

Electronic Supplementary Information

Bulk Charge-Transfer Doping of Amorphous Metal Oxide: Fullerene Blends for Solution-Processed Amorphous Indium Zinc Oxide Thin-Film Transistors

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Table S1. Summary of the energy level values for C60-MA

Method	E _g (eV)	HOMO (eV)	LUMO (eV)
DFT ^{a)}	2.60	-5.88	-3.28
CV ^{a)}	2.22	-5.87	-3.65

^{a)} Values from density functional theory (DFT) calculations are taken from ref. 1; ^{b)} Values from cyclic voltammetry (CV) study presented in **Figure S1**.

The CV value is evaluated by these equations:

$$\text{HOMO(eV)} = -4.8 - (E_{\text{onset,Ox}} - E_{1/2,\text{ferr}})$$

$$\text{LUMO(eV)} = -4.8 - (E_{\text{onset,Red}} - E_{1/2,\text{ferr}})$$

$$\text{Where } E_{1/2,\text{ferr}} = (E_{\text{onset,Ox,ferr}} + E_{\text{onset,Red,ferr}})/2$$

Table S2. Summary of the energy levels obtained for *a*-IZO:*x*% C60-MA composites from UPS and optical spectroscopy measurement

<i>x</i> (wt%) ^{a)}	E_G (eV)	ΔE_{VBM}^* (eV)	Ecut-off (eV)	VBM (eV)	Fermi level (eV)	CBM (eV)
0.0	3.68	-3.29	-16.85	-7.66	-4.37	-3.98
0.5	3.70	-3.47	-17.00	-7.69	-4.21	-3.99
1.0	3.71	-3.47	-17.16	-7.53	-4.06	-3.83
1.5	3.70	-3.58	-17.29	-7.51	-3.93	-3.81
2.0	3.71	-3.58	-17.16	-7.63	-4.06	-3.92

^{a)} C60-MA concentration (wt%)

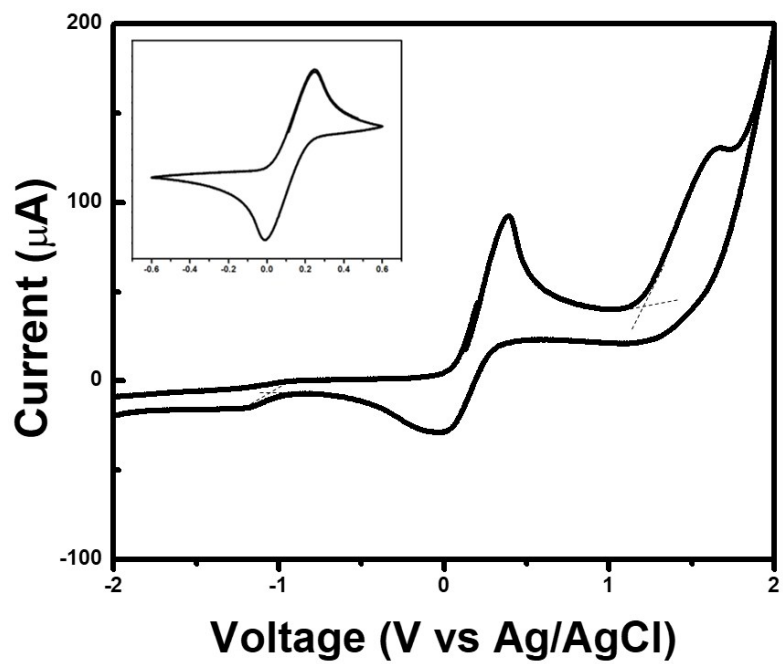


Figure S1. Cyclic voltammetry (CV) curve of C60-MA (inset shows the CV curve for ferrocene in 2-methoxyethanol).

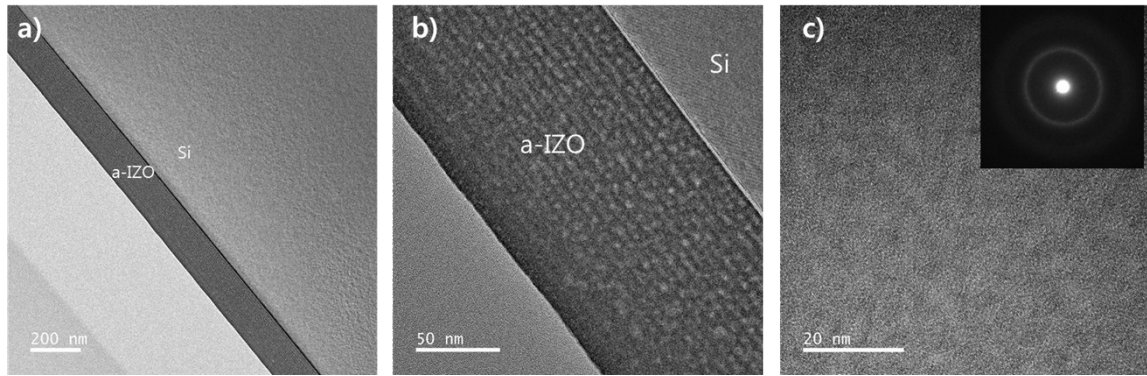


Figure S2. Cross-section transmission electron microscopy (TEM) image of 1% doped a-IZO composite film with different scales of 200 nm (a), 50 nm (b), 20 nm. The inset in (c) is selected area electron diffraction (SAED) pattern.

