Supporting information

Gel Based Precursors for High-Performance of n-channel GaInSnZnO and p-channel CuGaSnSO Thin-Film Transistors

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Figures

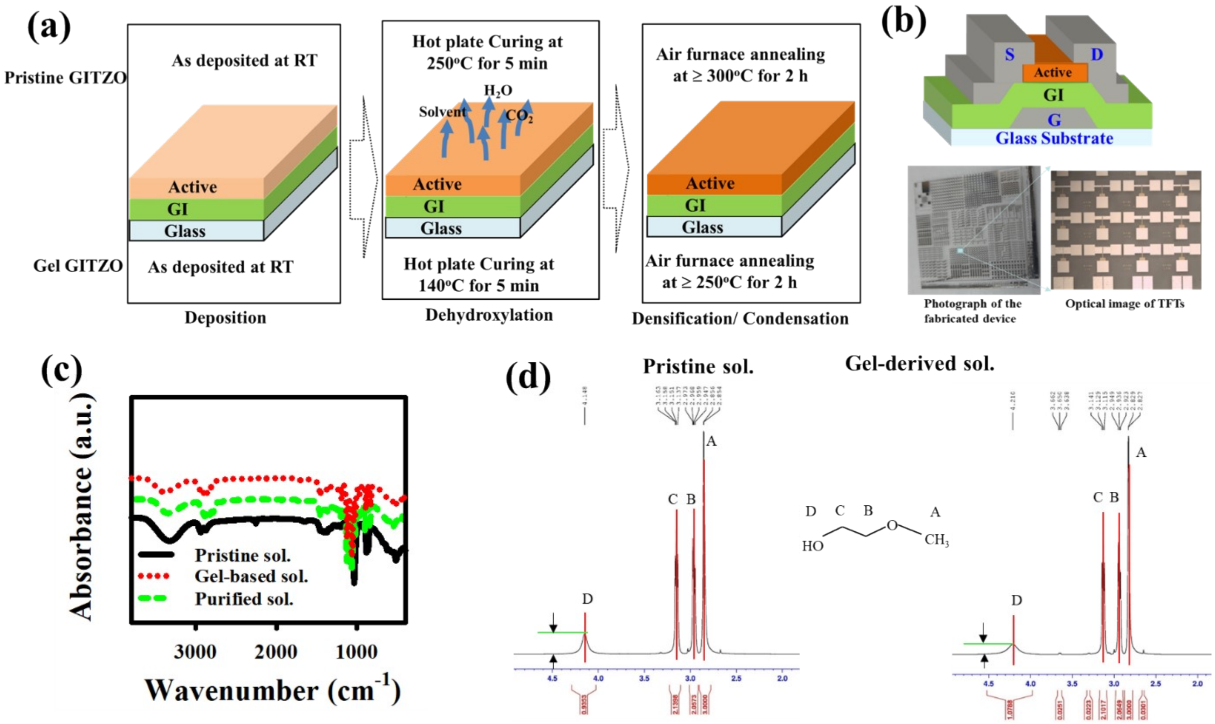

Figure S1. Schematic diagram for the (a) GITZO thin film synthesis and (b) cross-sectional view of GITZO TFTs using the staggered bottom-gate (bottom gate-top contact, BG-TC) structure on a glass substrate, and photograph of the fabricated device with expanded image showing several TFTs. (c) FTIR spectra for the pristine, gel-derived, and purified solution-based GITZO (annealed at 250°C). (d) ^{1}H NMR spectra of pristine and gel-derived GITZO precursor solution.

