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OTFT Circuit Design for Actuator Driving Control in an Organic Fluid Pump

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Abstract

We report an organic thin-film transistor (OTFT) driver-circuit design for the actuator of an organic fluid pump, which is planned for application in a portable-size artificial lung. Compared to traditional pump designs, lightness and compactness are achieved by adopting a creative pumping mechanism with a completely organic-material-based system concept. The simulations are based on an accurate surface-potential OTFT compact model and demonstrate that the necessary driving waveforms can be efficiently generated and adjusted to the actuator requirements.

1. Introduction

Organic thin-film transistors (OTFTs) have been widely investigated and successfully used in applications, such as flexible displays or wearable electronics, due to their advantages of light weight and low-cost fabrication [1-2]. Advanced applications of organic electronic circuits in artificial human organs such as artificial retina and skin are under development. It was also verified that organic semiconductor devices can achieve good performance in robot applications [3-4].

Recently, a new type of organic material with deformability characteristic by applied electrical biases was reported [5]. We exploit this bias dependent deformation characteristic and integrated OTFT circuits, which generate an appropriate bias control, to construct a novel organic fluid pump. The operating principle of the fluid pump is similar to a mechanical roller pump, generating the fluid flow by moving a narrowed portion of the organic fluid pipe in flow direction. The reported organic circuit is designed with the accurate compact OTFT model HiSIM-Organic [6] and generates the required positive and negative bias voltages to drive the deformation of the organic fluid pipe. The envisaged application is a portable artificial lung [7].

2. Organic actuator design for generating the fluid flow

The organic actuator consists of a polymer coated with carbon nanotube layers [5]. If positive and negative biases are connected to its opposite surfaces, the actuator bends to the positively biased side as shown in Fig. 1a. The amount of this deformation is dependent on the magnitude of the bias applied. Fig. 1b shows the measured periodic bending magnitude when an AC bias of 1Hz with an amplitude of 4.5Vis used. By combining pairs of the basic organic actuator structure, each with connection electrodes to both sides, movements with narrowing and widening of the fluid path can be created as illustrated in Fig. 2. The organic stripe pairs with metal electrodes can be combined to realize a pumping movement as explained in Fig. 3. Here the fluid path is controlled by magnitude and sign of applied biases, realizing narrowed and widened sections which can be moved in one direction to generate a fluid flow in the same direction, similar to the mechanism applied in a mechanical roller pump. To create the periodic actuator deformation for the roller pump like movement, the biases on all actuator nodes have to be controlled appropriately. The developed actuator circuit for this purpose in the example of a 4 section fluid pump is shown in Fig. 4. Only PMOS OTFTs, which are easier to build and have higher carrier mobility with present organic materials, are used and the ring-oscillator principle is applied. A PMOS-only Pseudo-CMOS NAND, shown in Fig. 5 (right), activates the circuit operation. Five non-inverting buffers with even numbers of Pseudo-CMOS inverters, shown in Fig. 5 (left), serve for the bias-signal timing control. XOR-gates composed of 4 Pseudo-CMOS NANDs, shown in Fig. 6, generate the actuator control outputs, sqo1, sqo2, sqo3 and sqo4 used as alternating bias voltages. The crossed-style overlap connection with two adjacent buffers leads to an overlapped compression of two fluid-pipe sections for guaranteeing a controlled fluid-flow direction.

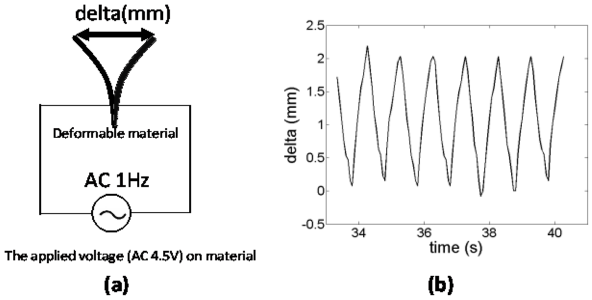

Fig. 1 Bias-dependent bending of the deformable organic actuator.

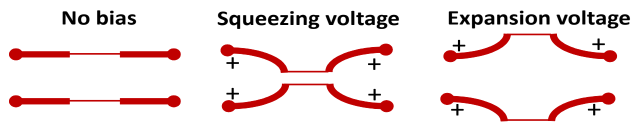

Fig. 2 Basic construction and operating principle of a fluid-pipe section controlled by applied bias voltages.

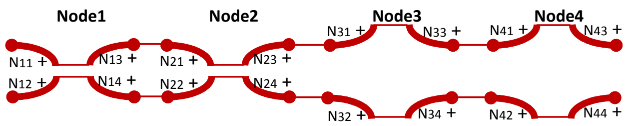

Fig.3 Corresponding biases of 4 connected sections with 2 sequential narrowed and 2 sequential widened sections.

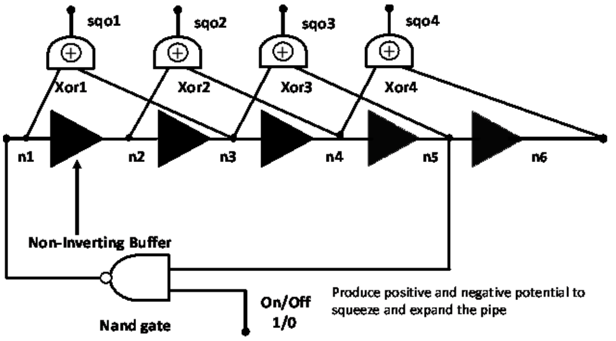

Fig. 4 Bias control circuit for fluid pump actuator part.