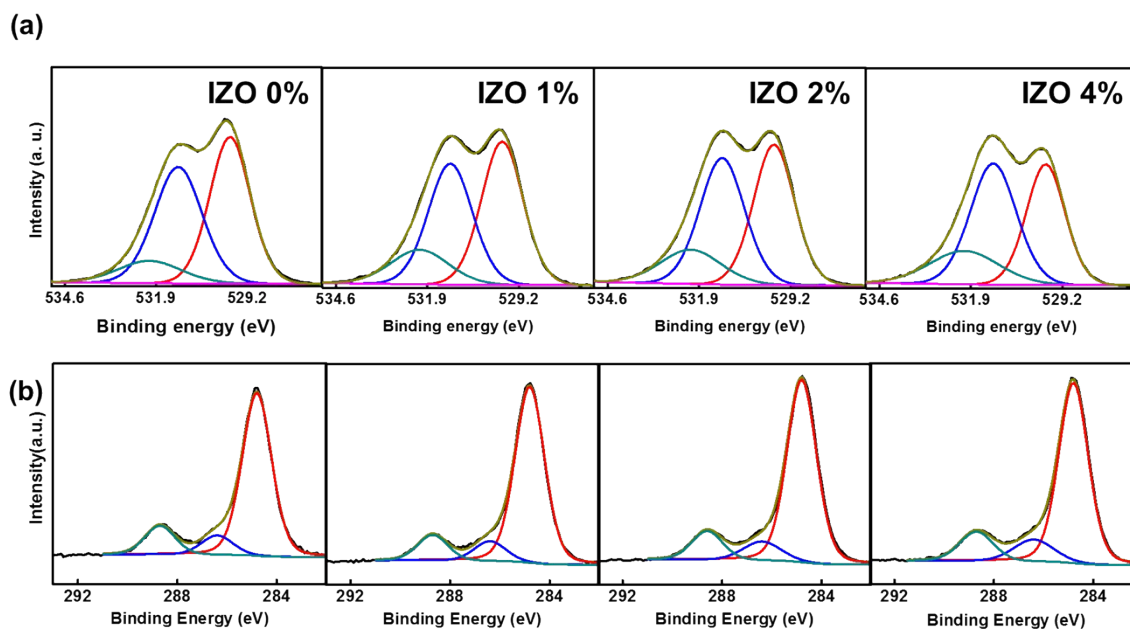


Figure S3. X-ray photoelectron spectra of O1s (a) and C1s (b) levels of *a*-IZO:*x*% C60-MA composites for *x* = 0.0%, 1.0%, 2% and 4% without surface sputtering.

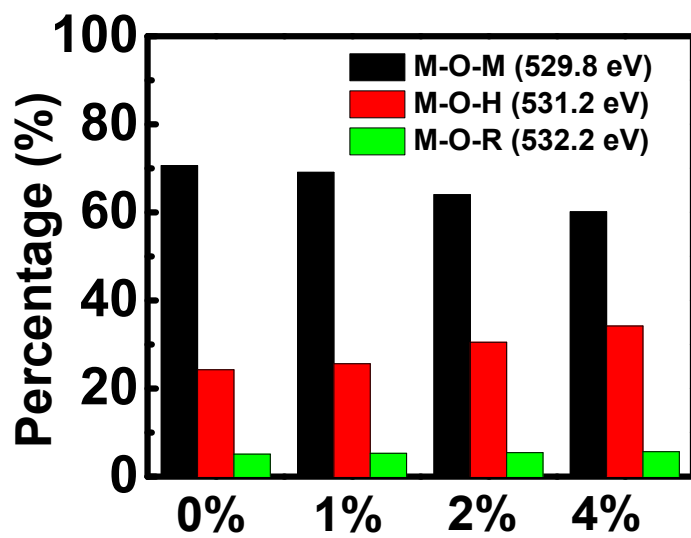


Figure S4. O1s XPS peak ratio analysis for the composite films with surface sputtering.

