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Electronic Supplementary Information

Efficient and stable perovskite solar cells based on high-quality $CH_3NH_3PbI_{3-x}Cl_x$ films modified by V_2O_x additives

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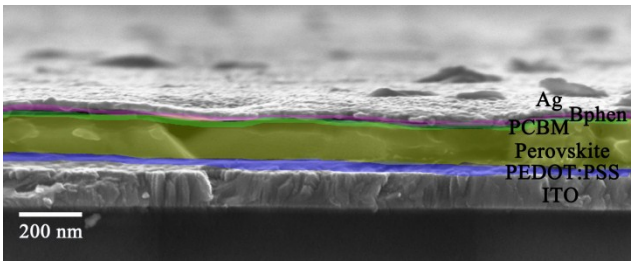

Fig. S1 The cross-section FESEM image of PSC with $CH_3NH_3PbI_xCl_{3-x}$:V_2O_x (2.5 wt%).

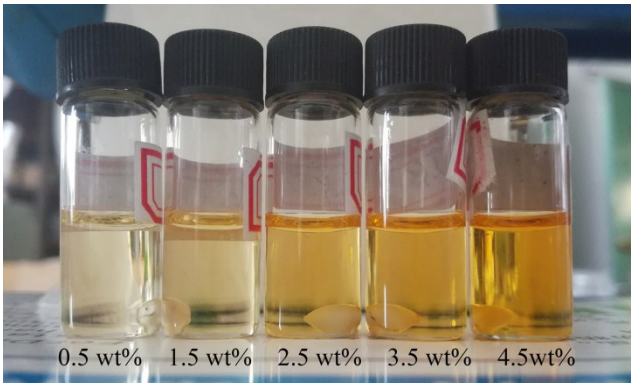

Fig. S2 The photograph of mixed DMF solvents with different V_2O_x aqueous solution (0 wt%, 0.5 wt%, 1.5 wt%, 2.5 wt%, 3.5 wt% and 4.5 wt%).

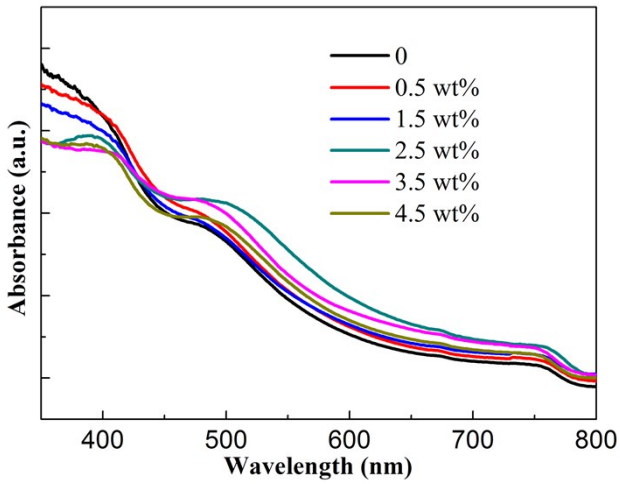

Fig. S3 The absorption spectra of the perovskite films with different V_2O_x additives concentration (0 wt%, 0.5 wt%, 1.5 wt%, 2.5 wt%, 3.5 wt% and 4.5 wt%).

