Supplementary Information

Vitamin A as a simple, dual-role agent for the band bending-induced passivation of perovskite solar cells

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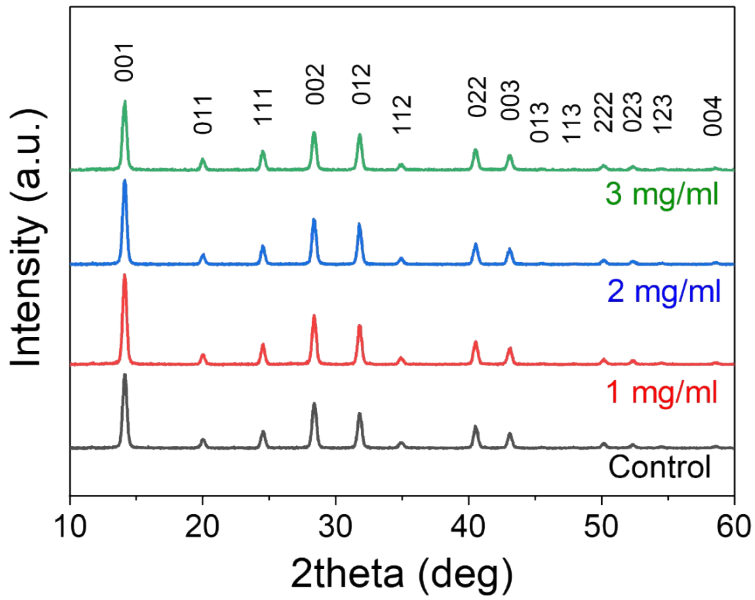

Fig. S1. XRD patterns of perovskite films with 0 (control) 1, 2 and 3 mg/ml of vit A.

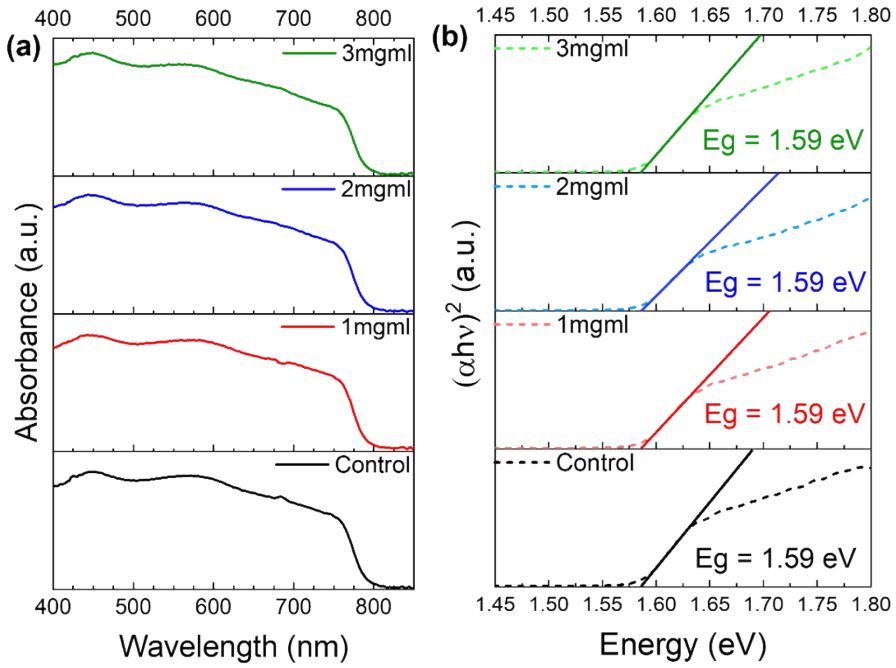

Fig. S2. UV-vis absorption spectrum (a) of perovskite films with 0 (control), 1, 2 and 3 mg/ml of vit A and its corresponding Tauc plots and estimated band gap (b).