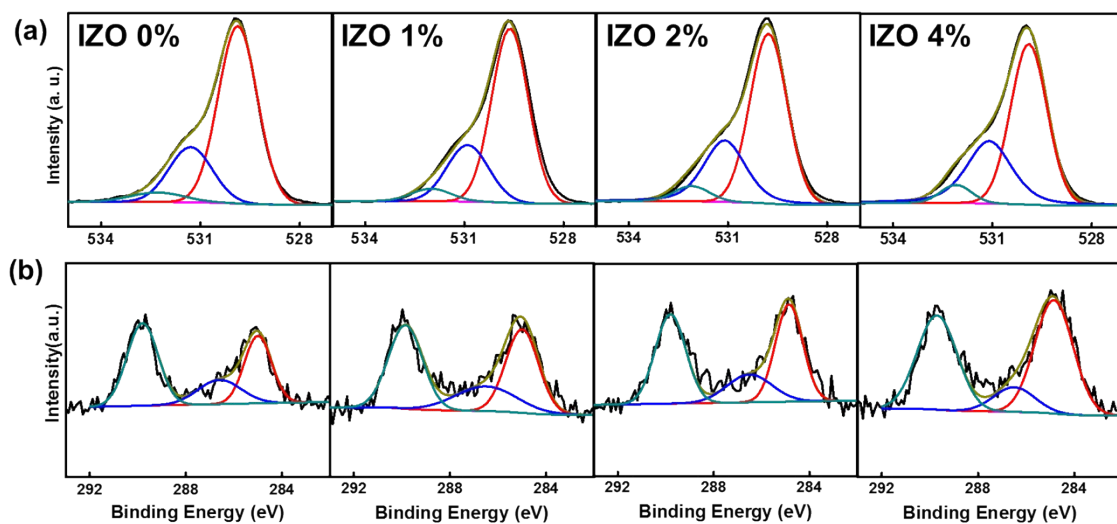


Figure S5. X-ray photoelectron spectra of O1s (a) and C1s (b) levels of *a*-IZO:*x*% C60-MA composites for *x* = 0.0%, 1.0%, 2% and 4% with surface sputtering.

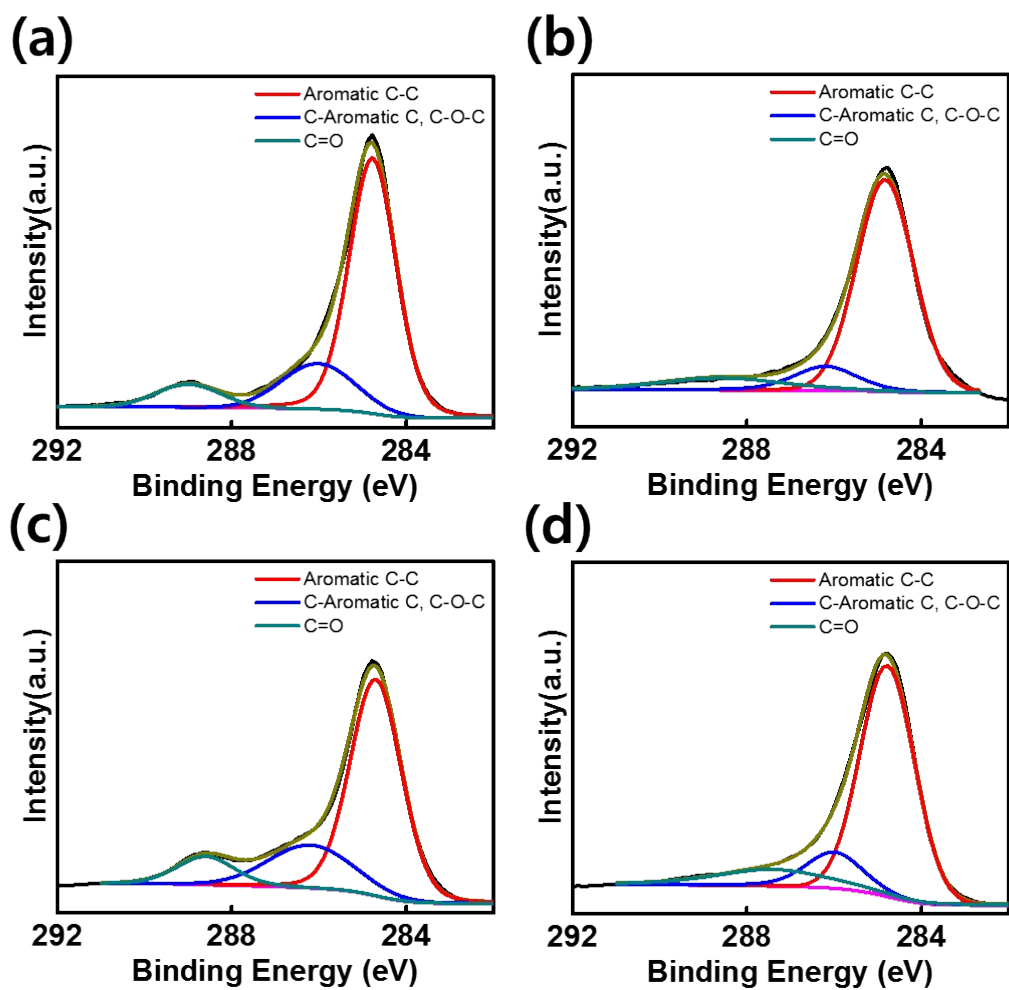


Figure S6. C1s XPS spectra of C60-MA. (a-b) C1s peak analysis of as spun C60-MA C1s without sputtering (a), with sputtering and C60-MA (b). (c-d) C1s peak analysis of 250oC annealed C60-MA without sputtering (c) and with sputtering (d).

