Supporting Information

Low Temperature, High Performance, Solution Processed Indium Oxide Thin Film Transistors

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Device fabrication

Heavily boron doped p+ silicon substrates were used in an inverted gate structure for the fabrication of In₂O₃ thin film transistors. Silicon dioxide with a thickness of 1000 Å was thermally grown on top of the silicon substrate and was used as the gate dielectric, a 500 nm gold layer was sputtered on the back side of the bare Si substrate for gate contact. The substrate was cleaned in 1M of NaOH aqueous solution in an ultrasonic bath for ~ 5 min, washed with DI water and then dried with flowing nitrogen gas before use. Microscope glass slides were prepared in a similar fashion for film characterization.

In₂O₃ thin film transistors were fabricated on 10 x 15 mm² oxidized silicon substrates by spin coating at 3000 rpm for 30 s with heating from a light source. As-deposited thin films were dried on a hot plate at 100 °C for a few minutes. Film annealing was performed at various temperatures of 200 ~ 600 °C under different environmental conditions including air, and O₂/O₃ for 2 hours.

Ozone was generated with molecular oxygen passed through an ozone generator (Jelight Co. Inc., Model 1000) operated by a power supply (Jelight Co. Inc., 120-240V, 60Hz). The flow rate of

the supplied molecular oxygen was 0.176 L/min and approximately 5600 parts per million (ppm) of ozone was generated.

Photolithography was used to pattern the In_2O_3 thin film layer for the purpose of avoiding gate leakage at edge of silicon substrate from blanket spin-coated films. The patterned In_2O_3 was annealed at 100 °C for a few minutes before deposition of Al source and drain by thermal evaporation using a shadow mask for patterning. The channel length was 200 μm and the channel width to length ratio was 7.

Characterization

Device characterization was performed in the dark at room temperature with a HP 4157B Semiconductor Parameter Analyzer. The morphologies and roughness of surface of In_2O_3 thin films were characterized by atomic force microscope (AFM, Veeco Nanoscope digital instruments). Optical transmittance and estimated bandgap of In_2O_3 thin films deposited on microscope glass slide were conducted by UV-vis spectroscopy (Ocean Optics Inc, USB 2000 optic spectrometer). The transmittance of bare glass slide substrate was set as 100%. The structural characterization was carried out by X-ray diffraction (XRD, Bruker D8 discover). X-ray photoelectron spectrometer (XPS, ESCALAB 200-IXL instrument with Mg K radiation) was used to characterize the chemistry for synthesized In_2O_3 thin films. For XPS measurements the samples were annealed to 100 °C for 5 min. just prior to introduction into the system. The thickness of solution-processed films was investigated by scanning transmission electron microscope (STEM, Philips CM12).

Figure S1. AFM images of In_2O_3 thin film annealed under (a) air (RMS = 0.245 nm) and (b) O_2/O_3 (RMS = 0.267 nm) atmospheres at 300 °C for 2 h.

Figure S2. Optical transmittance spectra of In_2O_3 thin films annealed under (a) air and (b) O_2/O_3 atmospheres, and (c) estimated optical band gap of In_2O_3 thin films annealed under air and O_2/O_3 atmospheres as a function of annealing temperature in range the of 200 ~ 600 $^{\circ}\text{C}$.

Figure S3. (a)/(b) Output and (c)/(d) transfer characteristics of solution-processed indium oxide TFTs: (a)/(c) and (b)/(d) devices annealed in air and O₂/O₃ atmospheres at 300 °C for 2 h, respectively.

Figure S4. V_{on} of indium oxide TFTs as a function of annealing temperatures under air (T_a = 200, 230, 250, 280 and 300 °C) and O_2/O_3 (T_a = 300, 400, 500 and 600 °C) for 2 h, respectively.

Table S1. In/O atomic ratio of films annealed air and O₂/O₃ at 300 °C corresponding to figure 2
(a) For reference the In/O atomic ratio for stoichiometric In₂O₃ is 0.67.

	air	O ₂ /O ₃
In/O1s (530.6 eV)	1.075	1.071
In/O1s (total)	0.715	0.748
$\frac{\text{O1s (530.6 eV)}}{\text{O1s (total)}}$	63.4%	71.3%

Table S2. Device characteristics of solution based In₂O₃ TFTs with different annealing temperatures under air and O₂/O₃ environment.

Environment	Temperature							
	200 °C	230 °C	250 °C	280 °C	300 °C	400 °C	500 °C	600 °C
air								
μ_{FET} (cm ² /V·s)					3.8	17.43	55.26	37.75
$I_{\text{on/off}}$					10 ⁶	10 ⁶	10 ⁷	10 ⁵
O ₂ /O ₃								
μ_{FET} (cm ² /V·s)	0.85	1.05	11.18	22.14	16.76			
$I_{\text{on/off}}$	10 ⁵	10 ⁶	10 ⁶	10 ⁶	10 ⁵			