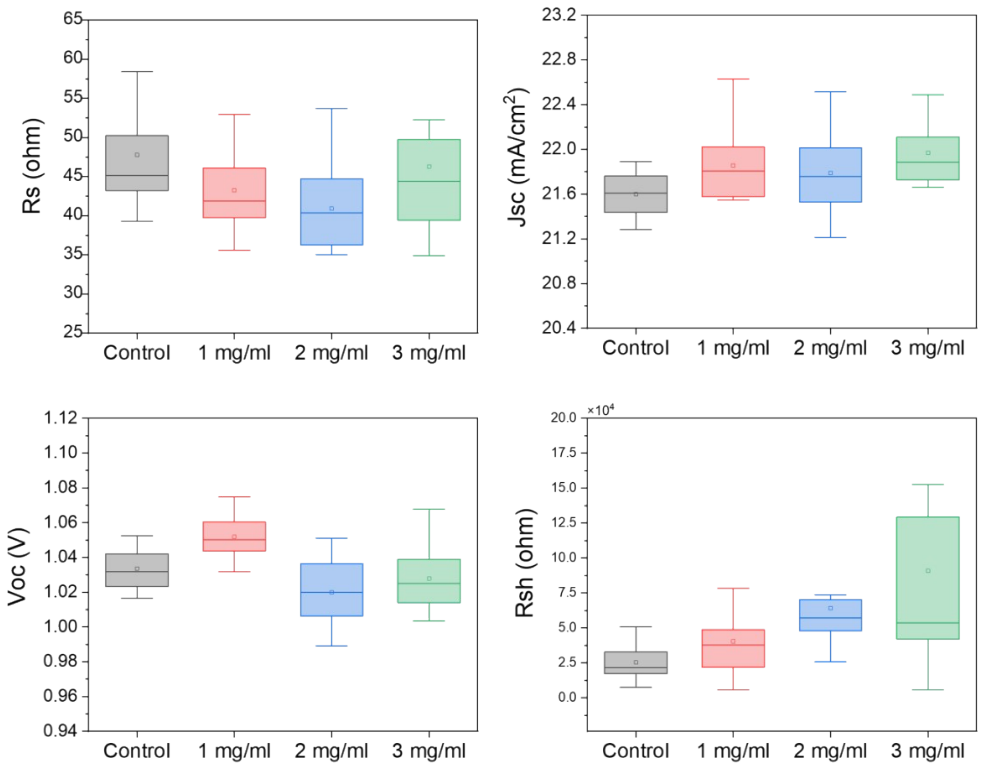

Fig. S3. Photovoltaic property distributions of perovskite solar cells with 0 (control), 1, 2 and 3 mg/ml of vit A.