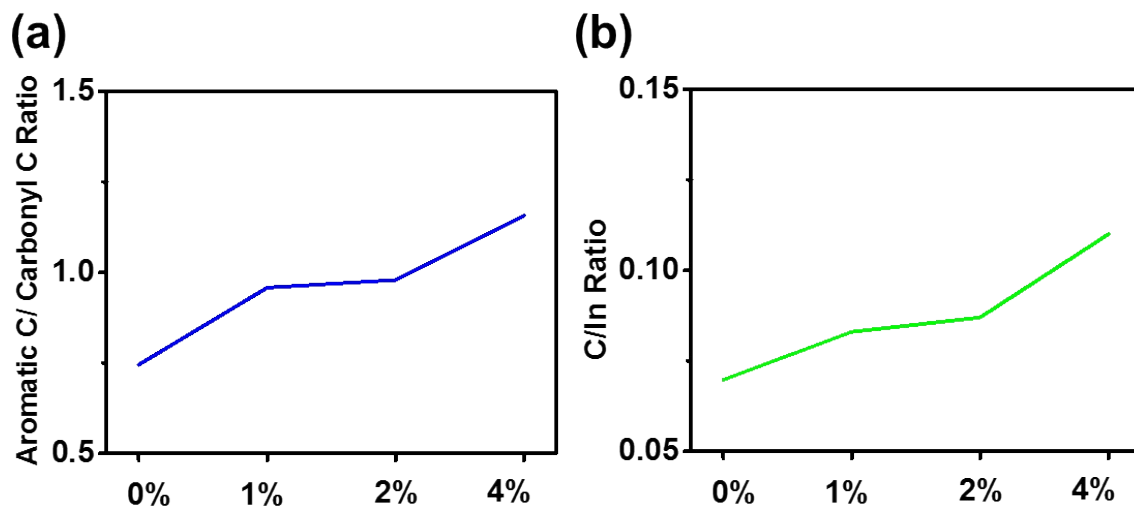


Figure S7. XPS peak ratio analysis of *a*-IZO:*x*% C60-MA composites for *x* = 0.0%, 1.0%, 2% and 4% with surface sputtering. (a) The aromatic C to carbonyl C ratio and (b) the C1s to In content ratio of *a*-IZO:*x*% C60-MA composites for *x* = 0.0%, 1.0%, 2% and 4% with surface sputtering.