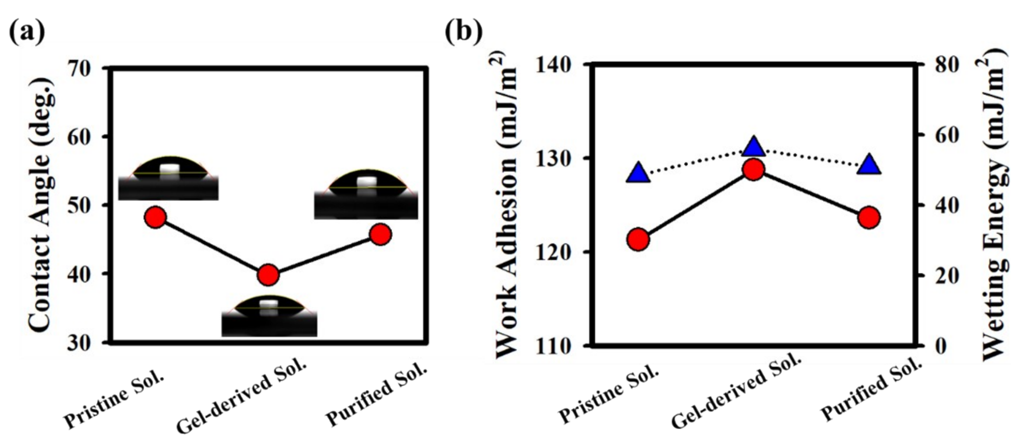

Figure S2. (a) Contact angle, and (b) work adhesion and wetting energy of the pristine, gel-derived, and purified precursor solution-based GIZTO film.

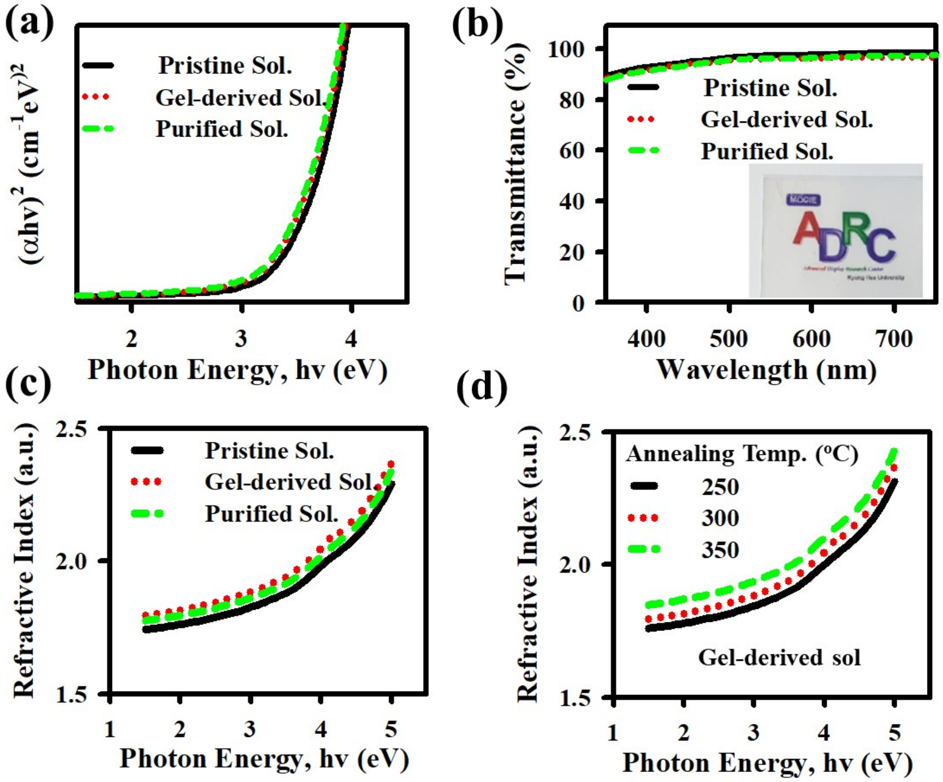

Figure S3. (a) Bandgap, (b) transmittance, and (c) refractive index for GITZO films with pristine, gel-derived, and purified precursor solution. The inset shows the photograph of a-GIZTO/glass placed on the ADRC logo. (d) The RI of the gel-based GITZO thin film was annealed at 250, 300, and 350°C, and their corresponding values are 1.79, 1.83, and 1.88, respectively. The RI value for GITZO thin-film slightly increases upon the annealing temperature.

