Oxide TFT Frontend Amplifiers for Flexible Sensing Systems

Yuming Xu, Sunbin Deng**, Rongsheng Chen**

*School of Microelectronic, South China University of Technology, Guangzhou, China

**Purdue University，West Lafayette, IN, U.S.A.

Introduction

Flexible electronics, as an emerging technology, enables ubiquitous flexible devices to bring more convenience and possibilities to human life [1]. Sensing systems are one of the most exciting applications of flexible electronics. A fully flexible sensing system, including sensors and signal processing circuits integrated on a same foil, helps reduce interference and costs, and improves the comfort of wearable devices [2]. Thin film transistor (TFT) technologies are regarded as a potential candidate for the realization of flexible circuits, thanks to its advantage on the compatibility with flexible electronic products compared to the standard CMOS technologies [3].

A frontend amplifier, as the first stage of the signal processing chain, is one of the key elements of the sensing system. Such an amplifier should be AC-coupled to block the sensor offset interference. Also, it should have a relatively large input impedance, to avoid the gain attenuation caused by the large output impedance of the sensor. Furthermore, it should have a differential structure with high common mode rejection ratio (CMRR) to resist the common mode noise (mainly the power line interference). There are strict requirements on the noise performance of the amplifier for some weak signal detection applications such as bioelectric signal measurement. In addition to the above requirements, power consumption of the amplifier should be as low as possible, especially for portable and wearable devices. Finally, for applications that require multi-channel measurement, the amplifier is also desirable to have a small area and high integration. Therefore, it is a challenging task to realize a high-performance frontend amplifier, even with the CMOS technologies. This task becomes more difficult when using TFT technologies, due to the lack of complementary devices (in most cases) and the poor device performance.

In this paper, we present an oxide TFT based frontend amplifier design towards the realization of flexible sensing systems. The amplifier is fabricated with our n-type metal oxide TFT technology. Electrical measurement including gain, bandwidth, input impedance, noise, and CMRR are displayed. An *in-vitro* measurement of the heart-rate signal is performed to demonstrate the circuit practicality.

Device

A three metal layers n-type indium-tin-oxide (ITO)-stabilized ZnO TFT technology was used [4]. Circuits in this paper were still fabricated on a glass substrate to improve yield and stability. Typical device parameters are summarized in Table I. In addition to transistors, metal-insulator-metal (MIM) capacitor with a capacitance of 40 nF/cm^2 is also available, by sandwiching the metal layers and isolation layers. Top plate of the capacitor is realized by the Gate metal, while the bottom plate is realized by the SD metal and Top metal. The SD metal and Top metal are connected through contact holes. Device structure is shown in Fig. 1.

Circuit Design

In this paper, an external-biased, open-loop, capacitor bootstrap amplifier structure is used, as shown in Fig. 2. The zero-V_{gs} connected back-to-back stacked T0 form the pseudo-resistor to bias the common mode voltage V_{cm}. The T0 and T3 have a W/L less than 1 because they act as resistors. The C_{in} is designed to be 1.6 nF, which only introduce a gain attenuation of 0.9 times. To improve the gain, g_{m1} should be as large as possible. For a given current budget, T1 should be biased with a small overdrive voltage and have a large W/L. In order to maintain high gain at low frequencies, a relatively large C_f is used. To reduce thermal noise, g_{m1} is designed to be much larger than g_{m2}, which is the same way as improving the gain. To reduce 1/f noise, the T1 is designed to have a very large area of 0.4 mm^2. The circuit is loaded with an oscilloscope probe with 10 MΩ||12 pF.

Results and Discussions

Fig. 3 shows the photograph and micrograph of the amplifier. The amplifier has an area of 41 mm^2 and a power consumption of 0.1 mW. It is fully integrated on-chip and does not require external discrete components. Fig. 4 shows the measured Bode plot of the amplifier. The amplifier shows a 20 dB mid-band gain, a 3 Hz to 6 kHz bandwidth, and a 30 degrees phase margin. Fig. 5 shows the measured input impedance of the amplifier. The input impedance is up to 100 MΩ and the bandwidth is 10 Hz. Fig. 6 shows the measured input-referred noise of the amplifier. The input noise integrated from 1 to 200 Hz is 106 μV_{rms}. Fig. 7 shows the measured CMRR of the amplifier. In the frequency band of interest, the CMRR is higher than 33 dB and can reach up to 42 dB.