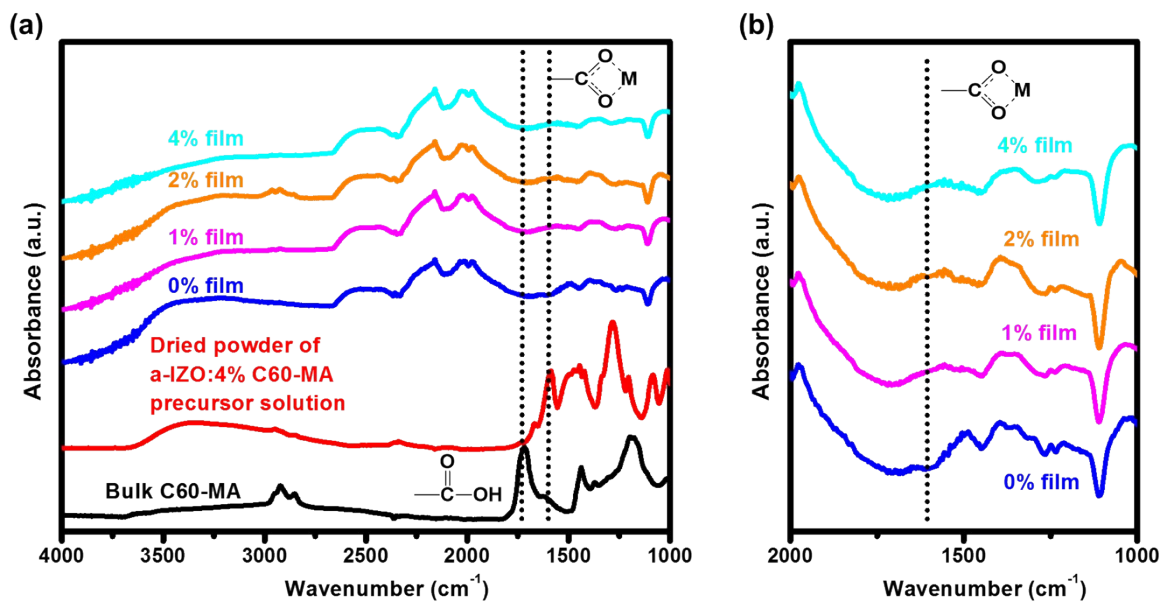


Figure S8. ATR-FTIR data of a-IZO:x% C60-MA composite films (repeated 20 times spin-coating), pristine C60-MA powder and dried mix precursor solution on native silicon substrate. (a) Whole range ATR-FTIR spectra of a-IZO:x% C60-MA composite films, and precursors. (b) Enlarged ATR-FTIR spectra of a-IZO:x% C60-MA composite films.

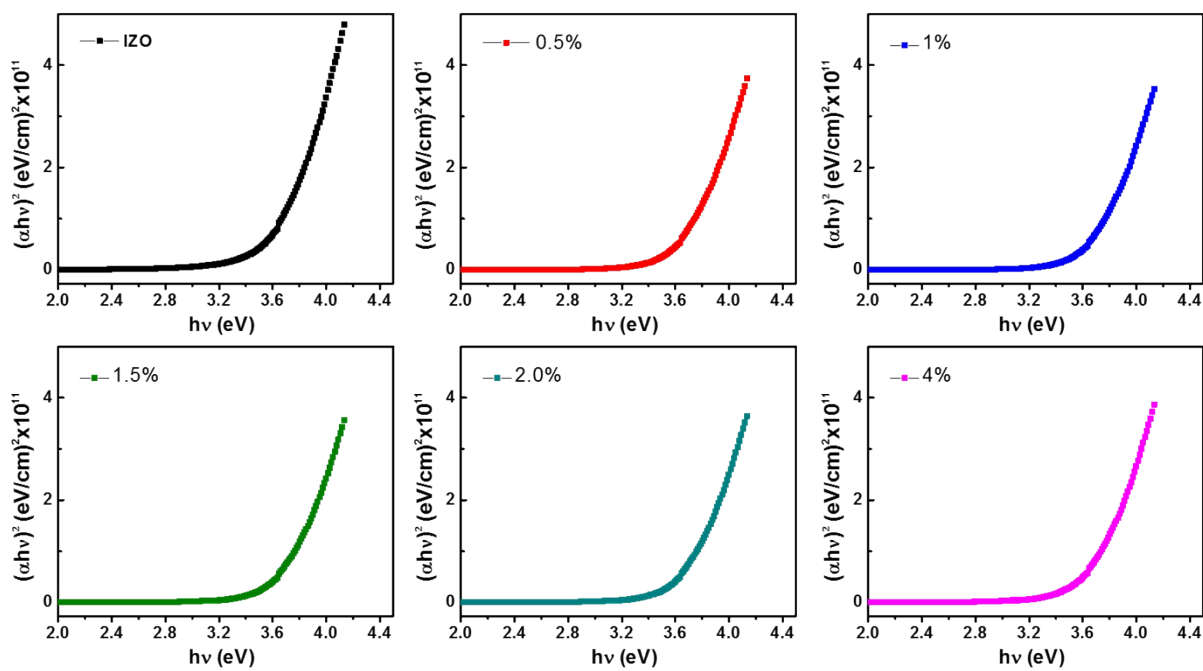


Figure S9. Ultraviolet photoemission spectra of *a*-IZO:*x*% C60-MA composites.

