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Solution Processed High-Performance of p-Channel Copper-Tin-Sulphur Thin-Film Transistor

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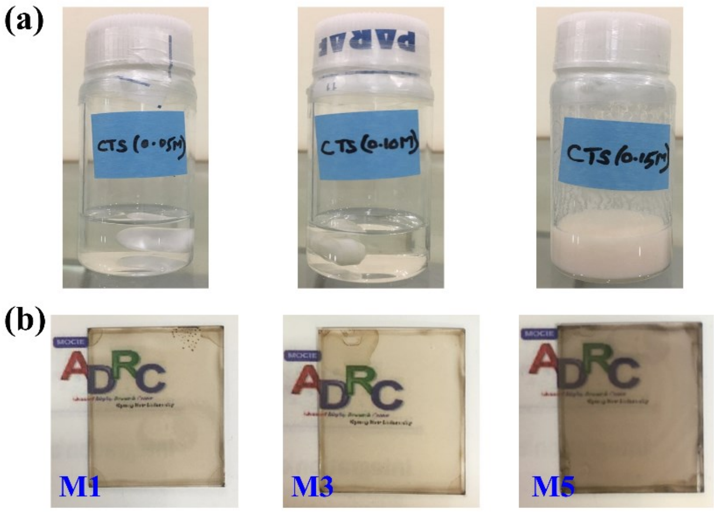

Figure S1. The optical photograph of (a) CTS precursor solutions and (b) thin-films using a different precursor solution concentration.

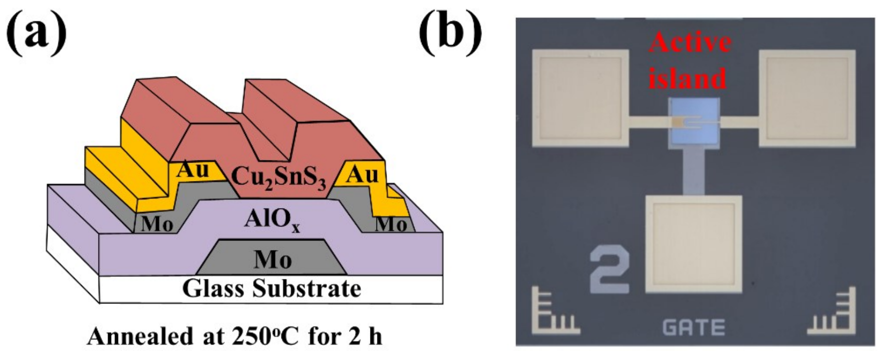

Figure S2. Schematic and optical properties of CTS TFT. (a) The schematic cross-sectional view of a bottom-gate, bottom-contact (BGBC) CTS TFT. (b) Optical photograph of the fabricated CTS TFT, with channel width and length of 100 and10 µm, respectively. A clear active island can be seen.

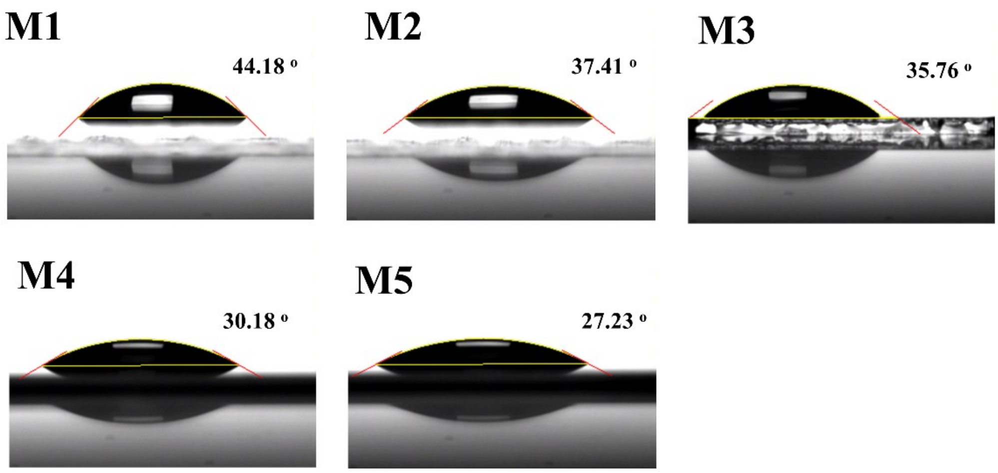

Figure S3. Water contact angles of the CTS films with different concentration (M1 = 0.05 M, M2 = 0.075 M, M3 = 0.10 M, M4 = 0.125 M, and M5 = 0.15 M).

