Amorphous indium zinc oxide (IZO) semiconductor films grown by atmospheric plasma-enhanced spatial ALD for application as high-mobility channel in Thin Film Transistors

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Less than a decade ago, InGaZnO has been reported as a new Amorphous Oxide Semiconductor (AOS) channel material replacing conventional amorphous silicon (a-Si:H) for application in thin-film transistor (TFT) circuits in display back panels [1]. Among these, indium zinc oxide (IZO) is emerging as the most promising AOS candidate for next-generation displays based on oxide TFTs because it combines a very high electron mobility with excellent optical transmission and thermal stability [2,3].

We have grown InZnO thin films by plasma-enhanced spatial atomic layer deposition (s-ALD) [4,5] and these layers have been manufactured into oxide TFT and ring oscillator devices which outperform the state-of-the-art. We will describe the growth of InZnO at atmospheric pressure and high deposition rates (~ nm/sec) starting with a short explanation of the basics and the advantages of this novel deposition technique including the use of a special atmospheric microplasma source design of the so-called Surface Dielectric Barrier Discharge (SDBD) type [6]. Next, we will show that by varying the ratio of the trimethyl indium and diethyl zinc chemical precursor vapors, the In/(In+Zn) ratio of the film can be accurately tuned over the entire composition range from zinc oxide to indium oxide. TFT test devices with an In/Zn ratio of 2:1 show very high field-effect mobility exceeding 30 cm^2/V.s (Fig. 1), excellent thermal (Fig. 2) and bias stress stability. We will further demonstrate the scalability of the IZO TFTs by fabricating 19-stage ring oscillators operating at 200 kHz which outperform the state-of-the-art.

This superior electrical performance, in combination with the intrinsic advantages of spatial ALD demonstrate the great potential of this atmospheric plasma concept for application in commercial manufacturing of low-cost and large-area AOS-based electronics.

[1] T. Kamiya, K. Nomura, H. Hosono, *Origins of High Mobility and Low Operation Voltage of Amorphous Oxide TFTs: Electronic Structure, Electron Transport, Defects and Doping*, J. Disp. Technol., **5**, 273-288 (2009).

[2] B. Yaglioglu, H.Y. Yeom, H.Y. Beresford, D.C. Paine, *High-Mobility Amorphous In_2O_3-10wt% ZnO Thin Film Transistors*, Appl. Phys. Lett., **89**, 062103 (2006).

[3] M.P. Taylor, D.W. Readey, M.F.A.M. van Hest, C.W. Teplin, J.L. Alleman, M.S. Dabney, L.M. Gedvilas, B.M. Keyes, B. To, J.D. Perkins, D.S. Ginley, *The Remarkable Thermal Stability of Amorphous In-Zn-O Transparent Conductors*, Adv. Funct. Mater., **18**, 3169-3178 (2008).

[4] P. Poodt, A. Lankhorst, F. Roozeboom, C. Spee, D. Maas, A. Vermeer, *High-speed atomic layer deposition of aluminum oxide layers for solar cell passivation*, Adv. Mater., **22**, 3564-3567 (2010).

[5] A. Illiberi, R. Scherpenborg, F. Roozeboom, P. Poodt, *Atmospheric Spatial Atomic Layer Deposition of In-doped ZnO*, ECS Journal of Solid State Science and Technology, **3** (5), 111-114 (2014).

[6] Y. Creyghton, A. Illiberi, M. Mione, W. van Boekel, N. Debernardi, M. Seitz, F. van den Bruele, P. Poodt, F. Roozeboom, *Developments in Plasma-Enhanced Spatial ALD for High-Throughput Applications*, Proc. Int. Conf. on Coatings on Glass and Plastics (ICCG 2016), Braunschweig, Germany, June 12-16, 2016, pp. 93-97.