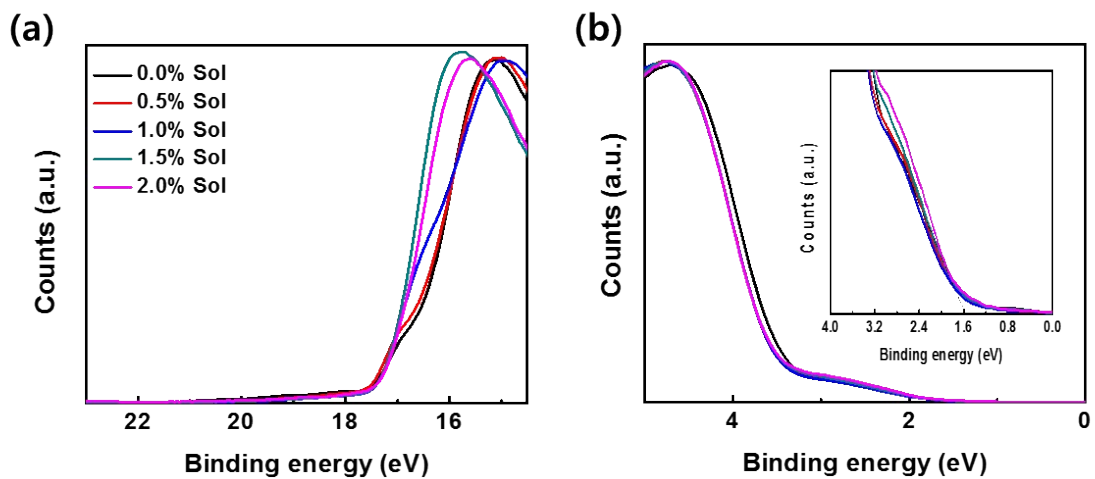


Figure S10. Analysis of the ultraviolet photoemission spectra of *a*-IZO:*x*% C60-MA composites.

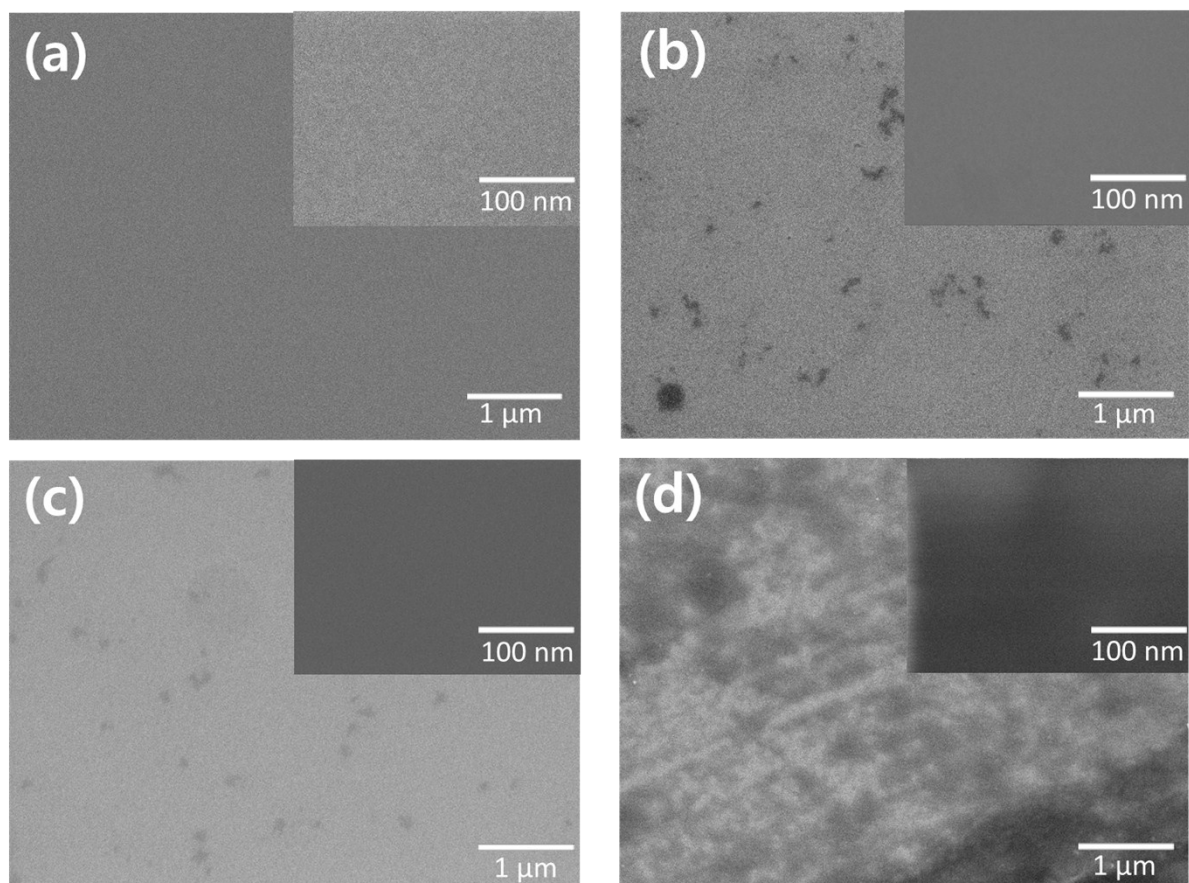
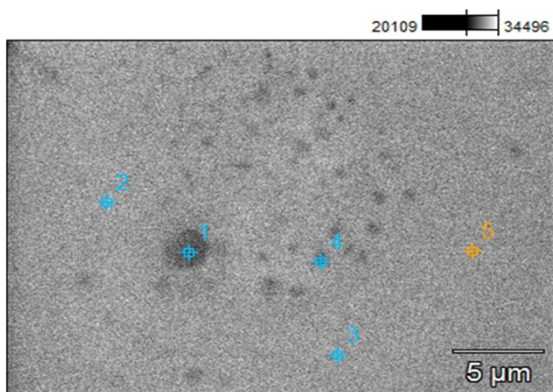


Figure S11. Field emission scanning electron microscopy (FESEM) image of *a*-IZO:*x*% C60-MA composites for *x* = 0.0% (a), 1.0% (b), 2.0% (c) and 4.0% (d) with 1 μm scale. The insets are 100 nm scale.