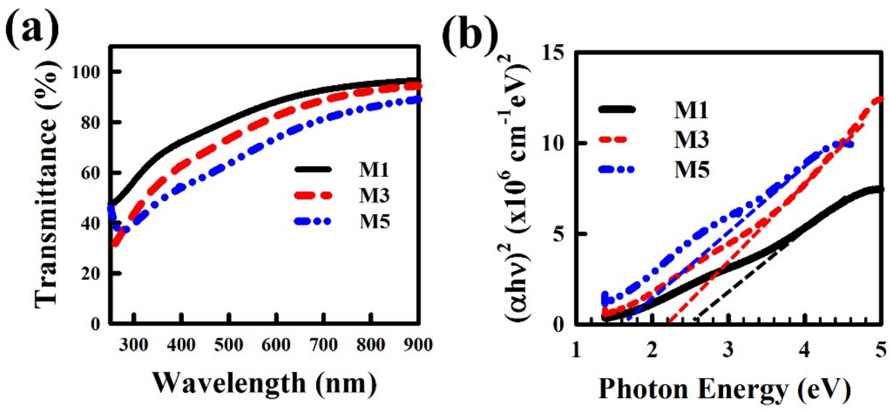

Figure S4. Optical properties of CTS thin films. (c) Transmittance and (d) optical bandgap. The bandgaps of CTS thin-films (M1, M3 and M5) are 2.65, 2.30, and 1.85 eV, respectively.

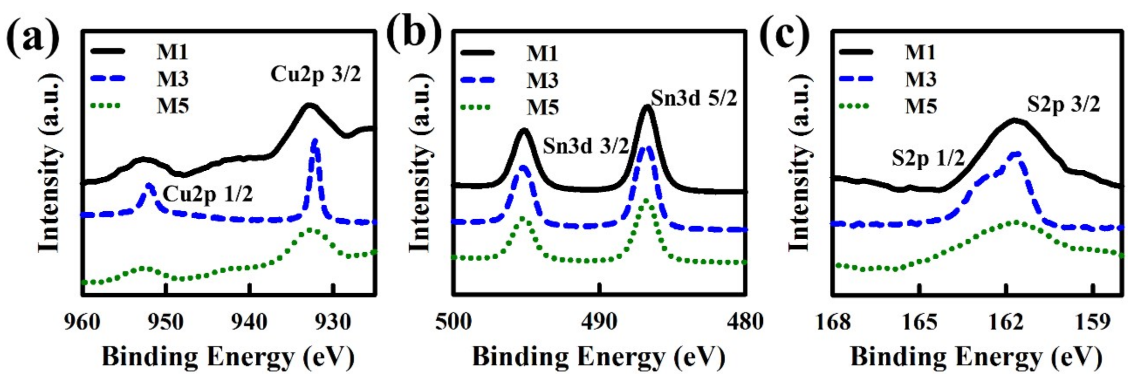

Figure S5. The XPS binding energy peaks for the (a) Cu2p, (b) Sn3d, and (c) S2p of CTS (M1, M3, and M5) films.