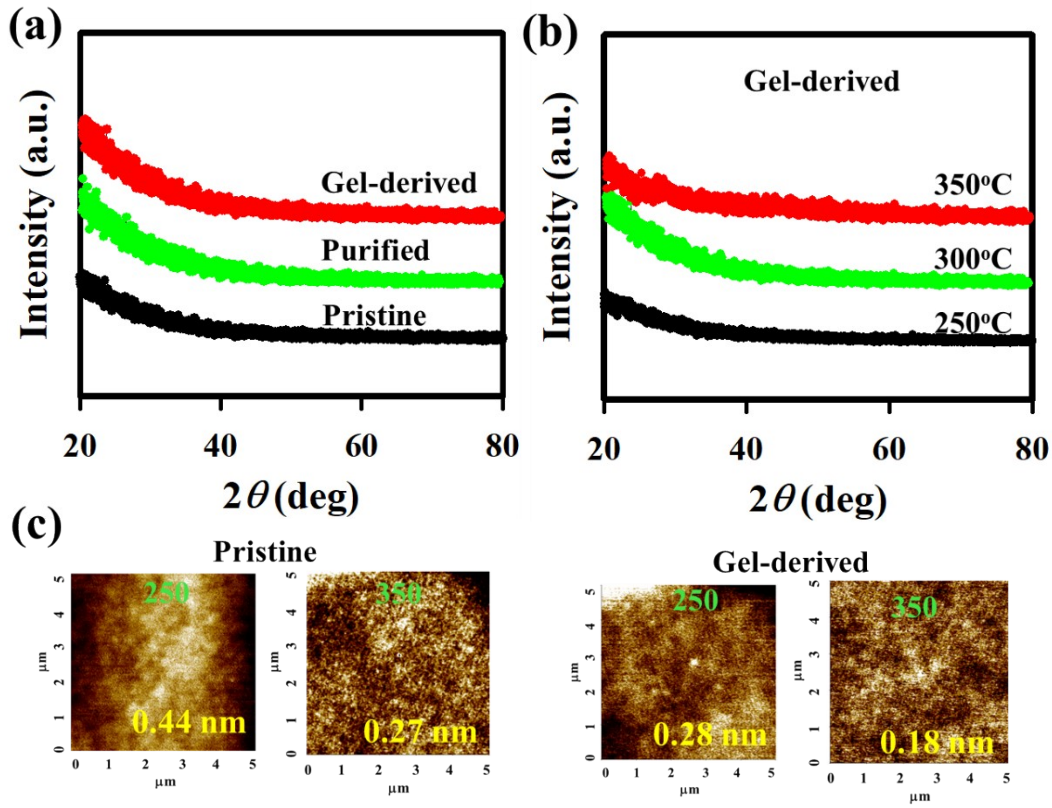

Figure S4. (a) XRD spectra for pristine, gel-derived, and purified solution-based GITZO films. (b) XRD spectra for gel-derived GITZO films annealed at 250, 300, and 350°C. There are no crystalline peaks in the entire spectra, indicating an amorphous structure. (c) AFM image (scan size: 5 μm x 5 μm) of the pristine and gel-based GITZO films annealed at 250 and 350°C in each case. The smooth surface of the film by gel-based precursor provides more electron-conducting pathways and reduces the trap density.