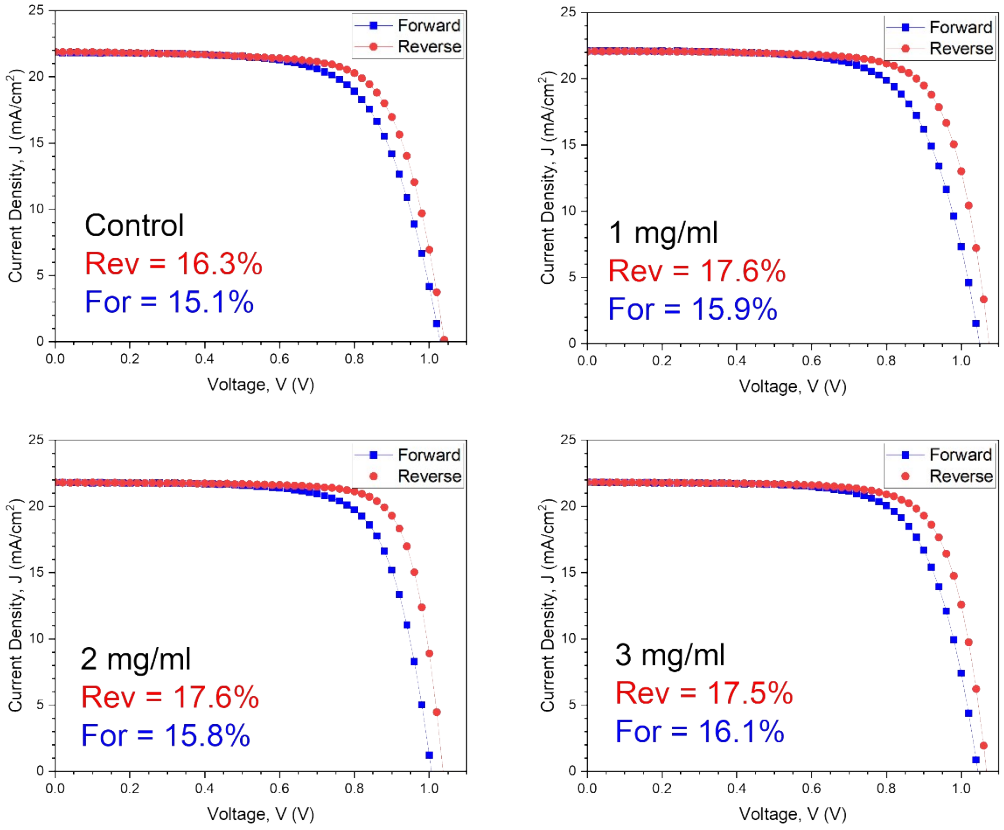

Fig. S4. Forward and reverse J–V scans of the best-performing perovskite solar cell devices with 0 (control), 1, 2, and 3 mg/ml of vit A.

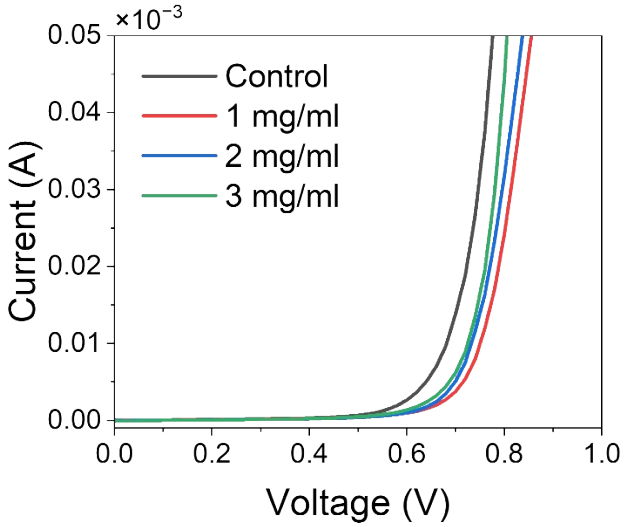

Fig. S5. Dark *J-V* curves of perovskite solar cells with 0 (control), 1, 2 and 3 mg/ml of vit A

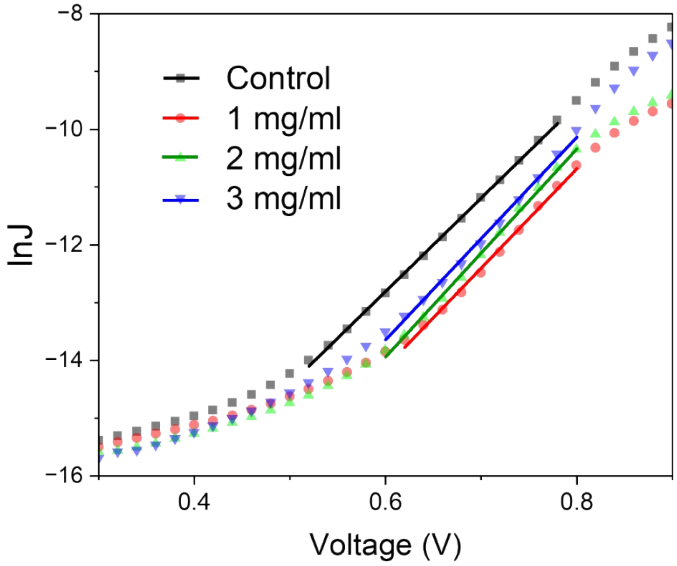

Fig. S6. ln J vs. V for for perovskite solar cells with 0 (control) of 1, 2, and 3 mg/ml of vit A surface treatments. The straight-line segments mark the voltage window used for linear fitting to extract the saturation current density J_0 by the Shockley-diode method. Detailed values of the fitting parameters are listed in Table S1.

