Supporting Information

Water-Mediated Photochemical Treatments for Low-Temperature Passivation of Metal-Oxide Thin-Film Transistors

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1. Composition analysis of *a*-IGZO films with different annealing conditions.

The chemical composition analysis of for the diversely treated *a*-IGZO films (1h DUV, 2h DUV, DW, DWD) was performed with X-ray photoelectron spectroscopy (XPS) analysis and Energy Dispersive Spectroscopy (EDS). Within typical error range of EDS and XPS, the chemical compositions from XPS and EDS showed identical atomic ratios for the same samples, which are proportional to molar concentration of indium, gallium, and zinc precursors (In: 0.085 M, Ga: 0.0125 M, Zn: 0.0275 M).[S1] The similar atomic ratios for entire *a*-IGZO samples confirm that the *a*-IGZO films maintained consistent chemical compositions during the diverse processing conditions, even after the water treatment.

Table S1.

Atomic %

Sample	In		Ga		Zn	
	XPS	EDS	XPS	EDS	XPS	EDS
1h DUV	69.53	69.43	6.87	7.51	23.61	23.06
2h DUV	68.79	73.61	7.25	6.58	23.96	19.8
DW	69.26	72.62	7.58	9.62	23.16	17.76
DWD	69.39	73.7	7.34	7.38	23.27	18.92

Table S1. Atomic composition ratio of 1h DUV, 2h DUV, DW, DWD-annealed *a*-IGZO films.

2. Electrical characterization of DUV-irradiated AlOx dielectric layer.

The areal capacitance vs. frequency (C-F) and leakage current density vs. electric field (J-E) characteristics of the DUV-annealed AlO_x gate dielectric layer are shown in Figure S1. The areal capacitance of the DUV-annealed AlO_x gate dielectric layer was 120 nF cm^{-2} at 100 Hz, showing a dielectric constant of 5.42. However, the capacitance value slight decreases with increasing frequency (104 nF cm^{-2} at 1 MHz) which can be attributed to structural defects such as hydroxyl group or oxygen vacancies in the film.[S2] Meanwhile, the DUV-annealed AlO_x gate dielectric showed an excellent insulating property as shown Figure S1(b). Particularly, the DUV-annealed AlO_x gate dielectric had a leakage current density of 7.14×10^{-8} A cm^{-2} at 2 MV cm^{-1} and a breakdown field of 7.8 MV cm^{-1}. Also, the distributions of leakage current density and dielectric breakdown field indicate that the DUV-annealed AlO_x gate dielectric has reasonable spatial uniformity over the tested substrate [Figure S1(c)].

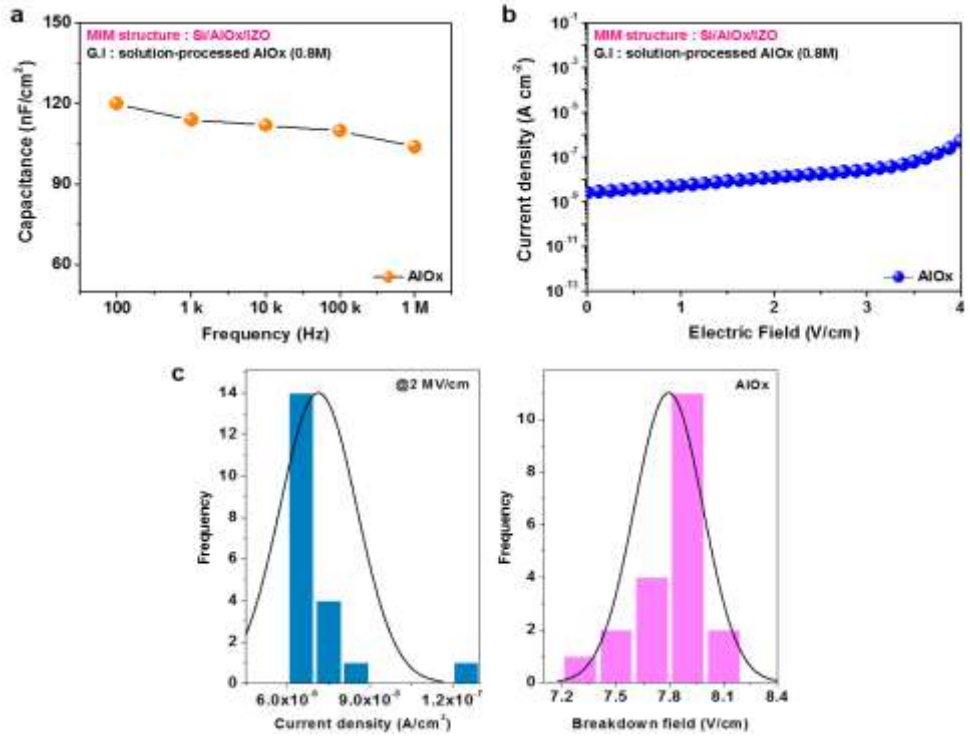

Figure S1. a, Capacitance per area-frequency (C-F) and **b,** Leakage current density-electric field (J-E) of AlO_x dielectric layer using M-I-M structure devices. **c,** Statistical distribution of current density and breakdown field of AlO_x dielectric layer.