(a)



(b)
Atom %

	C-K	Zn-L	In-L
Base(10)_pt1	57.34	15.99	26.67
Base(10)_pt2	44.13	28.72	27.15
Base(10)_pt3	44.91	22.54	32.55
Base(10)_pt4	60.04	16.72	23.24
Base(10)_pt5	38.94	28.48	32.59

Figure S12. a) Energy Dispersion X-ray Spectroscopy (EDS) image of a-IZO:4% C60-MA and b) atomic % of selected point in EDS image

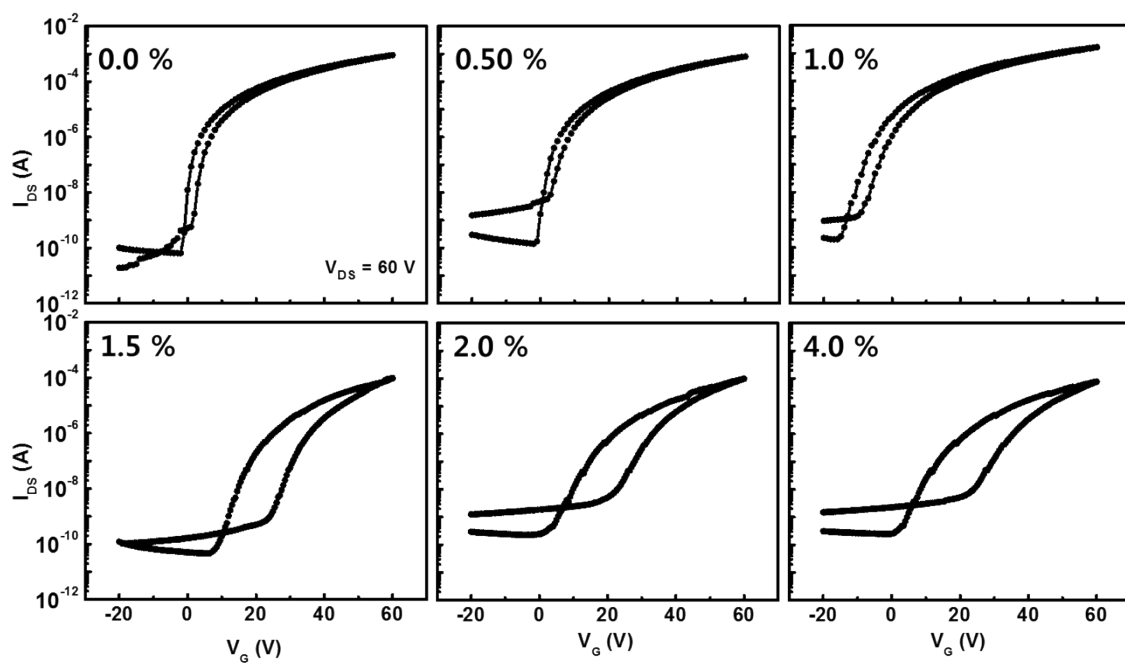


Figure S13. Representative thin-film transistor transfer characteristics of *a*-IZO:*x*% C60-MA composites.