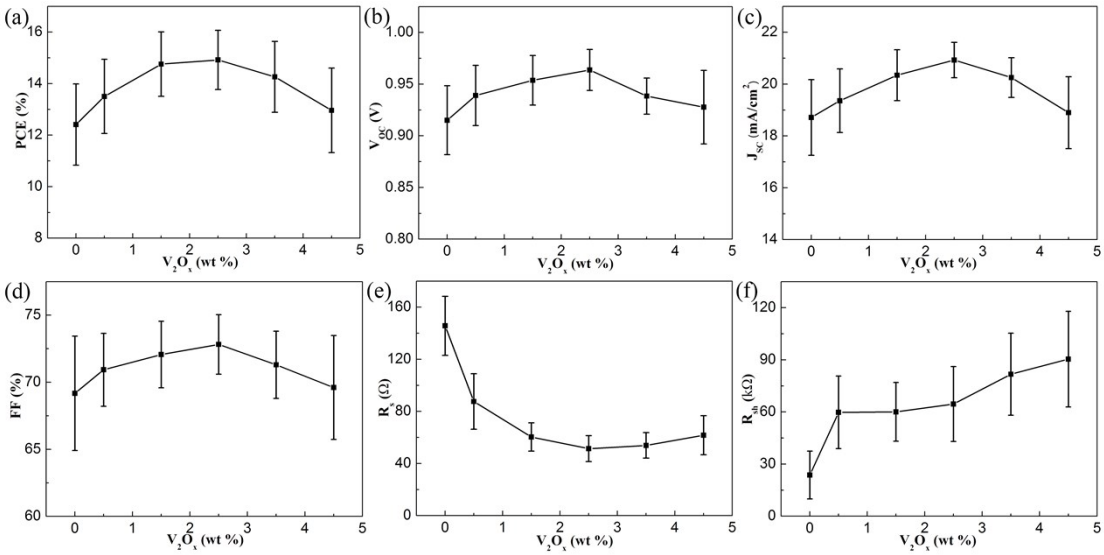

Fig. S4 The mean and standard deviations of the (a) PCE, (b) V_{OC}, (c) J_{SC} (d) FF, (e) R_s and (f) R_{sh} of the PSCs with different V_2O_x additives concentration (0 wt%, 0.5 wt%, 1.5 wt%, 2.5 wt%, 3.5 wt% and 4.5 wt%).

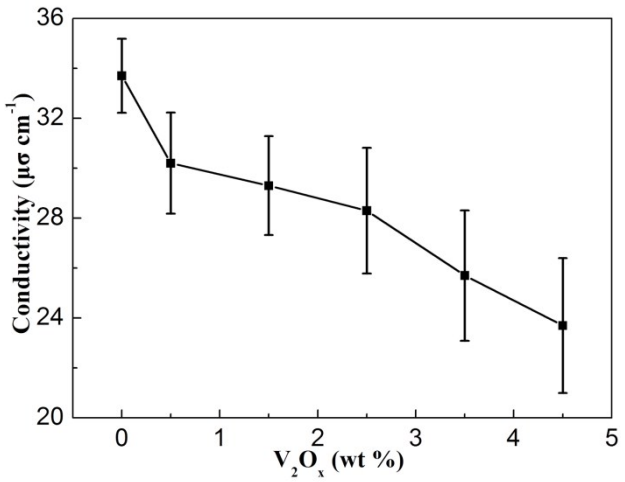

Fig. S5 The conductivity of $CH_3NH_3PbI_{3-x}Cl_x$ films with different V_2O_x concentration (0 wt%, 0.5 wt%, 1.5 wt%, 2.5 wt%, 3.5 wt% and 4.5 wt%).

