Thus, VO_2 inks were successfully obtained.

Inkjet printing: The ordinary VO_2 film and patterned VO_2 film were fabricated onto the PET substrate using a commercial Epson Stylus Photo R330 inkjet printer. The printed films were required further thermal treatment for 5 minutes in an oven at 80 °C after printing in order to solidify the films. No pretreatment of the substrate was required. VO_2 films were printed with different layers. It should be noted that one common problem during printing is the plugging of the nozzle of a printer, which is destructive for the inkjet printing process. To avoid any plugging of printing nozzles, VO_2 inks were filtered with a 0.45 μm filter to remove any large residues.

Characterization Techniques: X-ray diffraction (XRD) patterns were obtained using a Bruker D8 advance diffractometer equipped with monochromatic Cu Kα radiation

(λ=0.15406 nm). Raman spectroscopy was performed in a Horiba JY HR Evolution Raman Spectrometer with excitation wavelength 532 nm. SEM images and elemental composition were determined by a Hitachi S4800 field-emission scanning electron microscope with an energy dispersive spectrometry (EDS) attachment. TEM and HRTEM images were obtained using a FEI Tecnai F20 transmission electron microscopy at an acceleration voltage of 200 kV. The viscosity of the inks was measured via a digital MYR VR3000 viscometer at 25 ± 0.1 °C. The surface tension was examined by a KINO A101S surface tension instrument using the Wilhelmy plate method. The temperature was controlled through a thermostat water bath. All the measurements were repeated three times and averaged. The particle size analyses of the inks were performed using a Malvern Nano ZS90 zetasizer instrument.

Thermochromic Properties: The optical transmittance characteristics was monitored using a Perkin-Elmer Lambda-950 UV-VIS-NIR spectrophotometer equipped with a heating unit in the wavelength range of 350–2500 nm. The integrated visible transmittance (T_{lum} 380-780 nm) and solar modulating ability (ΔT_{sol}, 350-2500 nm) were calculated using the following equation:

$$T_i = \frac{\int \varphi_i(\lambda) T(\lambda) d\lambda}{\int \varphi_i(\lambda) d\lambda}$$

In which $T(\lambda)$ is the transmittance of VO_2 film. I denoted lum or sol for the calculations; φ_{lum} is the standard luminous efficiency function for photopic vision, and φ_{sol} is the solar irradiance spectrum for air mass 1.5 (corresponding to the sun standing 37° above the horizon). The hysteresis loop of the transmittance at the wavelength of 1500 nm was recorded at the temperatures ranging from 25°C to 95 °C.

