Scalable, Hybrid Complementary Integrated Circuits Based on Solution-Processed Organic and Oxide Thin-Film Transistors

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Printing electronics has been of considerable interest in recent years, since it offers a cost-efficient way to realize electronic applications, especially flexible devices. However, printing complementary circuits is still under way due to the lack of suitable material systems: high-performance solution-processable p- and n-type semiconductors of the same kind of material. This work reports a hybrid system, which combines the strengths of organic semiconductors (OSCs) and amorphous metal-oxide semiconductors (MOSs)[1-4], to print high-performance integrated circuits (ICs) on flexible substrates.

This research demonstrates an integration technology for hybrid complementary circuits towards scalable fabrication and high-speed operation. Employing high performance semiconductor materials: 3,11-dinonylldinaphto[2,3-*d*:2',3'-*d*']benzo[1,2-*b*:4,5-*b*']dithiophene (C_9-DNBDT-NW) single crystal as p-channel material and amorphous indium-zinc-oxide (IZO) as n-channel material, designing damage-free patterning processes for OSC- and IZO-based TFTs, and improving process durability of IZO-based TFTs allow the successfully fabrication of hybrid complementary circuits. The as-fabricated hybrid complementary inverters worked well at the ambient conditions, exhibited large noise margin, negligible hysteresis and power gain of 38 V/V at supply voltage of 7 V. Significantly, the hybrid inverters exhibited good long-term stability, working perfectly after exposure to air for 5 months. Besides, a good flexibility was demonstrated by a bending test. A 5-stage ring oscillator owning a propagation delay of 1.3 μs per stage was demonstrated, which is the fastest operation ever reported for flexible complementary inverter based on solution-processed MOSs or OSCs to our knowledge. The results indicate the possibility to print high-speed complementary circuits on flexible substrates directly.

[1] S. Kumagai, et al, *Sci. Rep.* **2019**, 9, 1.

[2] A. Yamamura, et al, *Sci. Adv.* **2018**, 4, eaao5758.

[3] K. Nomura, et al, *Nature* **2004**, 432, 488.

[4] Y.-H. Kim, et al, *Nature* **2012**, 489, 128.

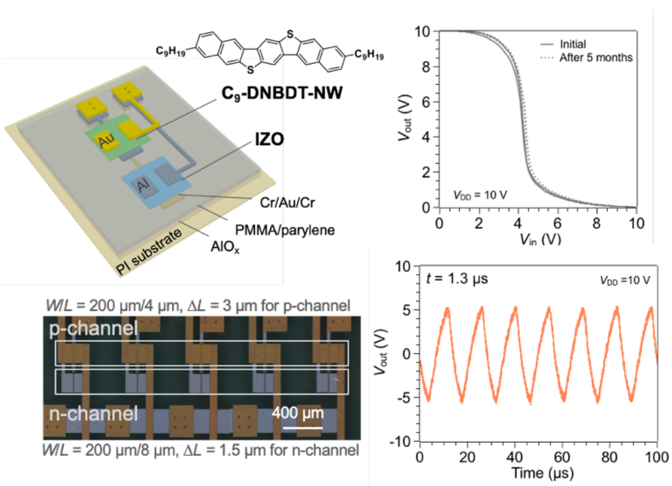

Fig.1. Hybrid complementary circuits based on C_9-DNBDT-NW and IZO. (a) Structure of hybrid complementary inverter. (b) Voltage transfer curves before and after exposure to air for 5 months (W/L=200 μm/9 μm for p channel, W/L= 200 μm/13 μm for n-channel). (c) Micrograph and (d) output signal of hybrid ring oscillator.