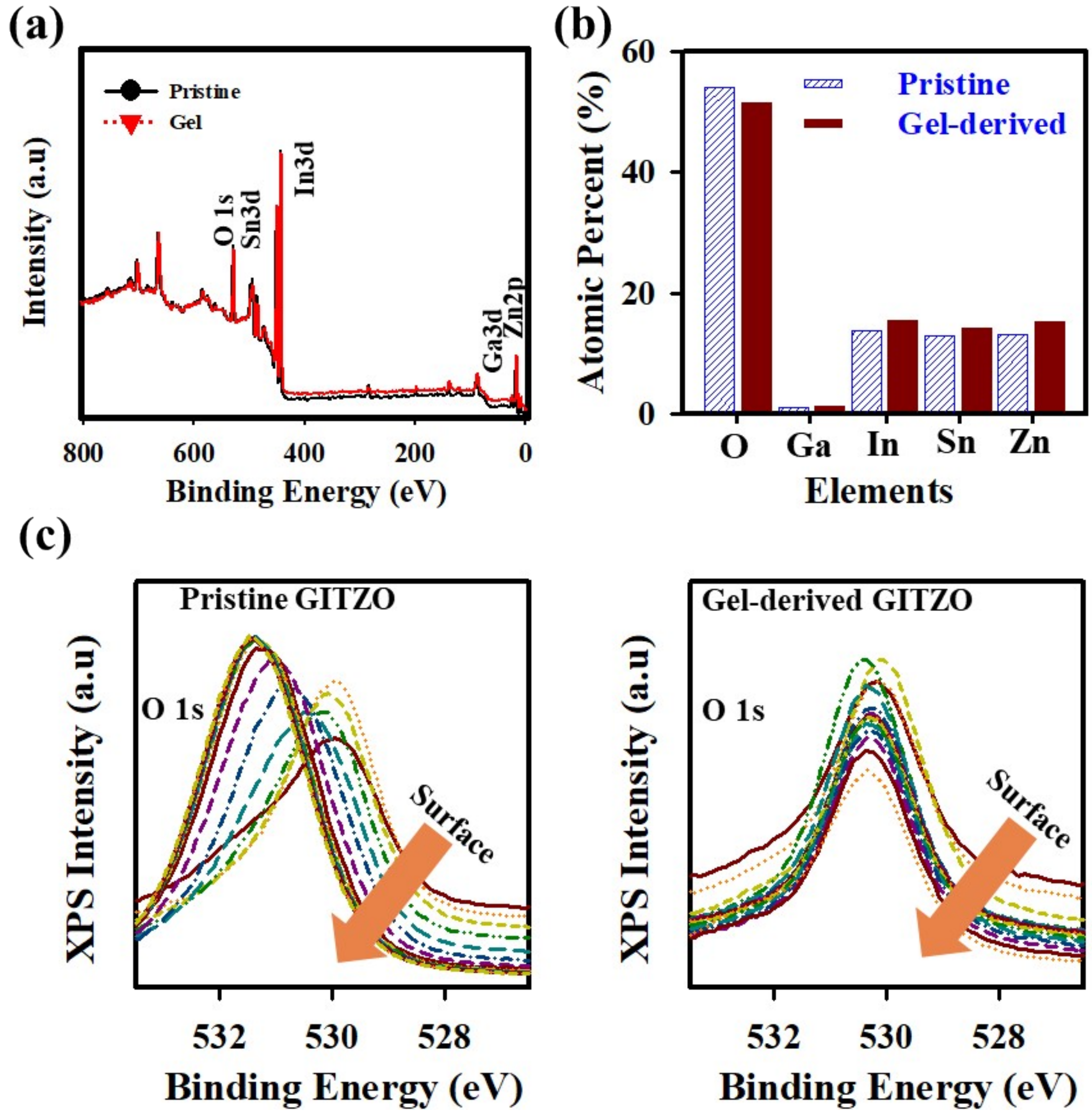

Figure S5. (a) The XPS survey scan spectra of pristine and gel-derived GITZO film for oxygen (O1s), gallium (Ga3d), indium (In3d5), tin (Sn3d5), and zinc (Zn3d5). (b) Comparison for the atomic percentage of oxygen (O), gallium (Ga), indium (In), tin (Sn), and zinc (Zn) for the pristine and gel-derived GITZO films. (c) The O1s spectra of pristine and gel-derived GITZO films, where orange color arrow indicates the O1s from surface to depth. The O1s peaks shifts to higher binding energy side in depth (bulk) position, indicate the increase of M-O-M network, consequently decrease oxygen-related defects.