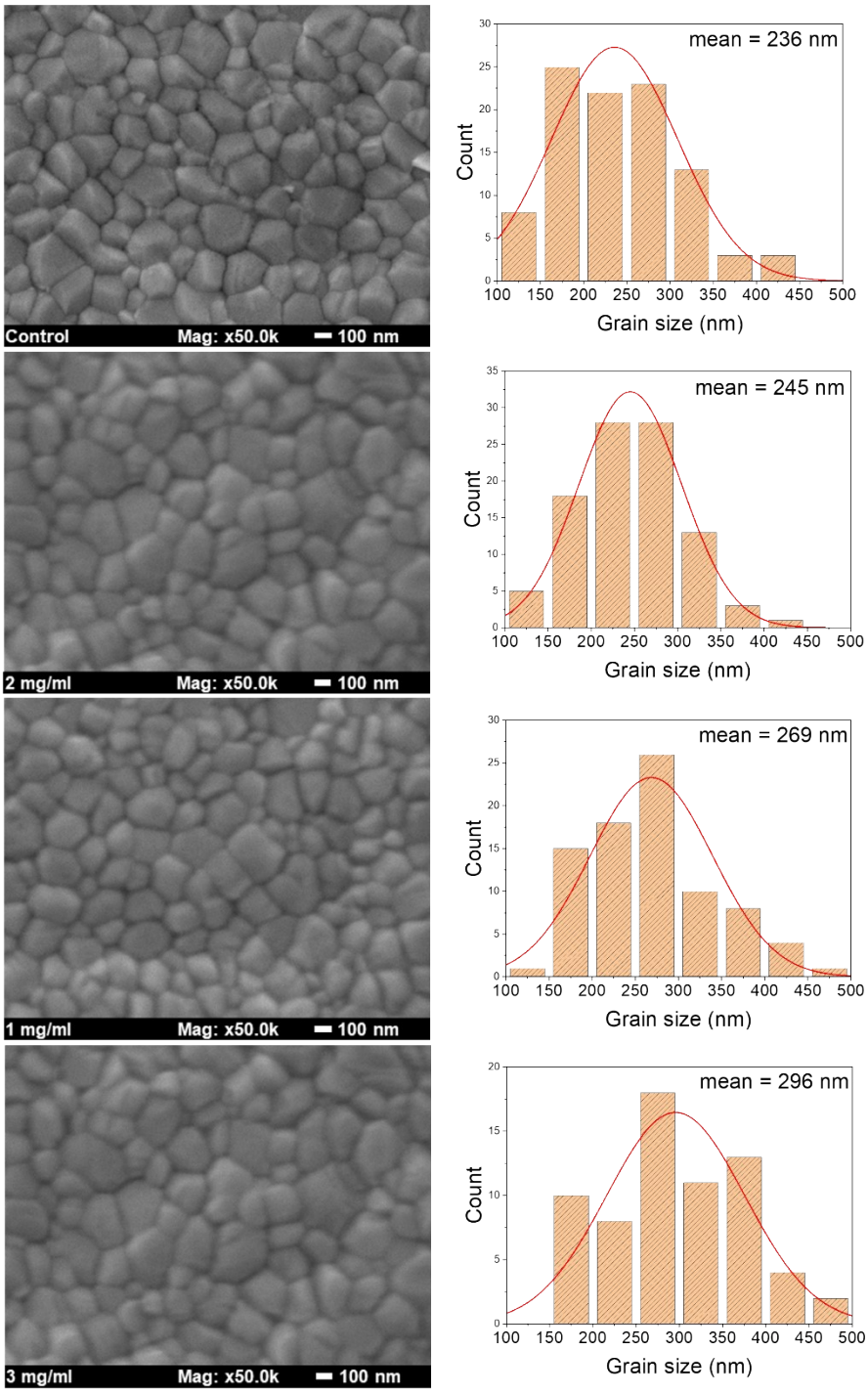

Fig. S7. Scanning electron microscopy (SEM) images of perovskite films with 0 (control), 1, 2 and 3 mg/ml of vit A, and their corresponding grain size distribution. The perovskite film samples were deposited on glass/FTO substrate with SnO_2.

