Supporting Information

Benzylphosphonic Acid treated Ultra-thin ALD-InOx for Long term Device Stability

Ju-Hun Lee [a,b], Jaehyun Moon[a,b] , Kitae Kim[c,e], Yeonjin Yi[e], Soohyung park[c,d], Jong-Heon Yang[a], Chi-Sun Hwang[a], and Seung-Youl Kang [a*]

[a] Reality Devices Research Division, Electronics and Telecommunication Research Institute (ETRI), Daejeon 34129, Republic of Korea

[b] Advanced Device Technology, ICT, University of Science and Technology (UST), Daejeon 34113, Republic of Korea

[c] Advance Analysis & Data Center, Korea Institute of Science and Technology (KIST), Seoul 02792, Republic of Korea

[d] Division of Nano & Information Technology, KIST School, University of Science and Technology (UST), Seoul 02792, Republic of Korea

[e] Department of Physics and van der Waals Materials Research Center, Yonsei University, 50 Yonsei-ro, Seodaemun-gu, Seoul 03722, Republic of Korea

* Corresponding author e-mail: kang2476@etri.re.kr

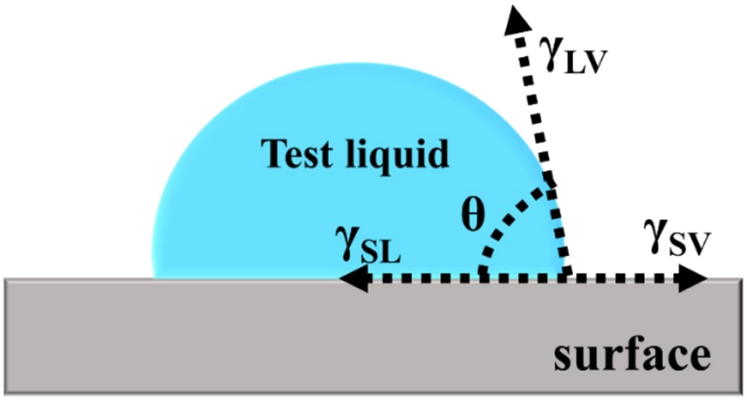


Fig. S1. Schematic of the CA depiction. γ_{SL} is the interfacial energy between the solid (S) and liquid (L), γ_{SV} is the SE the S-vapor (V), γ_{LV} is the SE. The SE L-V, and theta (θ) is the CA of the test liquid on the solid surface.

In general, for CA and SE, it has been useful to analyze between solid surfaces and other materials such as films. So, this system provides a wealth of information that can be used to interpret surface/interface properties. From this perspective, to investigate the SE, the CA method was used to confirm the change from hydrophilic to hydrophobic on the surface of untreated In_2O_3 film and BPA-In_2O_3 film. As shown schematically in Figure S1, the CA testing method appears to be a simpler option when compared to other characterization methods such as electrical and optical testing

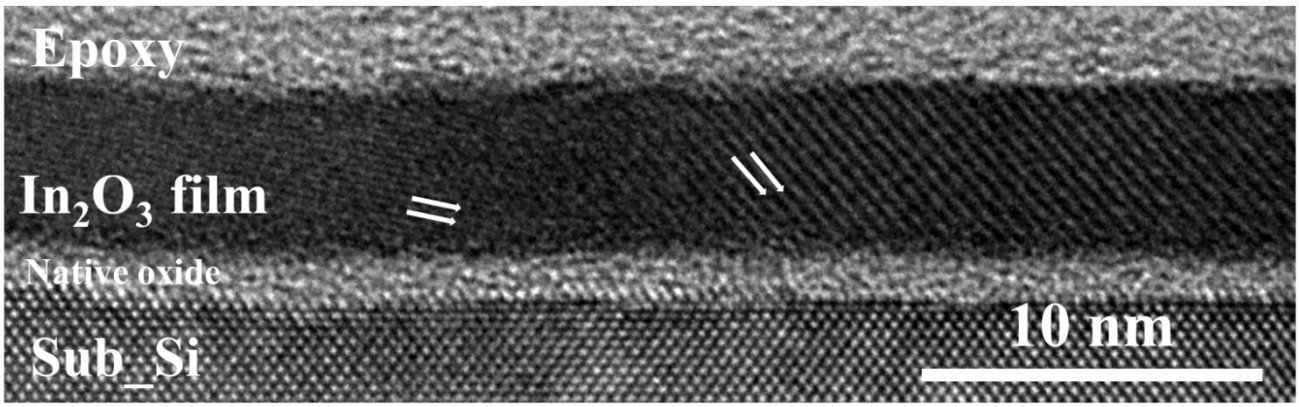
Table 1. Surface energy (SE) components of the test liquid with polar and dispersive SE