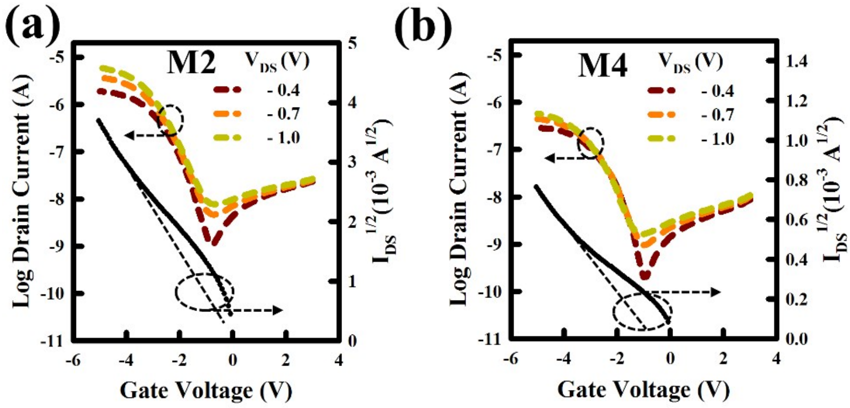

Figure S6. The electrical properties of p-type CTS TFTs. The transfer curves of CTS TFTs with different precursor solution concentrations of (a) M2=0.075 M and (b) M4=0.125 M. The $I_{DS}^{1/2}$ vs. V_{GS}, curves of CTS TFTs, respectively. The mobility was obtained from the linear part of the $(I_{DS})^{1/2}$ vs. V_{GS} curve. The transfer curves of the CTS TFTs were measured at drain voltage (V_{DS}) = -(0.4, 0.7, and 1) V, by sweeping gate voltage (V_{GS}) from +2 to -5 V. All the TFTs have the channel length (L) and width (W) of 10 and 100 μm, respectively.

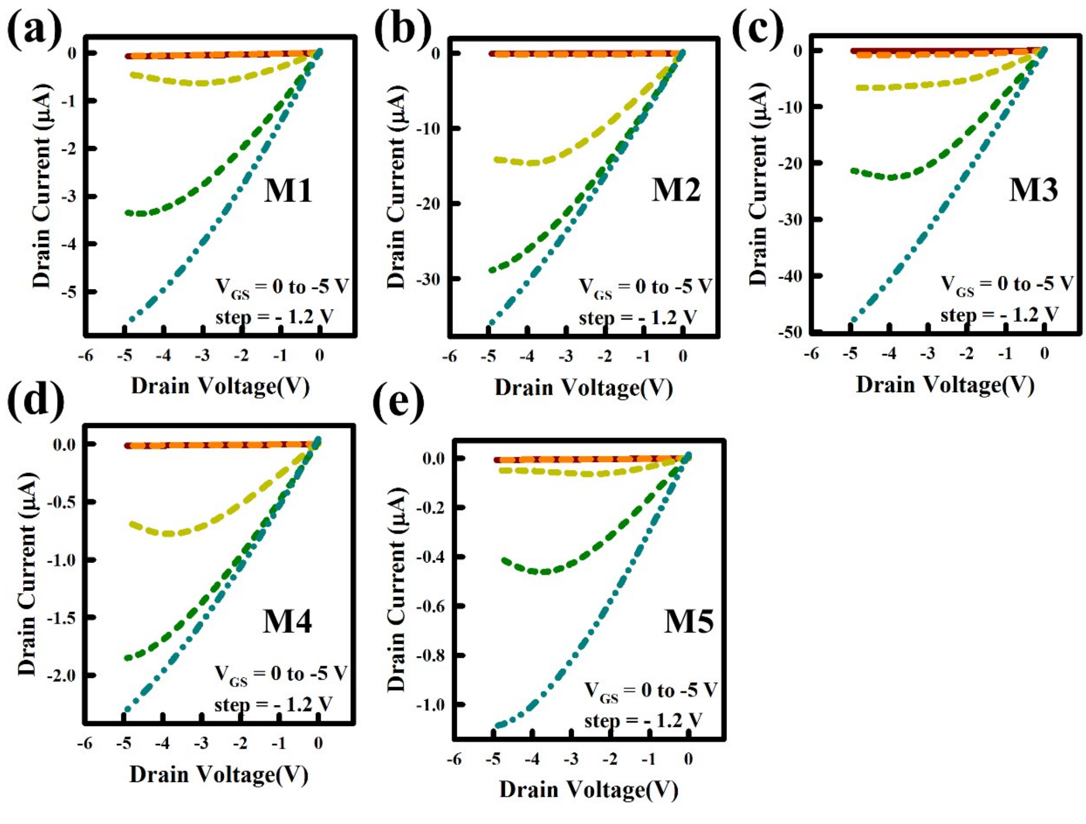

Figure S7. The output characteristics of the p-type CTS TFTs with different precursor solution concentrations. Output curves of all the CTS TFTs measured by applying V_{GS} from 0 to -5 V with a step of -1.2 V. All the TFTs have the channel length (L) and width (W) of 10 and 100 μm, respectively.