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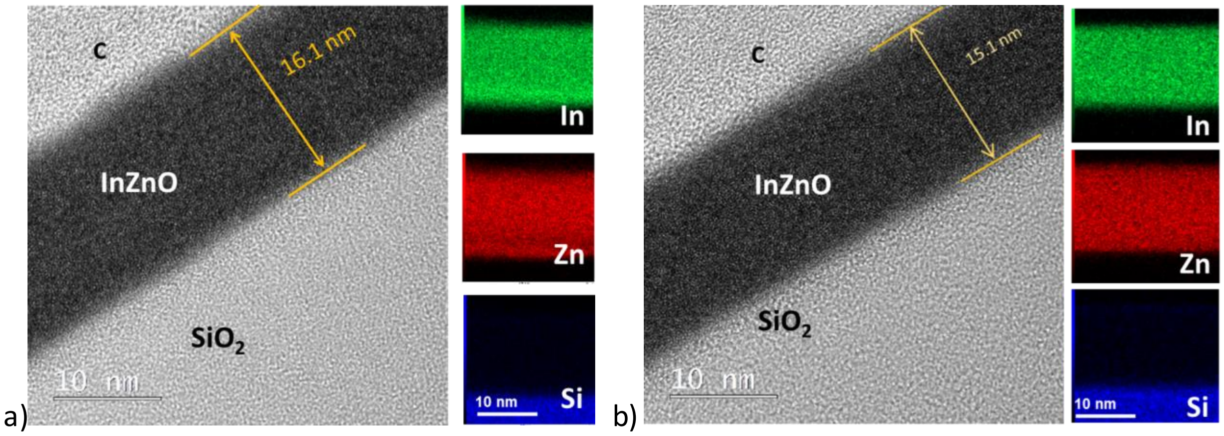

Figure 1: TEM cross-section and elemental composition images of IZO a) as-deposited, b) after annealing at 450 °C for 1 hour.

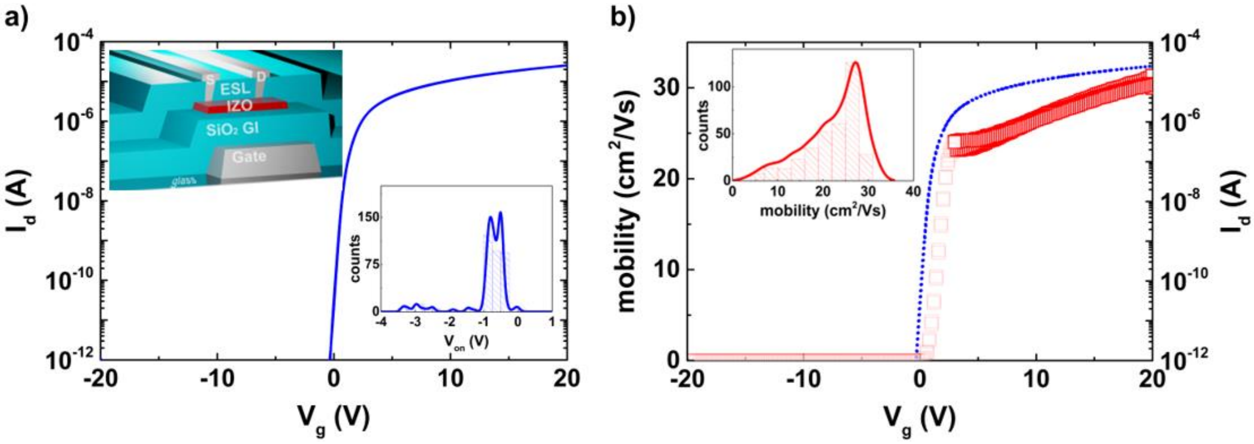

Figure 2. a) I_d-V_g transfer characteristics of 360 TFTs with 15 nm s-ALD grown IZO as active channel. The TFT architecture and the V_{on} histogram are shown in the insets. Transistor dimensions were 60 µm/ 20 µm (W/L) and double sweeps were recorded at 1 V source-drain bias.

b) Linear mobility of a typical TFT as a function of gate bias (□). The dotted blue line represents the corresponding transfer curve. The inset shows a histogram of the mobility of 360 TFTs spread across the 150-mm substrate. The solid red line is a kernel density estimate.