Test liquid	Tension (mJ/m^2)	Dispersive (mJ/m^2)	Polar (mJ/m^2)
Deionized water (DI)	72.8	22.5	50.3
Ethylene glycol (EG)	48.3	39.3	19

Table S1. The test liquid parameter values used here for polar and non-polar liquids.

As shown the Table S1, the conventional testing liquid with different polar and dispersive components is used for testing. The polar and dispersive SE components of the two test liquids used in the study. To interpret the SE from the acquired CA data acquisition, it used to the owens-wendt method (OW) equation method. The polar and non-polar testing liquids were used the DI and EG, respectively. The OW models obtained information about the trend of SE

as the surface changes from hydrophilic to hydrophobic temporal for untreated In_2O_3 and BPA-In_2O_3 films.



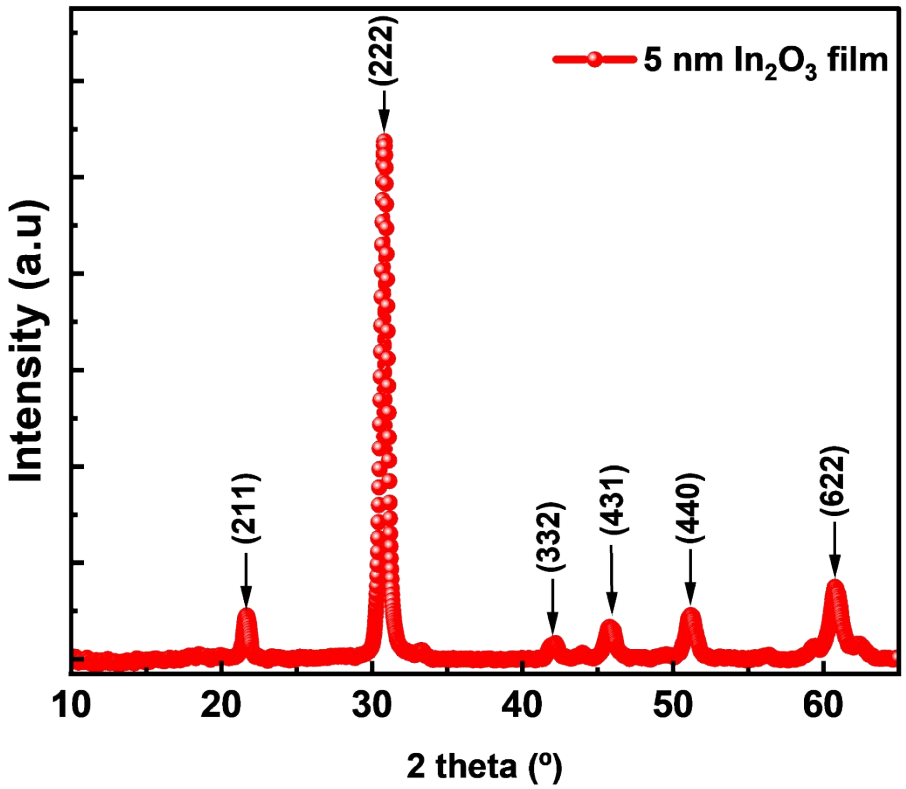


Fig. S2. The top image shows a TEM cross-section of a 5 nm polycrystalline In_2O_3 film. the bottom image shows the XRD peak information of the In_2O_3 film.