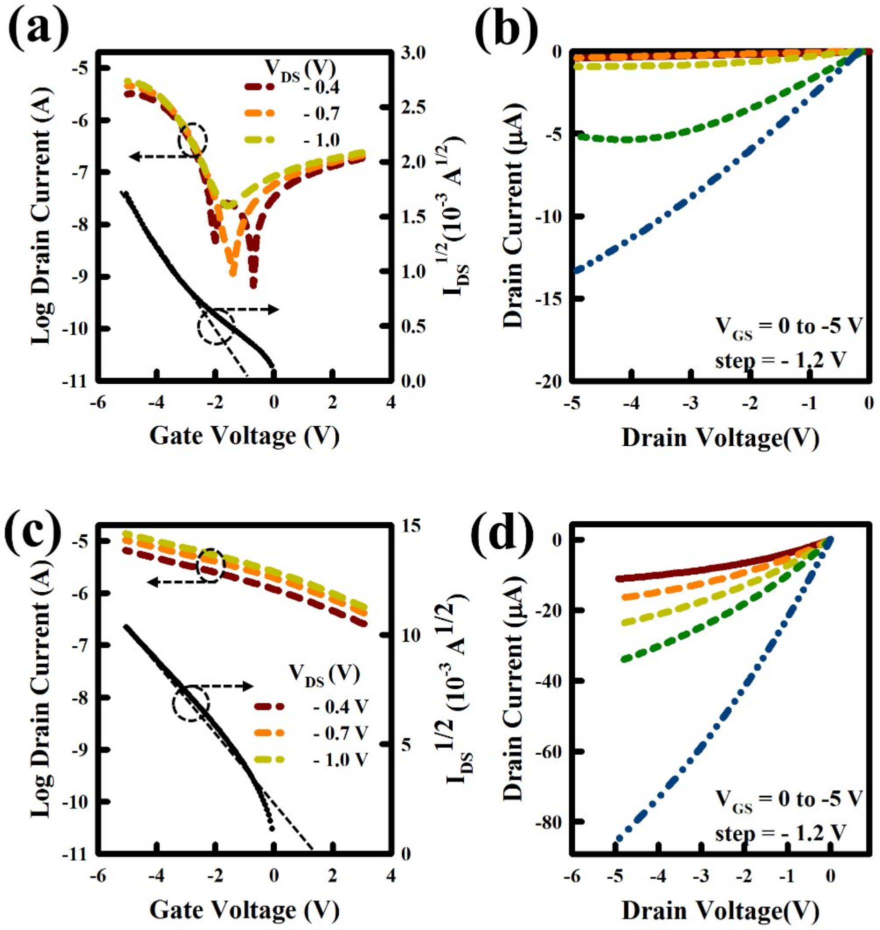

Figure S8. The electrical properties of the p-type CTS TFT annealed at 200 and 300^{o}C. (a) The transfer curve and $I_{DS}^{1/2}$ vs. V_{GS} curves of CTS TFT. (b) Output curves of the CTS TFT measured by applying V_{GS} from 0 to -5 V with a step of -1.2 V. (c) Transfer curve and $I_{DS}^{1/2}$ vs. V_{GS} curves and (d) output curves of the CTS TFT annealed at 300^{o}C. The transfer curves of CTS TFTs were measured at drain voltage (V_{DS}) = -(0.4, 0.7, and 1.0) V, by sweeping gate voltage (V_{GS}) from +3 to -5 V.

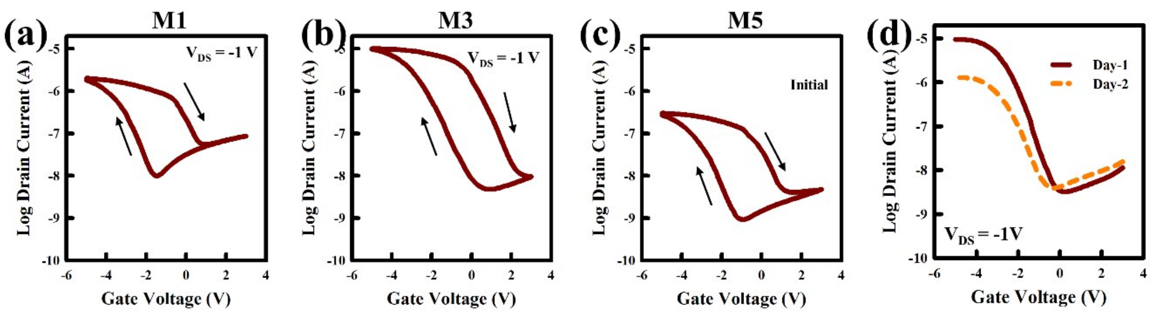

Fig. S9. Transfer curves with hysteresis characteristics for (a) M1, (b) M3 and (c) M5 CTS TFTs. (d) The comparison of transfer curves of CTS TFT measured at Day-1, Day-2, and Day-3, where the TFT were aged in air.