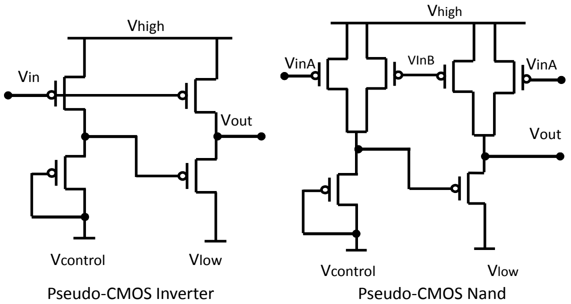

Fig. 5 PMOS-only Pseudo-CMOS inverter and NAND.

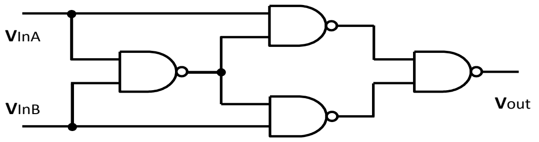

Fig. 6 XOR composed of 4 Pseudo-CMOS NANDs.

3. Simulation Results

For circuit simulations the compact OTFT model HiSIM-Organic, implemented into a commercial SPICE simulator, has been applied. The model considers the carrier-trap effect as well as the resistance effect induced by the bottom gate structure, and achieves good agreement with measured OTFT data [6]. The chosen supply voltages for the design are V_{high}= 4.5V, V_{low}= -4.5V and $V_{control}$= -4.5V, in accordance with the actuator requirements (see Fig. 1). Due to the necessary low frequency of about 1 Hz, the design resulted in long and narrow OTFTs (L=2.8mm, W=15μm). Each non-inverting buffer contains 16 inverters to obtain sufficiently long section narrowing time. Fig. 7 demonstrates the transient simulation results for the fluid-pump example with 4 sections. The actuator control circuit starts to output alternating high and low potentials after the "on/off" signal is asserted. A complete pumping cycle of the actuator is equivalent to a high-low cycle at any of the 4 actuator-control circuit outputs (sqo1, sqo2, sqo3, sqo4) as indicated in the upper part of Fig. 7. The designed pumping cycle is about 1.18 sec, which corresponds to a frequency of about 0.85 Hz.

The pumping-cycle length can be adjusted to any practical requirements by changing length L or width W of the OTFTs, the number of inverters for each buffer circuit or by adding intermediate load capacitors. As can be seen in Fig. 7, high times of actuator-control circuit outputs sqo1, sqo2, sqo3 and sqo4 mutually overlap, so that the narrowing of the next pump section is completed before the previous section expands, preventing backward flow of fluid. Fig.7 illustrates the complete pumping cycle, consisting of 4 periods t1, t2, t3 and t4. During t1, the 1st and 4th sections are narrowed while the 2nd and 3rd section are expanded. During t2, the 2nd section narrows and the 4th section expands, while the 1st section remains narrowed. During t3 and t4 the movement of 2 narrowed sections from left to right continues, with at least one section remaining narrowed at any time to guarantee fluid flow in one direction.

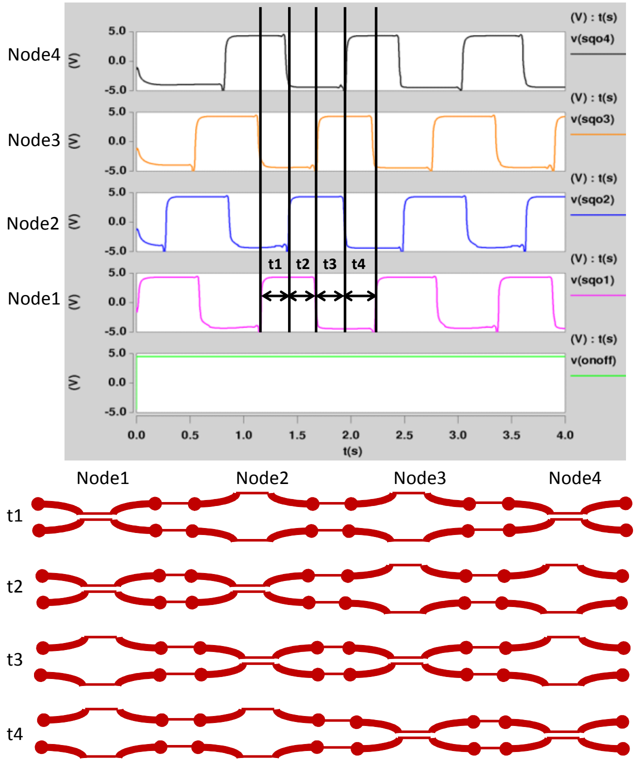

Fig. 7 Simulation result of the actuator-driving circuit (upper part) and illustration of a pumping cycle for a 4 section fluid pump during its 4 time periods t1, t2, t3 and t4 (lower part).

4 Conclusions

A novel OTFT driver-circuit design for the actuator part of an organic fluid pump has been developed. The control-bias voltages for coordinated narrowing and expanding of the fluid-pipe sections, as required by the bendable actuators for the fluid-pumping process, are accurately generated. The OTFT circuit design can be easily adapted to a changed timing for the control biases and can also be integrated with actuators and fluid pipe to create an all-organic fluid pump of small size and light weight. Thus it is an ideal pumping component for a portable artificial lung, which is the envisaged application of the reported research.

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