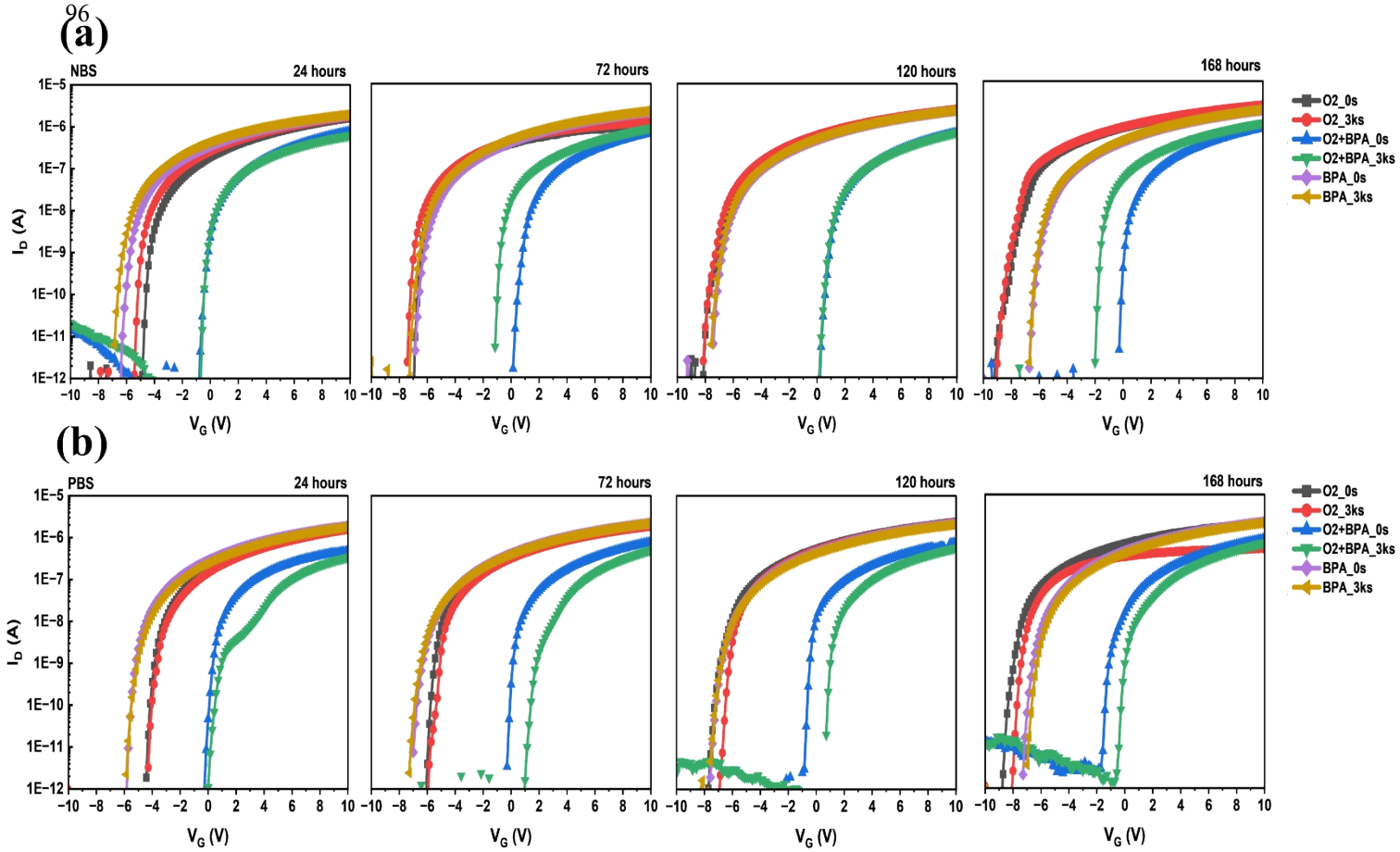


Fig. S3. The transfer curve of the 5 nm In_2O_3 TFT was analyzed under negative (a) and positive bias stress (b) (NBS, PBS) at V_G of ± 5 V over a period of 168 hours.