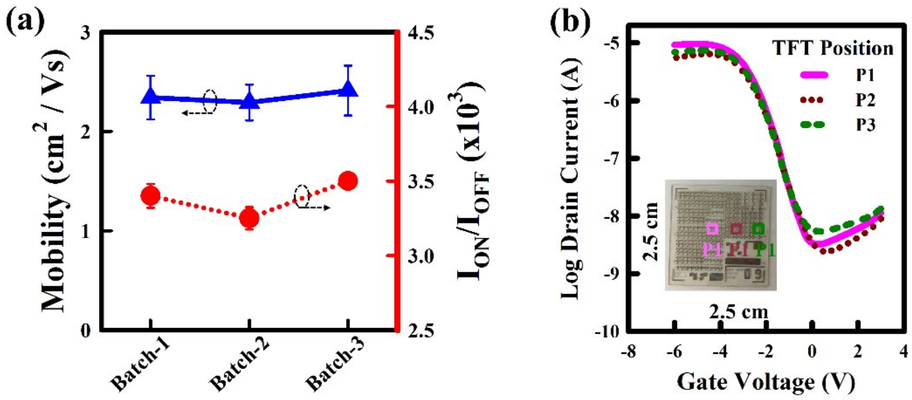

Fig. S10 (a) Mobility I_{ON}/I_{OFF} of CTS TFT as a function of batches (Batch-1, Batch-2, and Batch-3). (b) Evaluation for the transfer curves of CTS TFT as a function of TFT position. Inset of (b) shows fabricated sample indicating different positions.

Table S1. The summary of the water contact angle data for the p-type CTS thin films with different precursor solution concentrations.

Molar Concentration (M)	C.A (deg.)	γ_w (mJm²)	γ_s (mJ/m²)	W (mJ/m²)
0.050	44.18	52.21	38.36	125.01
0.075	37.41	57.83	46.32	130.63
0.100	35.76	59.08	48.44	131.88
0.125	30.18	62.93	54.54	135.73
0.150	27.23	64.74	57.11	137.54

Table S2. Hall effect measurement data of p-type CTS thin films with different precursor solution concentrations.

Molar Concentration (M)	Resistivity (Ω/cm)	Mobility (cm²/Vs)	Conductivity (10^{-2}S/cm)
0.050	0.85	4.02	0.77
0.075	0.75	5.05	1.22
0.100	0.61	9.81	4.30
0.125	0.55	5.10	3.02
0.150	0.41	3.57	2.21

Table S3. The summary of the electrical properties of p-type CTS TFTs with different precursor solution concentrations.

Concentration (M)	μ_{FE} ($cm^2V^{-1}s^{-1}$)	V_{TH} (V)	SS (mV dec^{-1})	N_{it} (10^{12} cm^{-2})
0.050	0.24	-1.65	903	7.09
0.075	1.68	-1.25	855	6.69
0.100	2.43	-0.53	664	5.05
0.125	0.11	-0.71	911	7.16
0.150	0.07	-0.82	921	7.24

Table S4. The summary of the device performances of the p-type TFTs reported.

Method	Channel	Annealing temp. °C)	μ_{FE} (cm^2 V^{-1} s^{-1})	I_{on}/I_{off}	Year[ref]
Spin coating	SnO	450	0.13	85	2012[1]
Spin coating	Cu_2O	700	0.16	~10^2	2013[2]
Spray coating	Cu_2O	275	10^{-4}–10^{-3}	1×10^{-2}	2013[3]
Spin coating	CuSCN	80	10^{-3}–10^{-2}	~10^4	2013[4]
Spin coating	NiO	500	0.14	--	2014[5]
Spin coating	Cu2O	600	0.29	~10^4	2015[6]
Spin coating	CuO	500	0.01	~10^3	2016[7]
Spin coating	NiO	250	0.07	~10^4	2016[8]
Ink-jet printing	CuI	60	4.4	10^{-1}–10^{-2}	2016[9]
Spin coating	CuO	250	0.32	~10^4	2017[10]
Spin coating	NiO	350	0.01	2	2017[11]
Spin coating	CuO	500	2.83×10^{-3}	~10^4	2018[12]
Ink-jet printing	NiO	280	0.78	5.3×10^4	2018[13]
Spin coating	CuI	RT	0.44	10^2	2018[14]

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