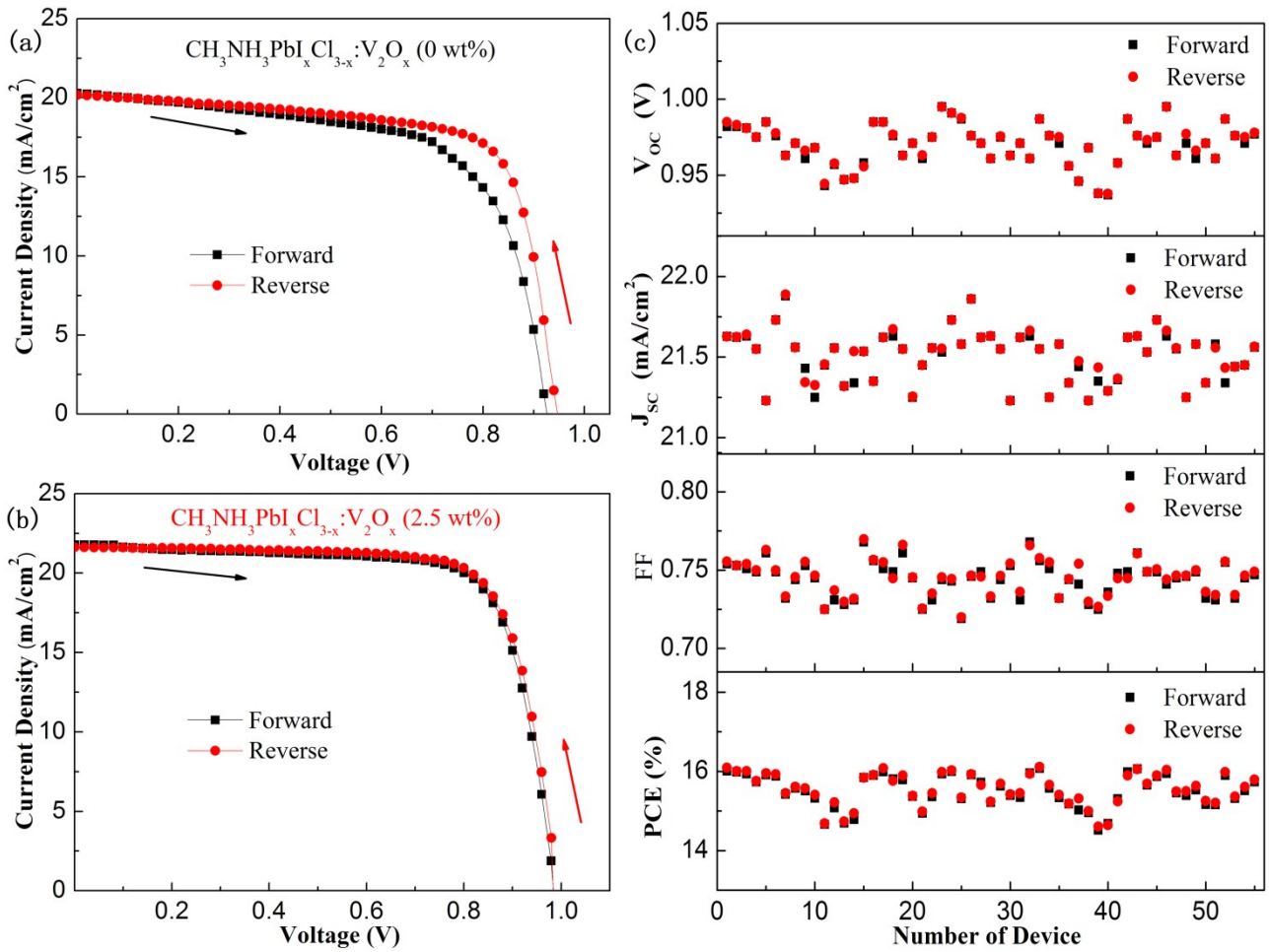

Fig. S6 *J-V* curves of devices with (a) $CH_3NH_3PbI_xCl_{3-x}:V_2O_x$ (0 wt%) and (b) $CH_3NH_3PbI_xCl_{3-x}:V_2O_x$ (2.5 wt%). (c) the hysteresis behavior of all the 55 cells with $CH_3NH_3PbI_xCl_{3-x}$ (2.5 wt%).

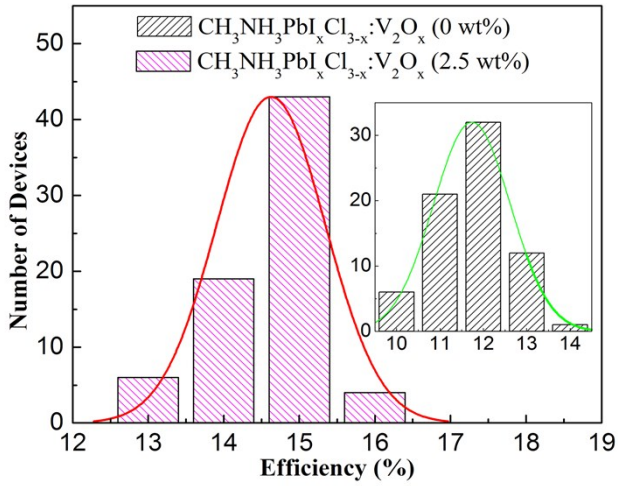

Fig. S7 The histogram of PCEs of 72 PSCs with $CH_3NH_3PbI_xCl_{3-x}$:V_2O_x (2.5 wt%). Inset is the histogram of PCEs of 72 PSCs with $CH_3NH_3PbI_xCl_{3-x}$:V_2O_x (0 wt%).