3. The summarized electrical properties of DUV-irradiated AlOx dielectric layer.

Table S2.

Sample	Breakdown field (MV/cm)	Current density (at 2MV/cm)	Capacitance (at 100 Hz)	Thickness	Dielectric Constant
AlOx_DUV1h	7.8	7.14 x 10^{-8} A/cm^2	120 nF/cm^2	40 nm	5.42

Table S2. The electrical characteristics of DUV-irradiated AlO_x dielectric layer.

4. The transfer characteristics of DWD-annealed *a*-IGZO TFTs.

For experimental simplicity, we used simple glass container with water spray as sample water treatment chamber. Therefore, the relative humidity of 70-80% for water treatment is not the optimized condition in this study. To investigate the water content effect, we tested different water content, 50-55% RH and 100% RH at 24 ± 1 ^{o}C, which corresponds to absolute water content of ~12 and 22 g/m^3. As shown in Figure S2, we do not observe any significant difference in device performance with water content increase. Compared with the water treated sample at 70-80% RH, the electrical properties of the water treated samples at both 50-55% RH and 100% RH show less than 10% difference.

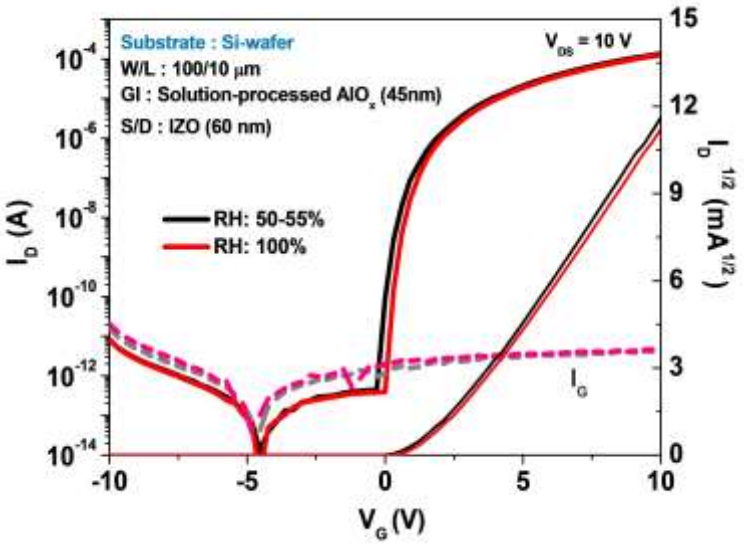

Figure S2. The transfer characteristics of DWD-annealed *a*-IGZO TFTs, which is stored at relative humidity of 50-55% and 100% for 1h.

5. The statistical distribution of hysteresis voltages.

We have defined the difference of threshold voltages (V_{TH}) obtained from forward gate sweep and reverse sweep current as hysteresis voltage.[S3, S4] The hysteresis level of our device is consistently quite small for all devices. The representative transfer plot shows similar minimized hysteresis within device-to-device variation range. The average hysteresis voltages of 1h DUV-annealed, 2h DUV-annealed, DW-annealed, and DWD-annealed *a*-IGZO TFTs have 0.83, 0.73, 0.77, and 0.72 V, respectively.