Heart-rate measurement, as one of the most popular applications of the flexible sensing system, is carried out in this subsection to further demonstrate the usefulness of our amplifier. Fig. 8 shows the measurement setup. Three commercial gel electrodes were used. The two outputs of the amplifier were directly connected to an oscilloscope, and converted to a single-end sign al by using the subtraction function of the oscilloscope. Then, the signal passed through a notch filter realized by a Matlab program to further eliminate the 50 Hz power line interference. Fig. 9 shows the acquired heart rate signal, from which the heartbeat rhythm (R wave) is observed. The average interval between R waves is ~750 ms, which indicates that the heart-rate of the 26-year-old male volunteer is ~80beats/min (within the normal range).

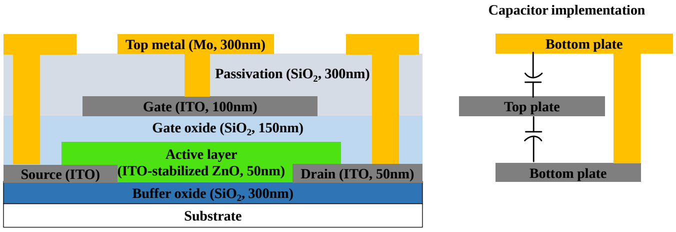
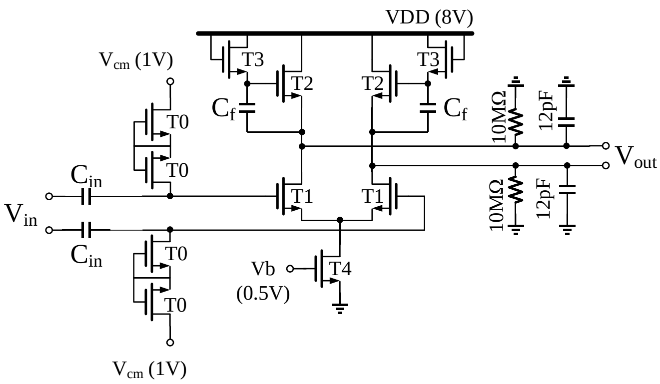


Fig. 1. Device structure of the oxide TFT used

Table 1. TYPICAL PARAMETERS OF THE OXIDE TFT USED

Mobility (μ)	15 $cm^2V^{-1}s^{-1}$
Threshold voltage (V_{th})	0.5 V
Subthreshold slope (SS)	100 mV/Dec
On/off current ratio (I_{on}/I_{off})	10^8
Gate oxide capacitance per unit area (C_{ox})	0.28 fF/μm^2
Overlap capacitance per channel width (C_{ov})	2 fF/μm



T0, T3	T1	T2	T4	Cf	Cin
10μm/100μm	8000μm/50μm	500μm/50μm	16000μm/50μm	2.4 nF	1.6 nF