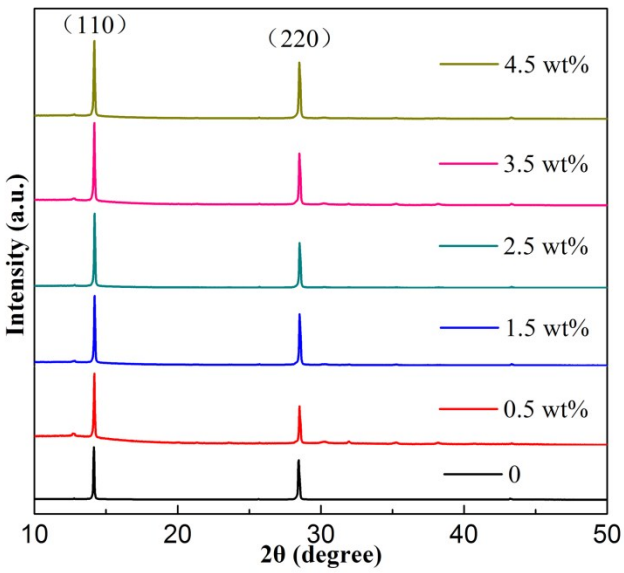

Fig. S8 XRD patterns of $CH_3NH_3PbI_{3-x}Cl_x$ films with different V_2O_x concentration (0 wt%, 0.5 wt%, 1.5 wt%, 2.5 wt%, 3.5 wt% and 4.5 wt%).

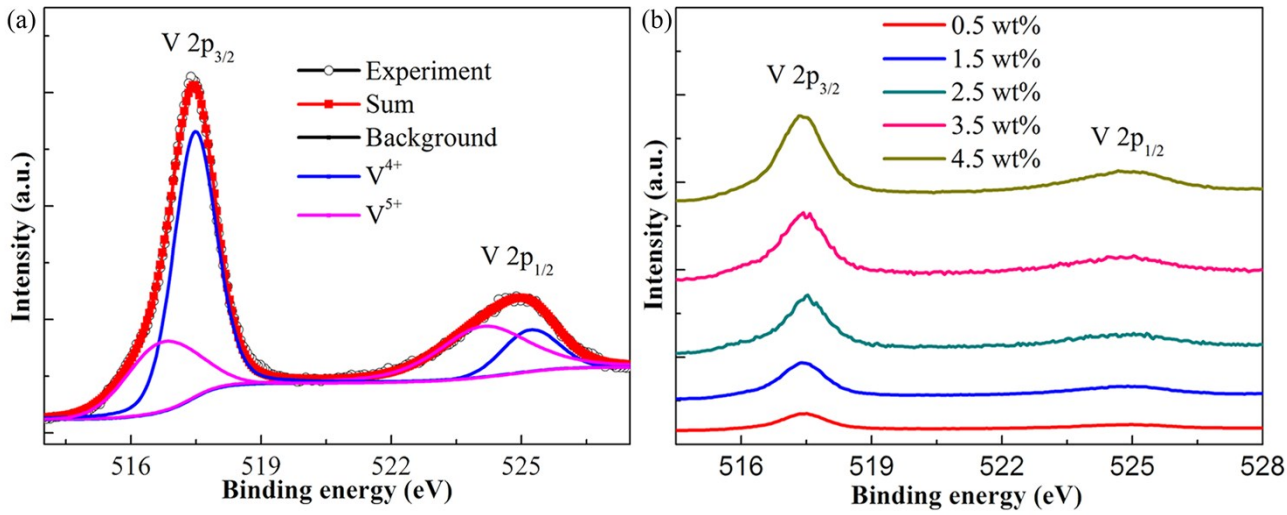

Fig. S9 (a) The high-resolution XPS spectrum of V of V_2O_x film in different oxidation states. (b) The XPS spectra of $CH_3NH_3PbI_{3-x}Cl_x$ films with different V_2O_x concentration (0 wt%, 0.5 wt%, 1.5 wt%, 2.5 wt%, 3.5 wt% and 4.5 wt%).