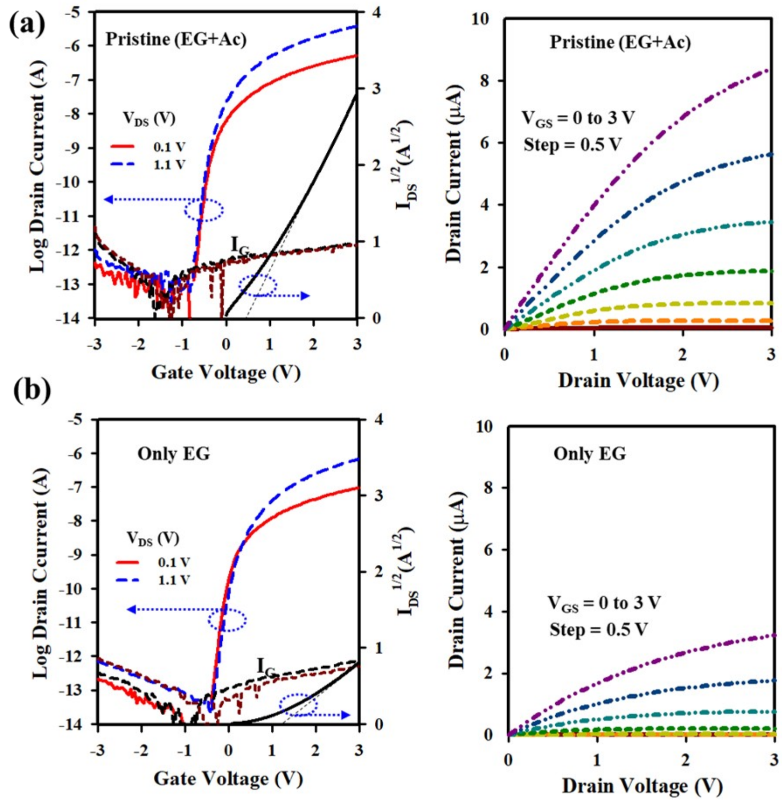

Figure S6. The transfer and output curves of the pristine GITZO TFT with (a) EG+Ac and (b) only EG used as a solvent. Transfer curves are measured by sweeping gate voltage from -5 to +5 V at the V_{DS} of 0.1 V. The output curve is measured by sweeping V_{DS} from 0 to 5 V, where V_{GS} = 0 to 5V with a step of 1 V. The TFT had a W/L of 20 μm/10 μm.

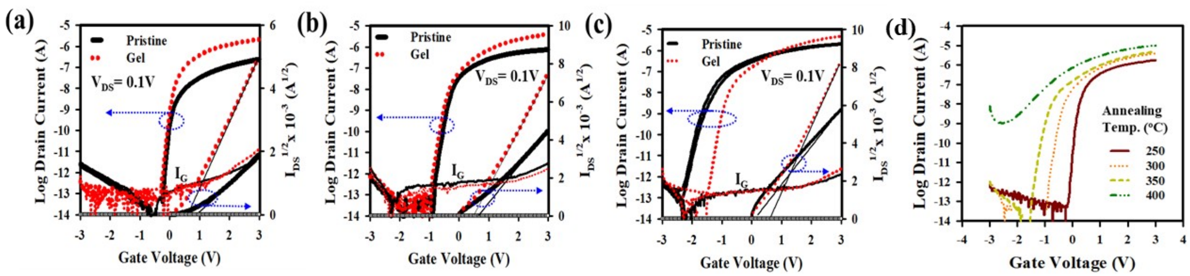

Figure S7(a-c). Transfer curves of the pristine and gel-derived a-GITZO TFT annealed at 250, 300, and 350°C. The right side Y-axis is showing $I_{DS}^{1/2}$ as a function of V_{GS}. (d) Transfer curves of a-GITZO TFT annealed at 250, 300,350, and 400°C. Transfer curves are measured by sweeping gate voltage from -3 to +3 V at the V_{DS} of 0.1 V. The channel width and length of the TFT are 20 and 10 μm, respectively.