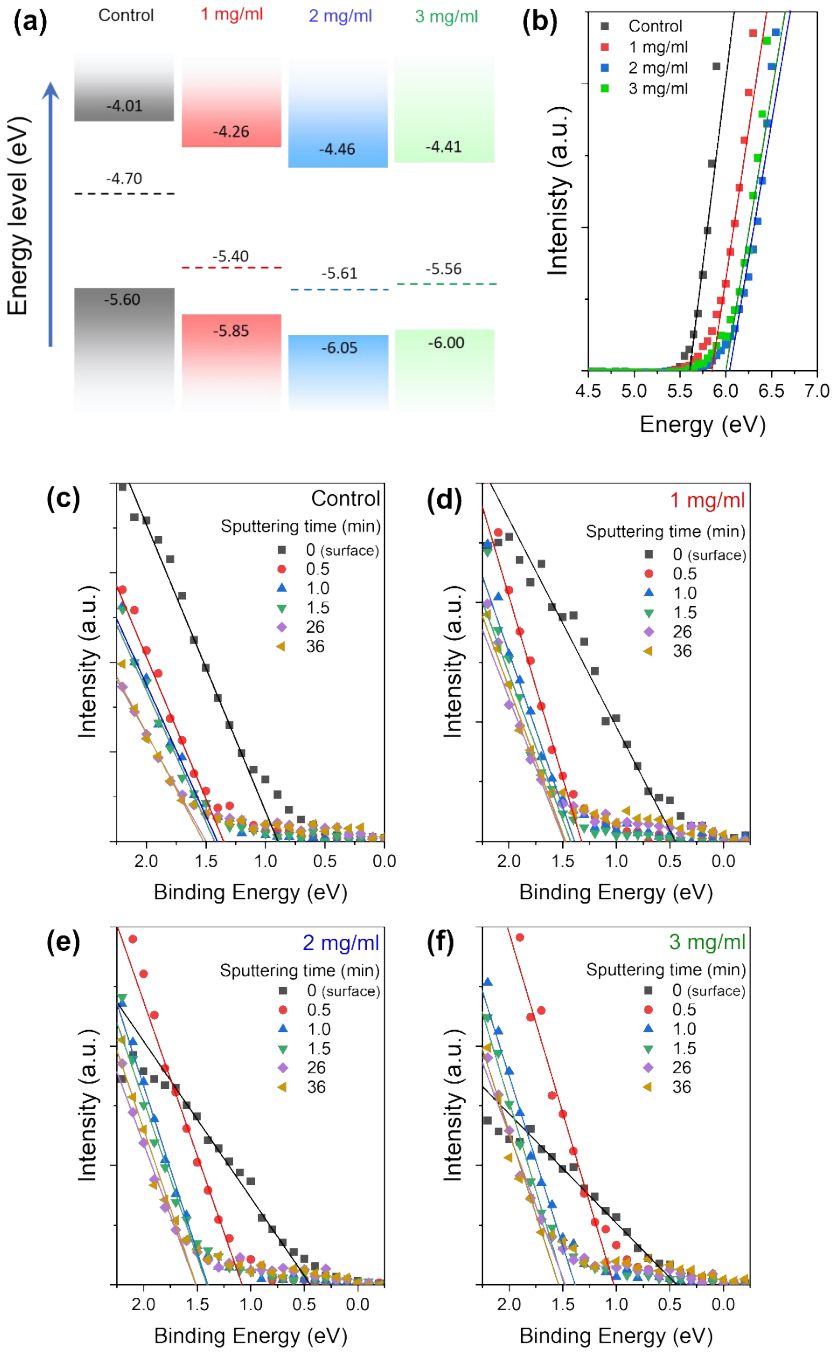

Fig. S8. Band diagram of perovskite films with 0 (control), 1, 2 and 3 mg/ml of vit A (a). Valence band edge values were measured by photoelectron yield spectroscopy (b). Fermi level values of the film surface and the bulk were determined using x-ray photoelectron spectroscopy via surface and depth profile analysis (c-f). The band diagram was completed by using the band gap data in Fig. S2.

