A New Achievement for

Ultra low Power logic circuit

Inverter Power consumption of

P = 600 pico Watt

published in Science

Feb. 15, 2019

DEVICE TECHNOLOGY

Printed subthreshold organic transistors operating at high gain and ultralow power < 1 nW

Chen Jiang[1,2], Hyung Woo Choi[1], Xiang Cheng[1,3], Hanbin Ma[1,4,5], David Hasko[1], Arokia Nathan[1,3,5]*

Overcoming the trade-offs among power consumption, fabrication cost, and signal amplification has been a long-standing issue for wearable electronics. We report a high-gain, fully inkjet-printed Schottky barrier organic thin-film transistor amplifier circuit. The transistor signal amplification efficiency is 38.2 Siemens per ampere, which is near the theoretical thermionic limit, with an ultralow power consumption of <1 nanowatt. The use of a Schottky barrier for the source gave the transistor geometry-independent electrical characteristics and accommodated the large dimensional variation in inkjet-printed features. These transistors exhibited good reliability with negligible threshold-voltage shift. We demonstrated this capability with an ultralow-power high-gain amplifier for the detection of electrophysiological signals and showed a signal-to-noise ratio of >60 decibels and noise voltage of <0.3 microvolt per hertz$^{1/2}$ at 100 hertz.

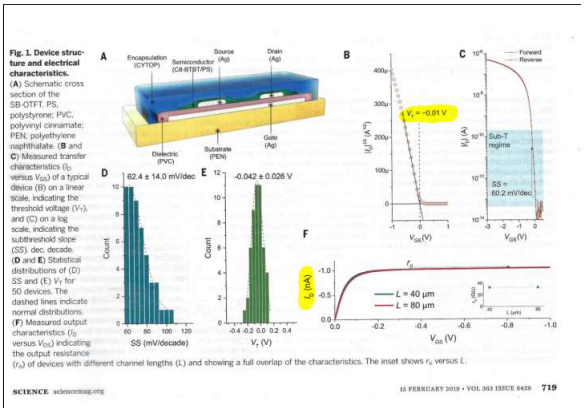

Fig. 1. Device structure and electrical characteristics. (**A**) Schematic cross section of the SB-OTFT. PS, polystyrene; PVC, polyvinyl cinnamate; PEN, polyethylene naphthalate. (**B** and **C**) Measured transfer characteristics (I_D versus V_{GS}) of a typical device (B) on a linear scale, indicating the threshold voltage (V_T), and (C) on a log scale, indicating the subthreshold slope (*SS*), dec, decade. (**D** and **E**) Statistical distributions of (D) *SS* and (E) V_T for 50 devices. The dashed lines indicate normal distributions. (**F**) Measured output characteristics (I_D versus V_{DS}) indicating the output resistance (r_o) of devices with different channel lengths (*L*) and showing a full overlap of the characteristics. The inset shows r_o versus *L*.

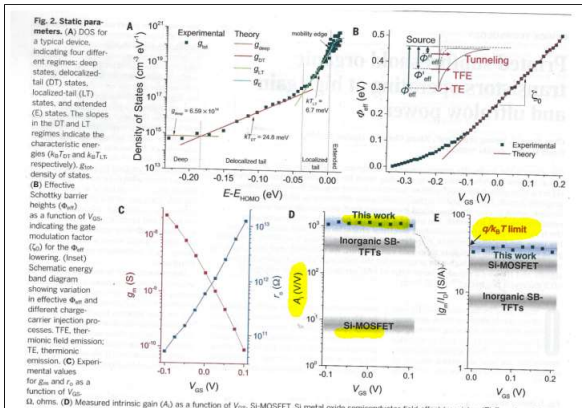

Fig. 2. Static parameters. (**A**) DOS for a typical device, indicating four different regimes: deep states, delocalized-tail (DT) states, localized-tail (LT) states, and extended (E) states. The slopes in the DT and LT regimes indicate the characteristic energies (k_BT_{DT} and k_BT_{LT}, respectively). g_{tot}, density of states. (**B**) Effective Schottky barrier heights (Φ_{eff}) as a function of V_{GS}, indicating the gate modulation factor (ζ_G) for the Φ_{eff} lowering. (Inset) Schematic energy band diagram showing variation in effective Φ_{eff} and different charge-carrier injection processes. TFE, thermionic field emission; TE, thermionic emission. (**C**) Experimental values for g_m and r_s as a function of V_{GS}. Ω, ohms. (**D**) Measured intrinsic gain (A_i) as a function of V_{GS}. Si-MOSFET, Si metal oxide semiconductor field-effect transistor. (**E**) Experimental values of transconductance efficiency (g_m/I_D) as a function of V_{GS}, reaching the theoretical thermionic limit of 38.7 S/A.

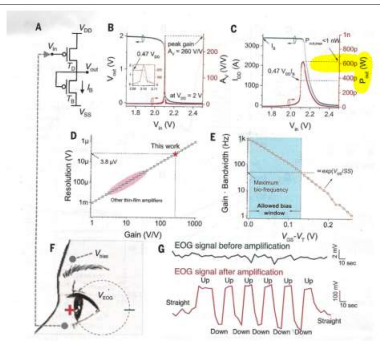

Fig. 4. Amplifier characteristics and demonstration of EOG detection. (**A**) Schematic circuit diagram of a common-source amplifier. V_{DD}, supply voltage; I_B, bias current. (**B**) Measured output voltage (V_{out}) and gain (A_v) as a function of input voltage (V_{in}). (**C**) Measured operating current (I_{DD}) and power (P_{out}) as functions of V_{in}. (**D**) Resolution of electrophysiological signal detection as a function of gain. (**E**) Gain-bandwidth product as a function of V_{GS} in the subthreshold regime. (**F**) Operating principle and circuit configuration for EOG amplification with the amplifier. (**G**) EOG signal obtained before and after amplification.