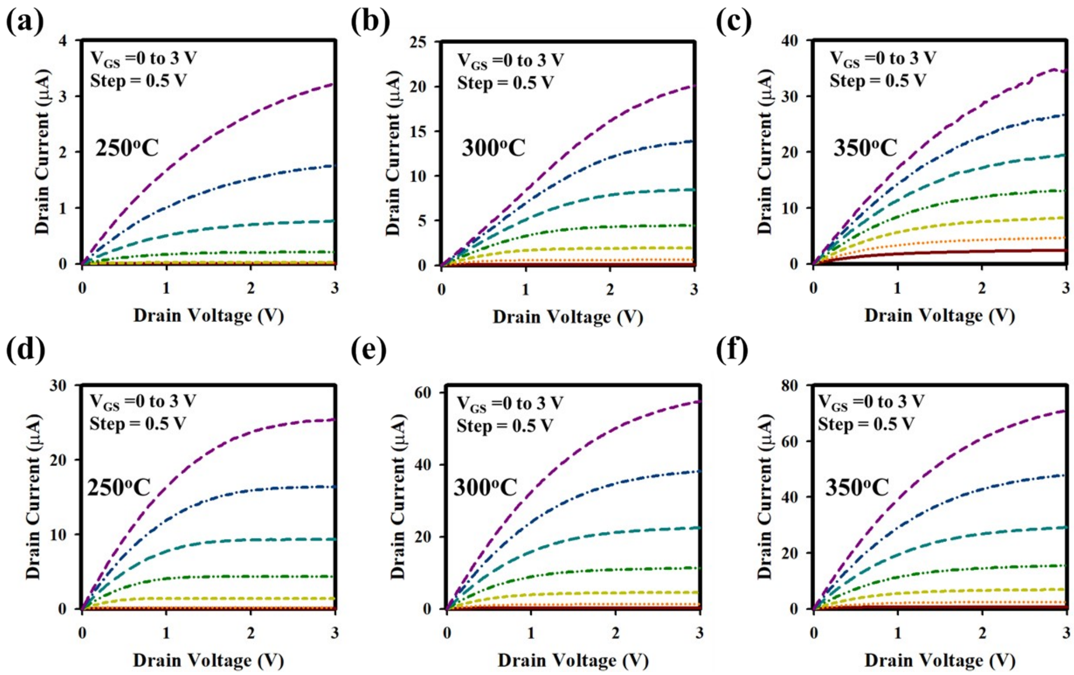

Figure S8. (a-c) and (d-f) output curves of pristine and gel-derived a-GITZO TFTs. The annealing temperature both the case varied from 250 to 350°C. The output current significantly increased by gel-derived a-GITZO TFTs compared with pristine one. The output curve is measured by sweeping V_{DS} from 0 to 3 V, where V_{GS} = 0 to 3V with a step of 0.5 V. There is no current crowding even at low V_{DS}, which enables excellent ohmic contact between semiconductor and S/D layers.

Table S1. The electrical properties of solution-processed pristine and gel-derived GITZO TFTs derived on ZrO_x gate insulator. Both the pristine and gel-derived GITZO TFTs were annealed at 250, 300, and 350°C.

GITZO	Annealing Temp. (°C)	μ_{sat} ($cm^2/V^{-1}s^{-1}$)	V_{ON} (V)	SS (mV/dec.)	Hysteresis (V)
Pristine	250	2.83	-0.12	154	0.15
	300	8.02	-0.85	145	0.03
	350	9.30	-2.31	183	0.11
Gel-derived	250	12.68	-0.18	136	0
	300	24.38	-0.93	132	0
	350	29.09	-1.50	130	0

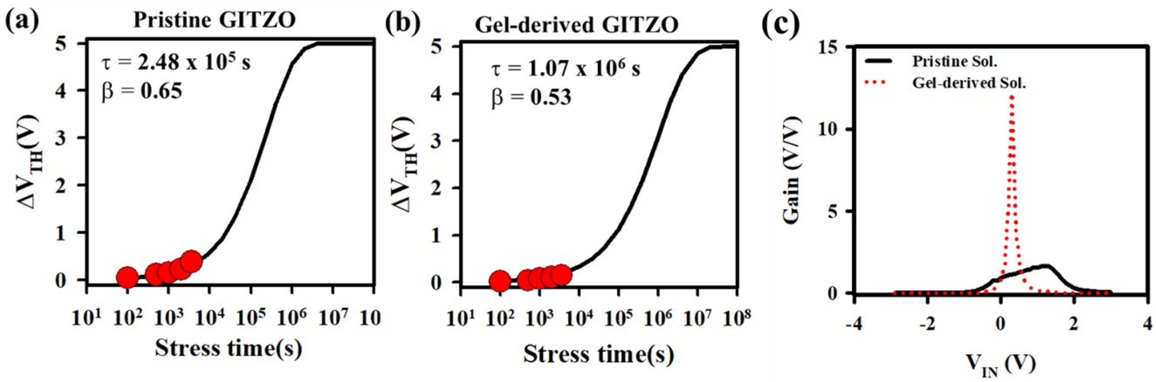

Figure S9. (a-b) Stretched exponential fitting for ΔV_{TH} as a function of stress time for pristine and gel-derived a-GITZO TFTs. (c) The comparison of voltage transfers characteristic of the inverter's voltage gains at a V_{DD} of 3 V.