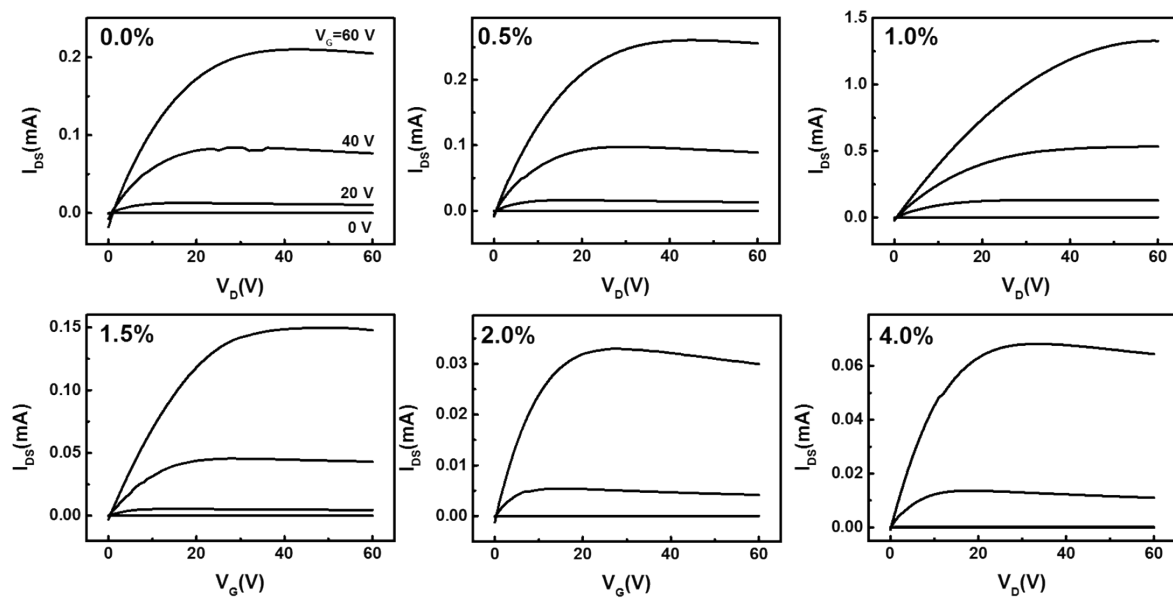


Figure S14. Representative thin-film transistor output characteristics of α -IZO: $x\%$ C60-MA composites.

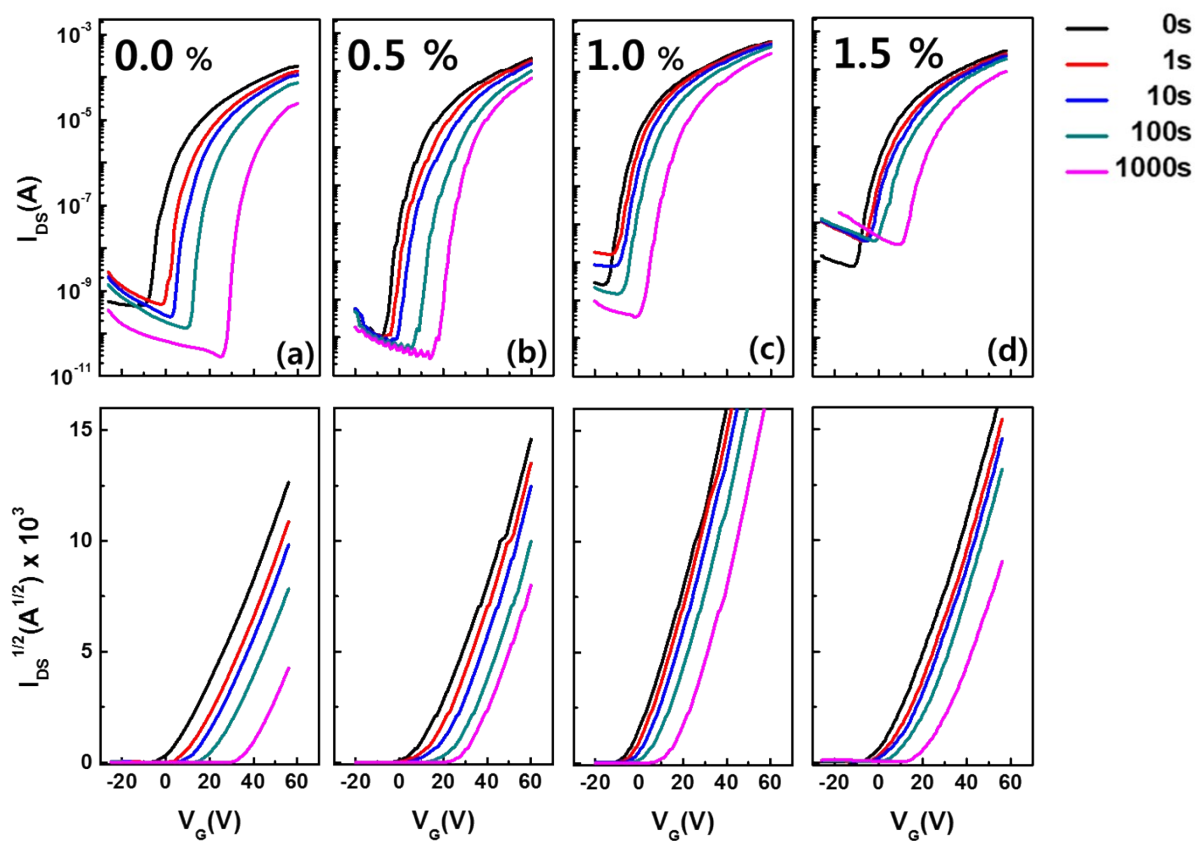


Figure S15. Positive bias stress test results for TFTs of *a*-IZO:*x*% C60-MA composites for *x* = 0.0% (a), 0.5% (b), 1.0% (c) and 1.5% (d) with $V_G = 50$ V and $V_{DS} = 25$ V.

References

1. B. D. Joshi, A. Srivastava, P. Tandon and S. Jain, *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy*, 2011, **82**, 270-278.