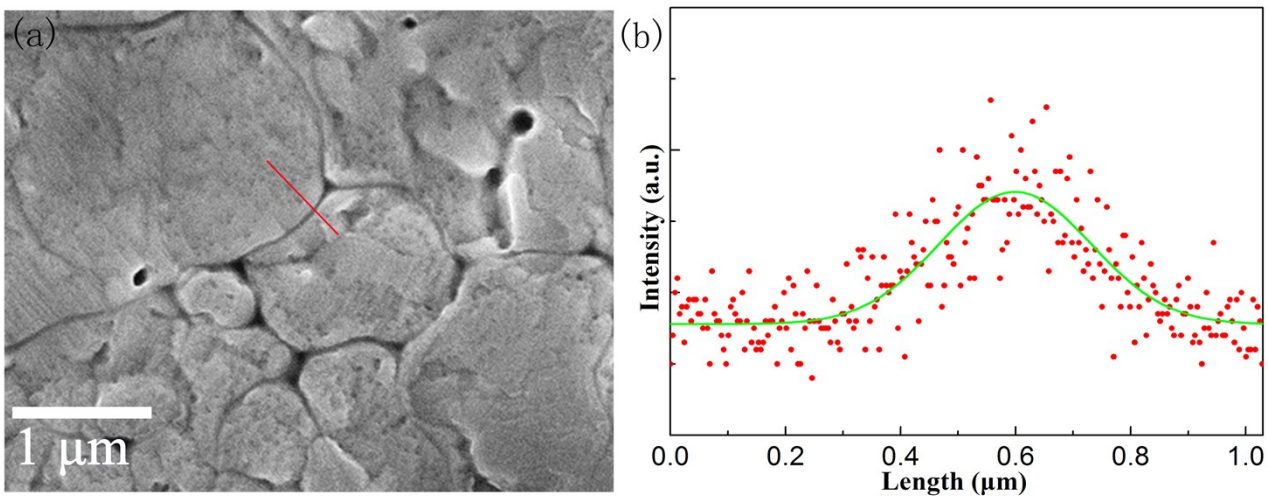

Fig. S10 (a) The FESEM images and (b) corresponding EDS line scan spectra are performed on the $CH_3NH_3PbI_xCl_{3-x}$:V_2O_x (2.5 wt%) film.

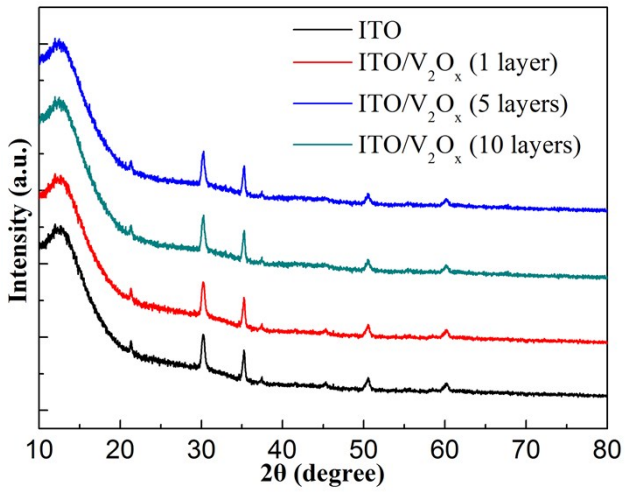

Fig. S11 The XRD pattern of V_2O_x films with different layers on ITO substrates.

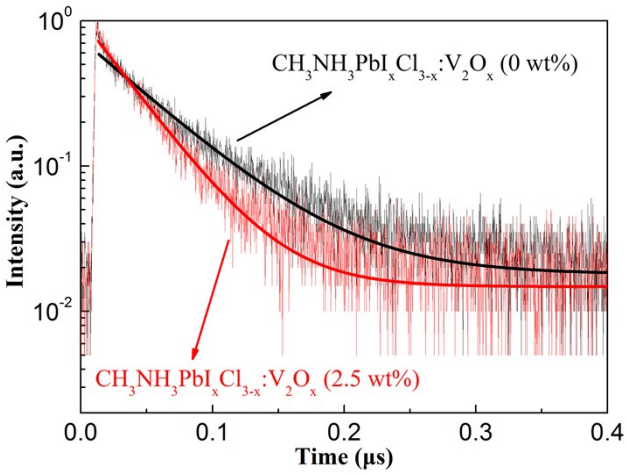

Fig. S12 The time-resolved PL spectra of the PSCs with $CH_3NH_3PbI_xCl_{3-x}$:V_2O_x (0 wt%) and $CH_3NH_3PbI_xCl_{3-x}$:V_2O_x (2.5 wt%),