Fig. 2. Schematic of the presented frontend amplifier

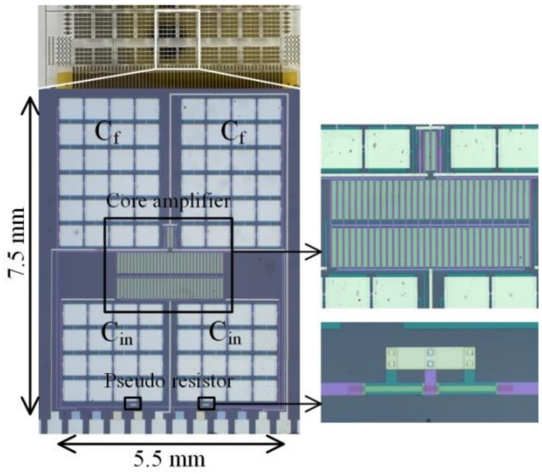


Fig. 3. Micrograph of the presented amplifier

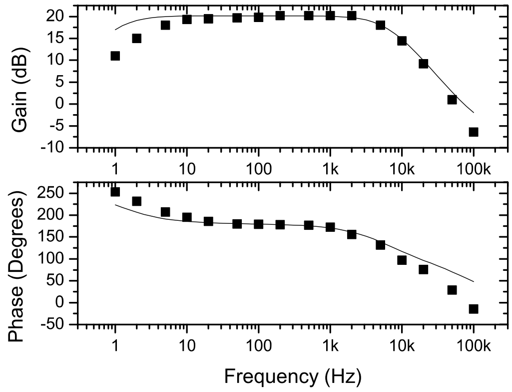


Fig. 4. Bode plot of the presented frontend amplifier

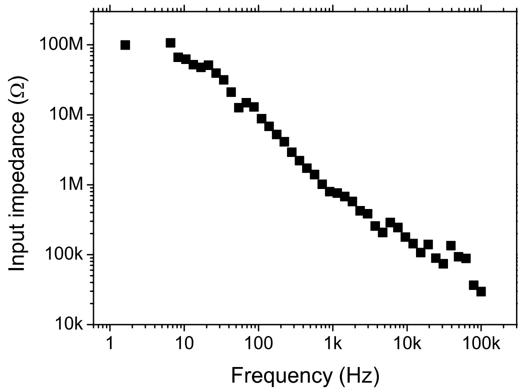


Fig. 5

Input impedance of the presented fontend amplifier

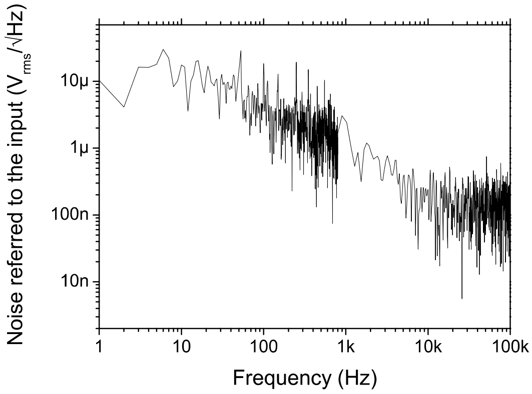


Fig. 6. Input-referred noise of the presented frontend amplifier

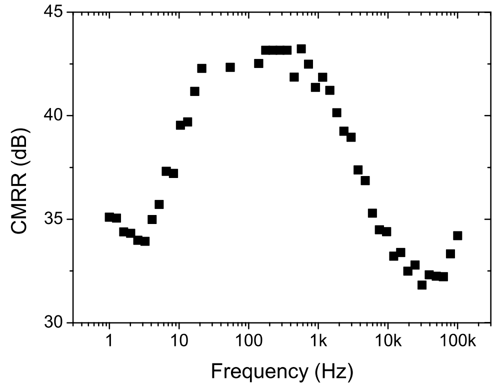


Fig. 7. CMRR of the presented frontend amplifier

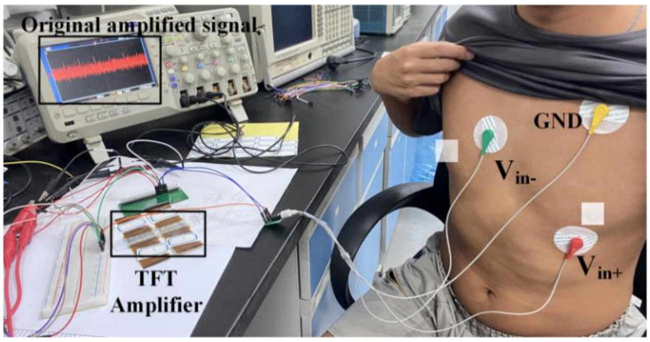


Fig. 8. *In-vitro* heart-rate measurement setup

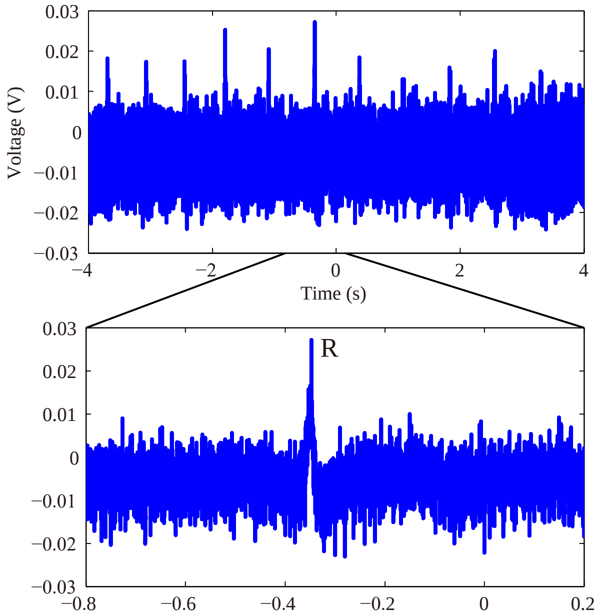


Fig. 9. The acquired heart rate signal

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