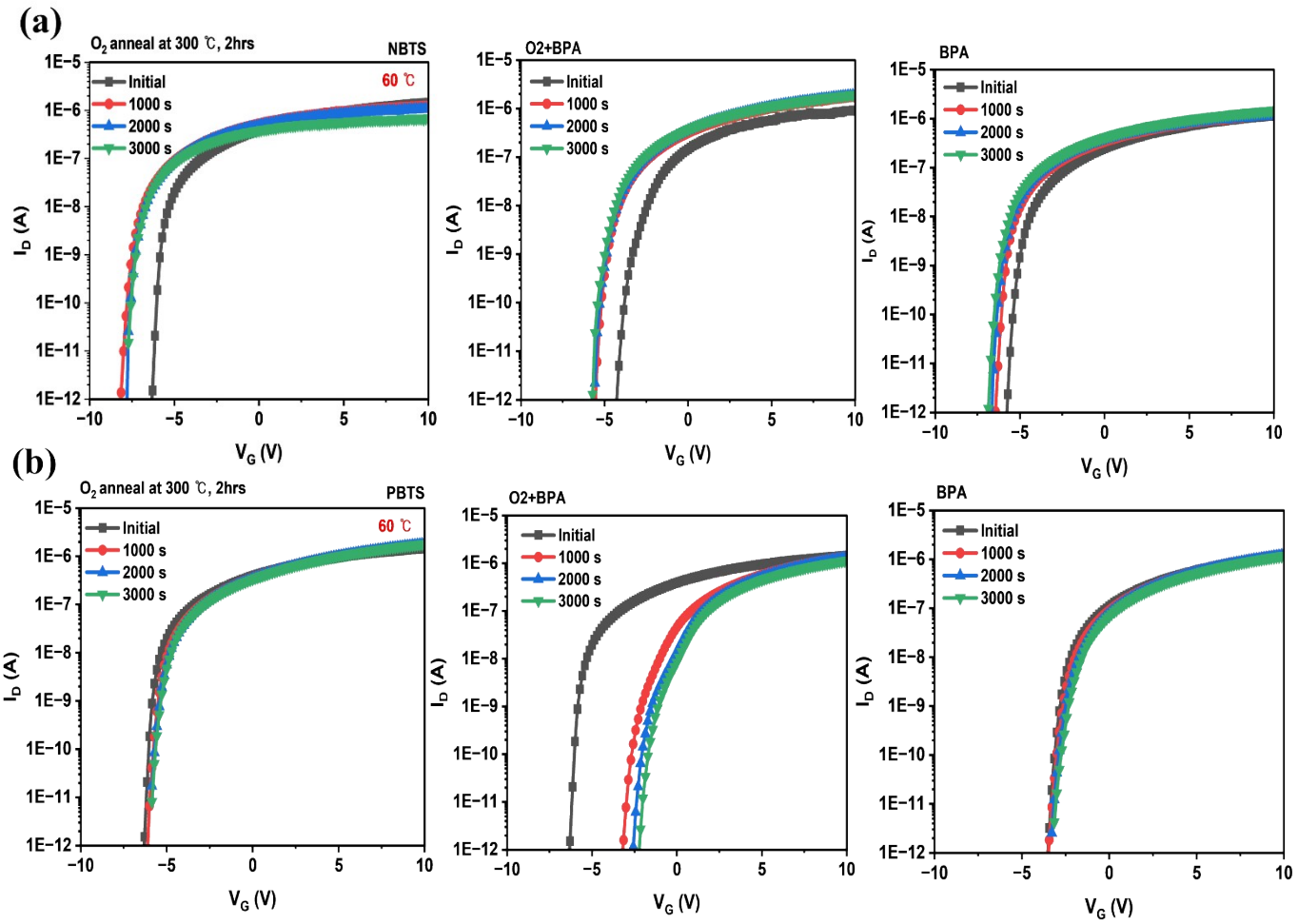

(a)
O2 anneal at 300 ℃, 2hrs
NBTS
60 ℃
O2+BPA
BPA
Initial
1000 s
2000 s
3000 s
ID (A)
VG (V)
(b)
O2 anneal at 300 ℃, 2hrs
PBTS
60 ℃
O2+BPA
BPA
Initial
1000 s
2000 s
3000 s
ID (A)
VG (V)

Fig. S4. This transfer curve shows the stability under thermal conditions at 60 °C. Positive and negative bias temperature stress (NBTS and PBTS).