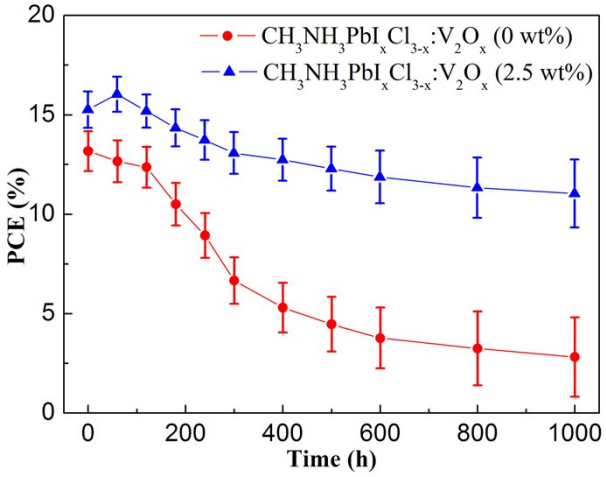

Fig. S13 The 1000 hour stability of PSCs with $CH_3NH_3PbI_xCl_{3-x}$:V_2O_x (0 wt%) and $CH_3NH_3PbI_xCl_{3-x}$:V_2O_x (2.5 wt%).

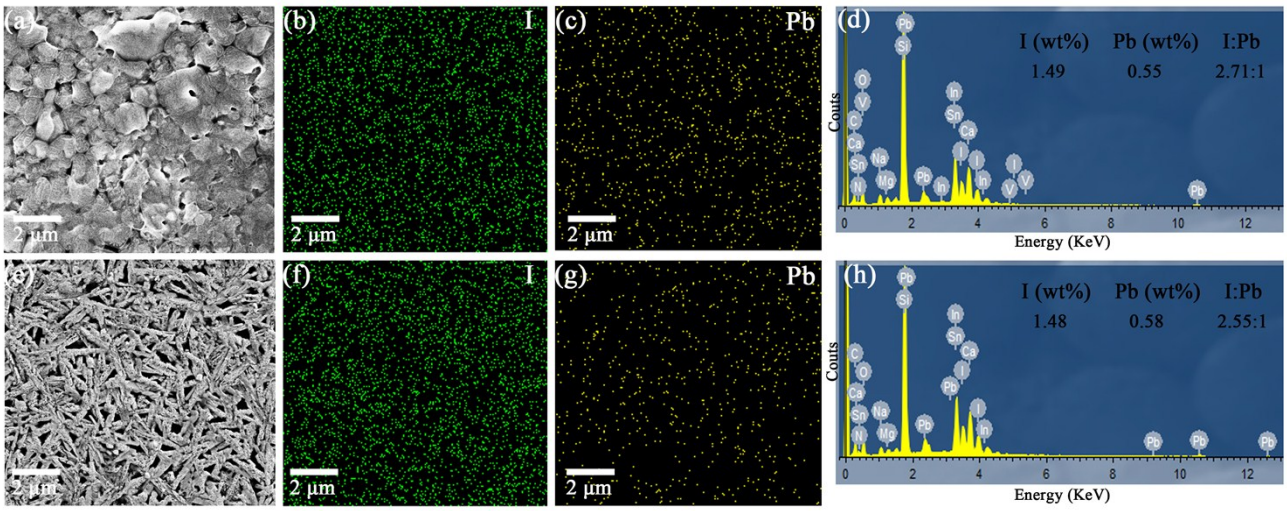

Fig. S14 The surface FESEM images together with elemental mappings and EDS spectra are performed on (a-d) the aged $CH_3NH_3PbI_xCl_{3-x}$:V_2O_x (2.5 wt%) film and (e-h) the $CH_3NH_3PbI_xCl_{3-x}$:V_2O_x (0 wt%) film, respectively.