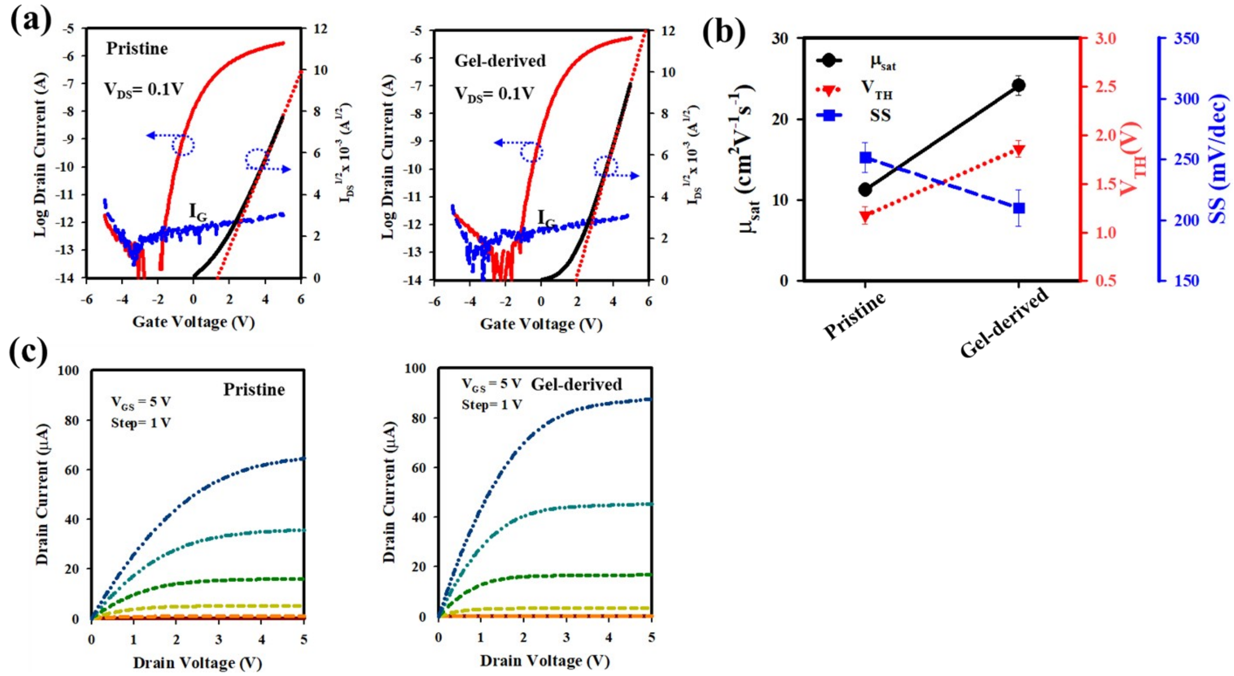

Figure S10. The comparison of the pristine and gel-derived spray-pyrolyzed ZnO TFT for (a) transfer and (b) statistical data for mobility, V_{TH}, and SS. Transfer curves are measured by sweeping gate voltage from -5 to +5 V at the V_{DS} of 0.1 V. (c) output curves of the pristine and gel-derived spray-pyrolyzed ZnO TFT. The output curve is measured by sweeping V_{DS} from 0 to 5 V, where V_{GS} = 0 to 5V with a step of 1 V. The TFT had a W/L of 20 μm/10 μm.

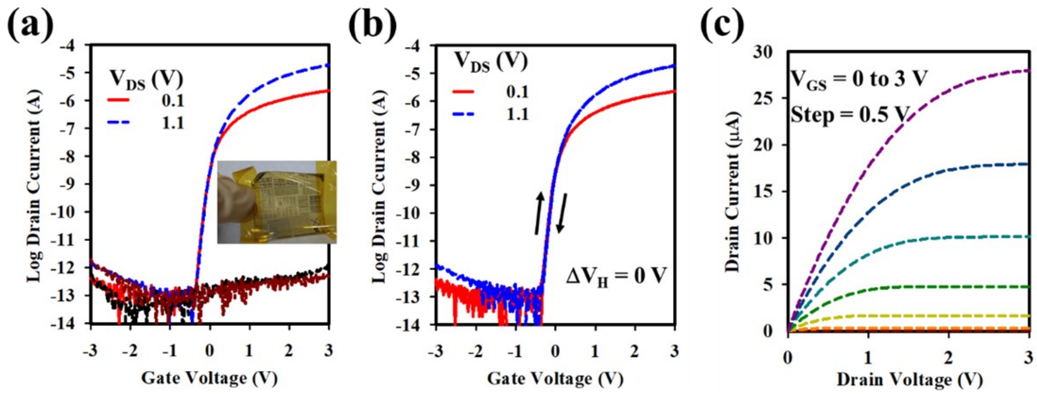

Figure S11. (a) Transfer, (b) hysteresis, and (c) output curves for flexible a-GITZO TFT with a bending radius of 3 mm, where a-GITZO annealed at 250°C. Transfer curves are measured by sweeping gate voltage from -3 to +3 V at the V_{DS} of 0.1 V. The output curve is measured by sweeping V_{DS} from 0 to 3 V, where V_{GS} = 0 to 3V with a step of 0.5 V. The TFT had a W/L of 20 μm/10 μm.