Fig. S4 (a) shows the NBTS under 60 °C at $V_G \pm 5$ V up to 3,000 sec. For the O_2 anneal In_2O_3 TFT, the V_{th} shifted further in the negative direction, from -3.62 V initially to – 6 V after 3,000 sec. The O_2 anneal with BPA and BPA In_2O_3 TFTs exhibited V_{th} values of -2.1 V and -0.4 V, respectively, after 3,000 sec. The stability of In_2O_3 TFT is due to the back-channel layer of the ultra-thin In_2O_3 film, which acts as the interfacial channel between the semiconductor and the insulator. This back channel is more dominant than the interfacial channel layer between the semiconductor and insulator, resulting in stable device characteristics with surface modification. The PBTS exhibits a similar trend to the NBTS measurement results. In the case of O_2 annealed In_2O_3 TFT, the initial -3.3 V shifted significantly in the positive voltage direction to -1.24 V after 3,000 sec. However, the O_2 annealed In_2O_3 TFTs with BPA passivation showed a larger positive voltage shift from an initial -3.3 V to 2.2 V after 3,000 sec. The increase in electron carriers at the interface is due to the oxygen injected through O_2 annealed treatment inside the film, which results in more In-O bonds being broken and the oxygen becoming more In-O. For the BPA-only In_2O_3 TFT, the V_{th} initially measures 0.35 V. As the existing carrier concentration remains constant, it shifts approximately 0.65 V in the positive direction. After 3,000 sec, the V_{th} value reaches 1 V, given that the initial V_{th} was 0.35 V and the existing carrier concentration remained constant. The results indicate that aromatic rings with a chemically stable structure can maintain the V_{th} stability of In_2O_3 TFT even in thermal environments.

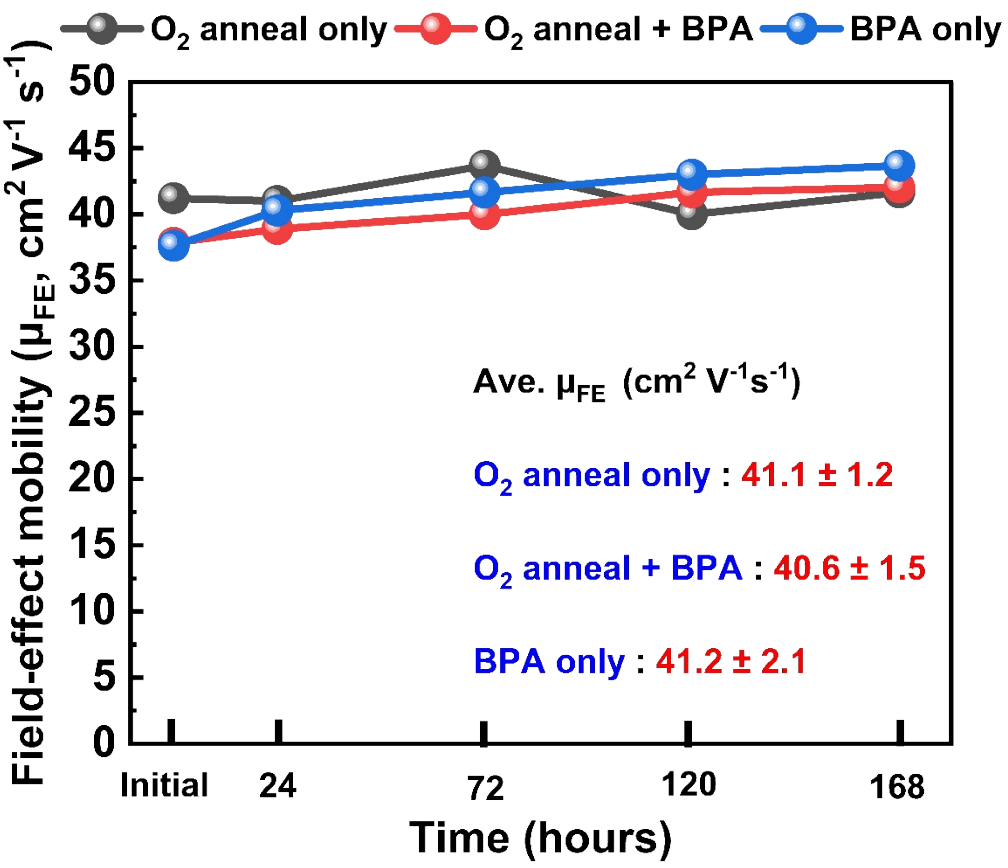


Fig. S5. This graph illustrates the temporal dependency of field-effect mobility in In_2O_3 TFTs treated with O_2 anneal, O_2 anneal+BPA, and BPA. As the results, regardless of the treatment method and time intervals, In_2O_3 TFTs exhibit non-varying mobility of 41.1 $cm^2\ V^{-1}s^{-1}$, 40.6 $cm^2\ V^{-1}s^{-1}$, and 41.2 $cm^2\ V^{-1}s^{-1}$ for the O_2 anneal only, O_2 anneal+BPA, and BPA only treatments, respectively.