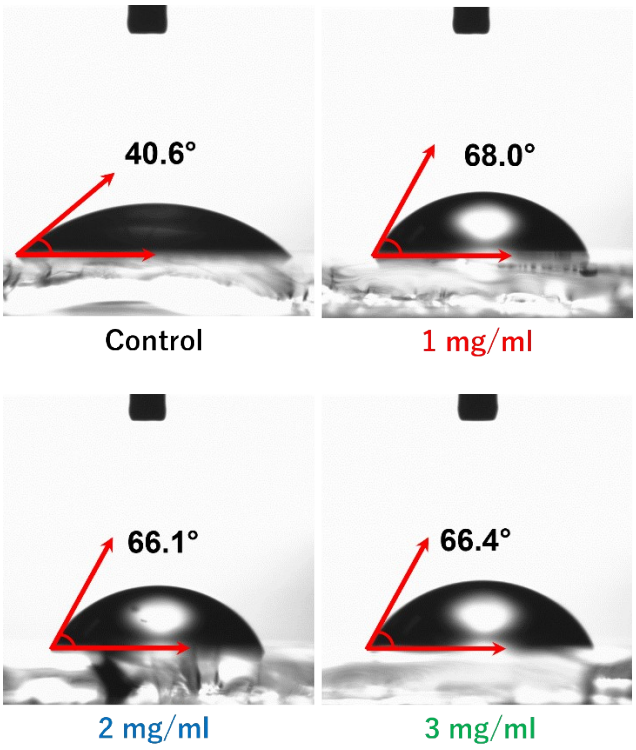

Fig. S9. Representative water-contact-angle images of perovskite films with 0 (control), 1, 2, and 3 mg ml^{-1} of vit A treatment.

Table S1. Linear-fit results for the semi-log dark J–V curves of perovskite solar cells. Data were fitted with the diode equation expressed in logarithmic form:

$$\ln J = \ln J_0 + \frac{q}{nkT}V$$

where $J_0 = e^{Intercept}$ is the saturation current density, n the ideality factor, q the elementary charge, k the Boltzmann constant, and $T = 300\ K$.

Fitted parameter	**Control**	**1 mg mL^{-1}**	**2 mg mL^{-1}**	**3 mg mL^{-1}**
Intercept, ln J_o	–22.50379	–24.42761	–24.74803	–24.17098
J_o (mA cm^{-2})	**1.7×10^{-10}**	**2.5×10^{-11}**	**1.8×10^{-11}**	**3.2×10^{-11}**
Slope, q/nkT	16.1615	17.1795	18.0090	17.5416
X-Intercept† (V)	1.39243	1.42191	1.37420	1.37792
Reduced χ^2	0.00173	0.00558	0.00348	0.00747
R^2	0.99913	0.99544	0.99781	0.99506
Pearson r	0.99956	0.99772	0.99891	0.99753

Table S2. Detailed fitting parameters for the time-resolved photoluminescence measurement of perovskite/vit A/HTL films deposited on glass. Excitation wavelength was 425 nm, with the light source directed onto the glass side of the samples. The fitted equation is

$$I = I_0 + A_1 exp\left(-\frac{(t-t_0)}{\tau_1}\right) + A_2 exp\left(-\frac{(t-t_0)}{\tau_2}\right)$$

Average time constant (τ_{ave}) was calculated by

$$\tau_{ave} = (A_1{\tau_1}^2 + A_2{\tau_2}^2)/(A_1\tau_1 + A_2\tau_2)$$

	Control	**1 mg/ml**	**2 mg/ml**	**3 mg/ml**
A_1	7673.72	7841.19	4335.03	4160.23
τ_1 (μs)	0.02996	0.02379	0.01301	0.01618
k_{HT} (s^{-1})	3.34×10^7	4.20×10^7	7.69×10^7	6.18×10^7
A_2	2570.39	2846.31	942.97	441.86
τ_2 (μs)	0.12017	0.07784	0.04942	0.07531
τ_{ave} (μs)	0.082	0.053	0.029	0.036
τ_{ave} (ns)	**81.7**	**53.1**	**29.5**	**35.7**