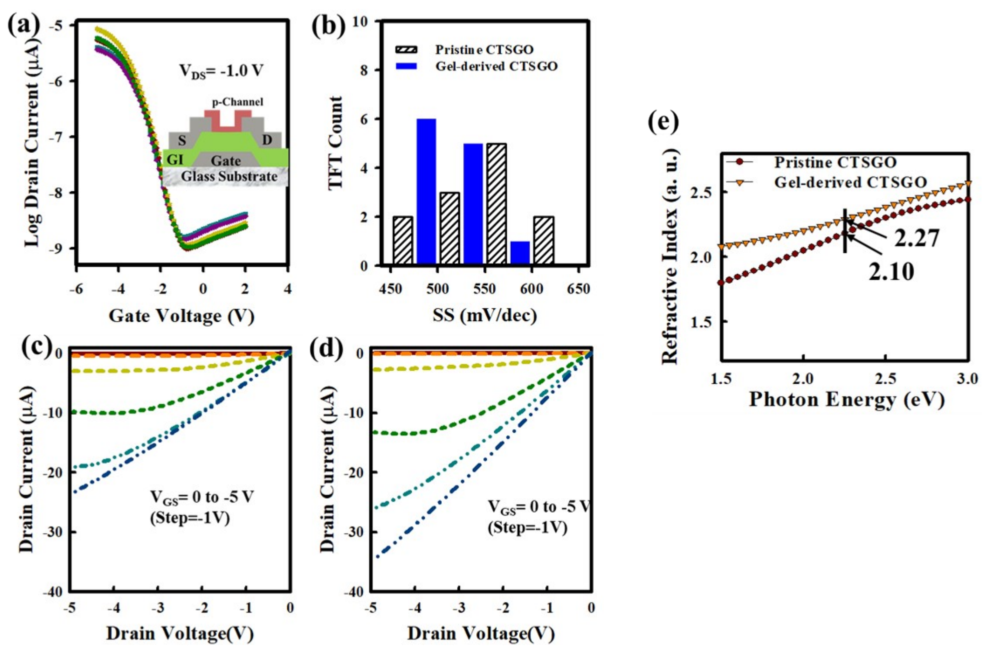

Figure S12. (a) Transfer curve and (b) subthreshold swing of 12 gel-derived p-channel CTSGO TFT. Output characteristics of the p-channel CTSGO TFTs with (c) pristine and (d) gel-derived precursor solution. The output curves were measured by sweeping V_{DS} from 0 to -5 V and V_{GS} from 0 to -5 V (Step = -1.0 V). The TFT had a channel width (W) of 100 μm and length (L) 10 μm. (e) Comparison of refractive index for the pristine and gel-derived precursor solution-based CTSGO film.

Table S2. The electrical properties of solution-processed pristine and gel-derived p-channelCTSGO TFT.

CTSGO	Annealing Temp. (^oC)	μ_{sat} ($cm^2/V^{-1}s^{-1}$)	V_{ON} (V)	N_{SS} ($10^{12}cm^{-3}$)	Drain Current (μA)
Pristine	250	1.71	0.23	4.41	22.38
Gel-derived	250	4.25	-0.67	3.54	34.50

Table S3. Comparison for Hall-measurement data for the pristine and gel-derived CTSGO thin film.

CTSGO	Annealing Temp. (^oC)	Film-density (g/cm^3)	RI	Surface Energy (mJ/m^2)	Work Adhesion (mJ/m^2)
Pristine	250	3.70	2.10	58.82	138.14
Gel-derived	250	4.10	2.27	64.32	141.02

Table S4. Summary of the electrical properties (such as mobility, SS, ΔV_{TH}) for multi-component metal oxide based TFTs.

Active layer	Process Temp. (^oC)	Mobility ($cm^2V^{-1}s^{-1}$)	SS (mV/dec)	ΔV_{TH} (V)	[Ref]Year
ZIZO	400	6.23	190	0.80	[3]2013
[a]ZATO	500	13.20	500	-	[4]2020
IZTO	300	9.50	87	0.30	[6]2019
IGZTO	300	~30	190	0.23	[9]2019
IGZTO	350	11.80	94	0.03	[10]2019
IGZTO	400	46.70	150	0.50	[11]2020
IZGO/ZnO	350	24.75	~300	1.31	[15]2020
IZTMO	350	36.60	340	4.40	[16]2019
LaZnO	350	22.43	225	0.10	[21]2020
IZO	350	12.65	-	2.91	[30]2020
IGZO	350	~10.0	-	0.70	[38]2020
[c]LiZnO	350	48.47	256	~0	[59]2021
[b]GITZO	300	24.38	118	0.05	This work