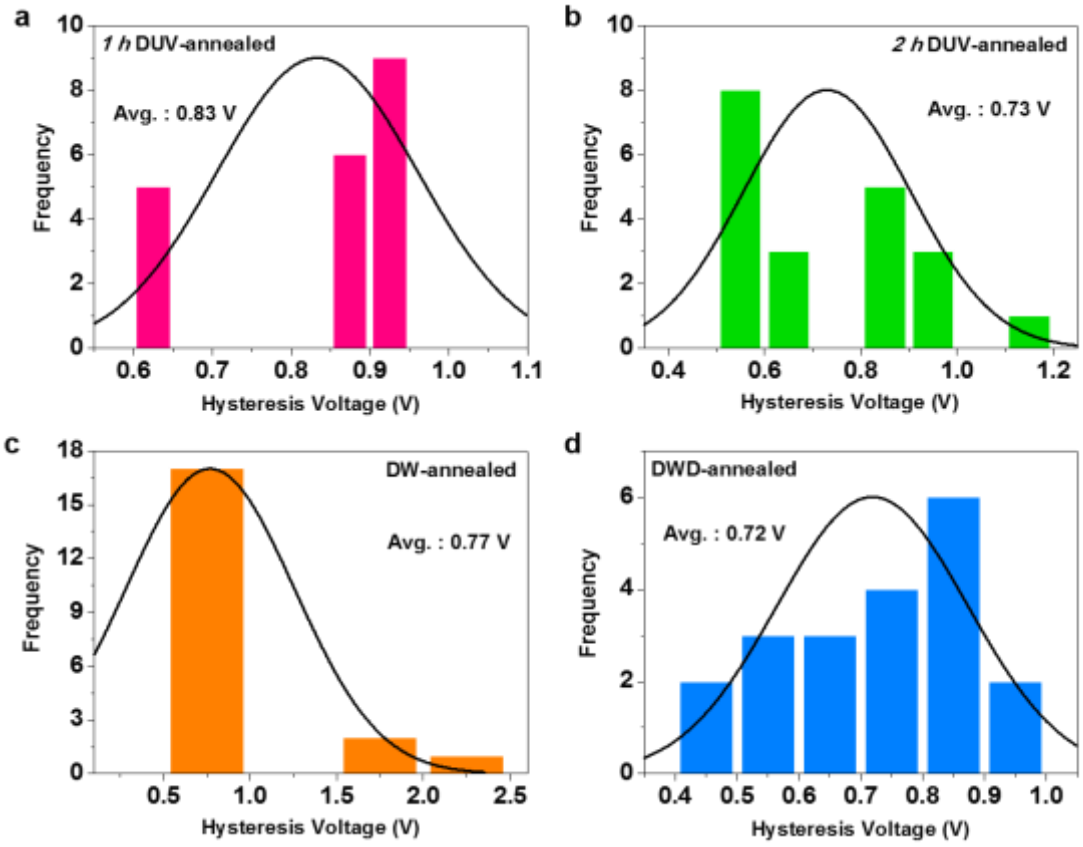

Figure S3. The statistical distribution of hysteresis voltages. **a.** 1 h DUV-annealed, **b.** 2 h DUV-annealed, **c.** DW-annealed, and **d.** DWD-annealed *a*-IGZO TFTs.

6. The threshold voltage shift of solution-processed *a*-IGZO TFTs under NBIS.

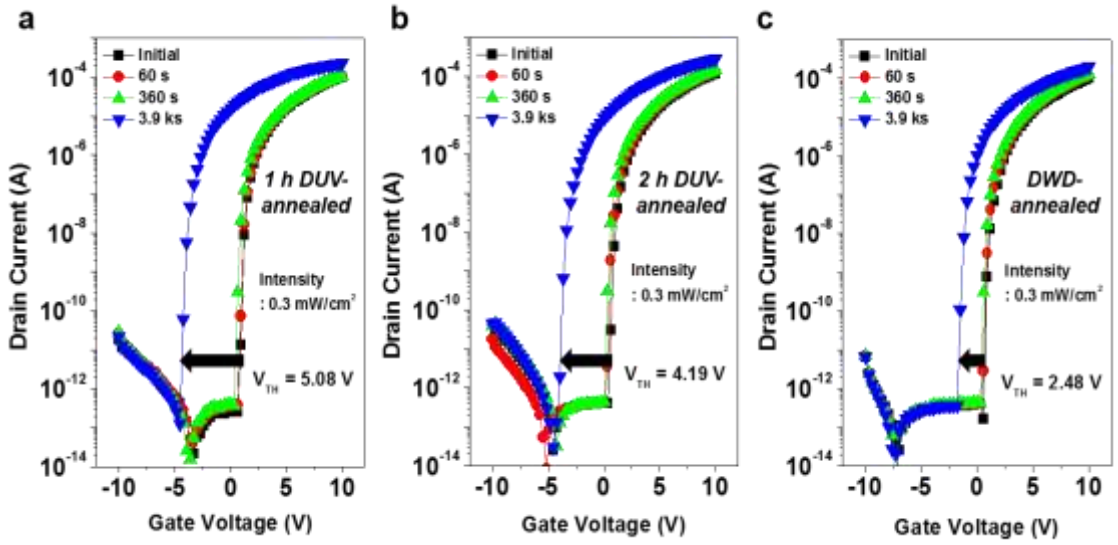

Figure S4. Threshold voltage shift of solution-processed *a*-IGZO TFTs under a negative illumination gate-bias stress (NBIS) (V_{GS} = -5 V, V_{DS} = +0.1 V, t = 3,900 sec). (a) 1 h DUV-annealed, (b) 2h DUV-annealed, and (c) DWD-annealed *a*-IGZO TFTs.

7. References

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