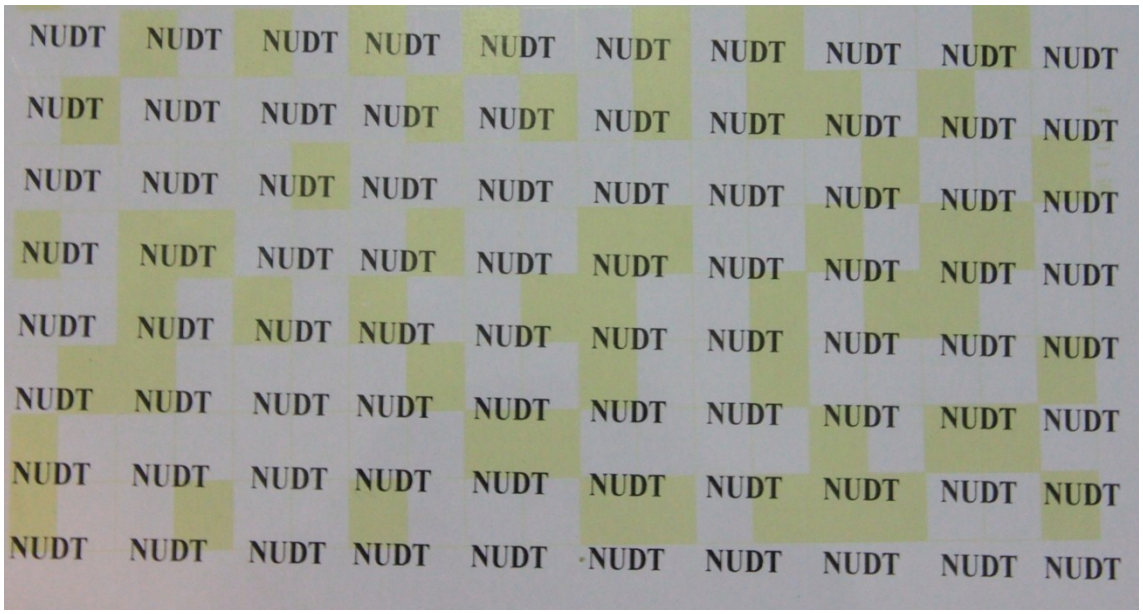

Figure S1. A digital pattern VO_2 film printed on a PET substrate

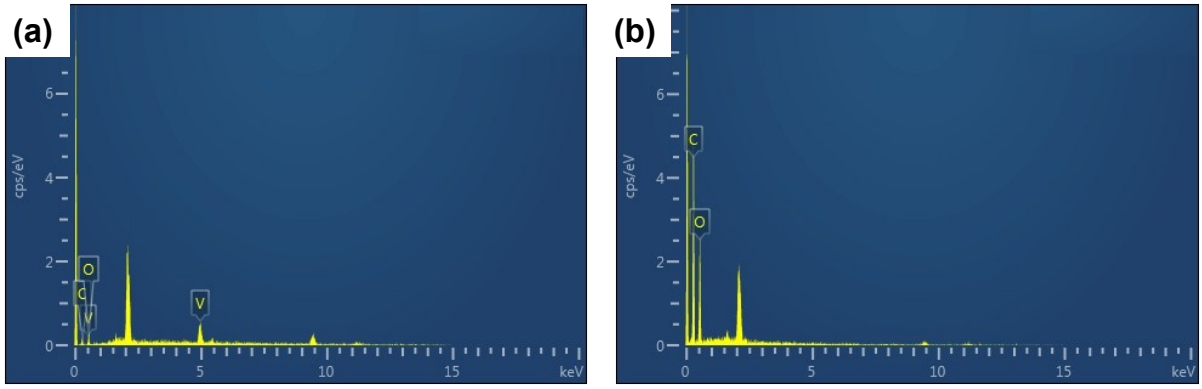

Figure S2. EDS spectra of two different regions a and b in the cross-sectional SEM images

Figure 4c.

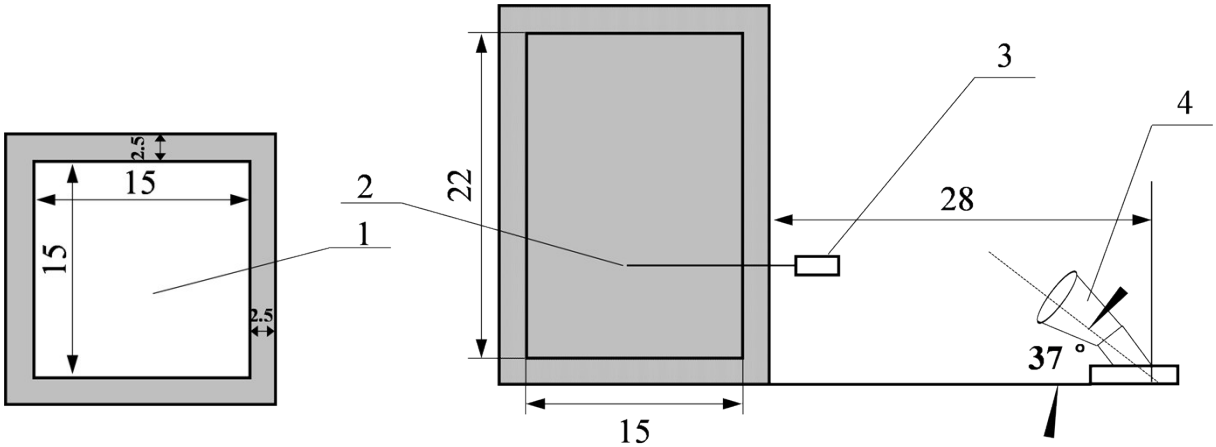

Figure S3. Schematic description of a model house (1.the blank float glass or VO2 glass; 2. temperature probe; 3. temperature monitor; 4. infrared lamp)

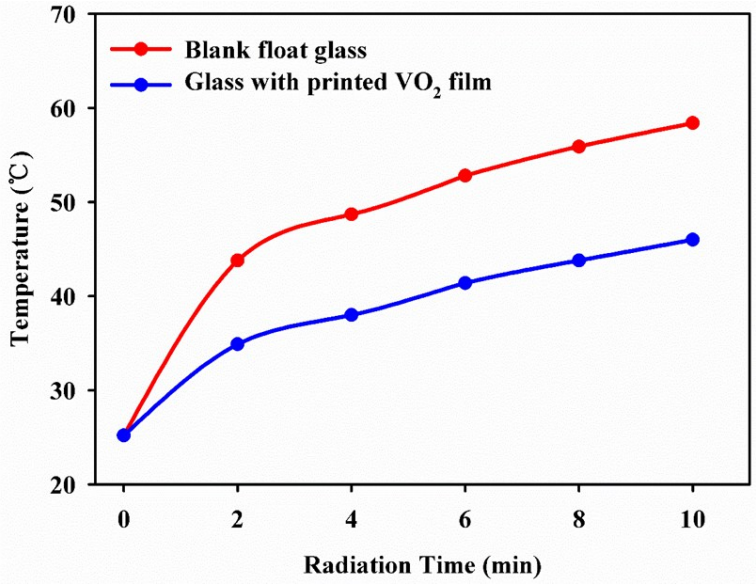

Figure S4. The temperature profiles of the blank float glass window and smart window under different radiation time