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Readout from Amorphous Silicon Thin-film Transistor-based Strain Sensing Sheets Over Non-contact Interfaces using a TFT Gilbert-Type Modulator

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Large-area, thin-film, electronics (LAE) enables the development of electronic sheets with transformational capabilities and conformal form factors. Combining these with co-designed CMOS integrated circuits allows for leveraging of the computational power of CMOS in tandem with the rich sensing and energy-harvesting capabilities of LAE. Through the ability to incorporate amorphous silicon (a-Si) thin-film solar modules (PV), transistors (TFT), and sensors, as well as Li-Ion thin-film batteries, on flexible substrates, we have created complete, self-powered, sensing skin sheets [1,2]. For this system, TFT-based sensors [3] (e.g. for strain/light/pressure/chemical detection) are attractive from an integration-on-plastic perspective. Such sensors can be readily formed, and they exploit a rich set of physical responses, typically expressed through changes in TFT parameters such as mobility [4] or threshold voltage ( $V_t$ ), resulting in TFT current shifts.

To enable the range of system components, patterning on different sheets, which are subsequently laminated, is preferred from a manufacturing perspective. To enable scalable system assembly, signal and power transfer between the sheets is performed wirelessly via non-contact interfaces using patterned planar capacitors/inductors; this enables large-scale systems without the need for costly and potentially low-reliability metallurgical bonding. Here, we demonstrate readout from a TFT strain sensor using a Gilbert-type modulator to achieve conversion of the sensor current output to an AC signal for transfer via a non-contact interface to a readout IC.

The Gilbert-type modulator consists firstly of a primary-TFT differential pair structure (T1/2), with thin-film  $n^+$  a-Si resistive loads ( $30 \text{ M}\Omega/\text{sq}$ ); a TFT sensor serves as the tail current source (T3), biased in an appropriate regime for sensing mobility changes as a result of applied mechanical strain. The two inputs to the differential pair TFTs (T1/2) are counter-phase sinusoidal signals, which generate an amplified and AC-modulated output whose amplitude is proportional to the sensor-TFT (T3) current. This differential AC output can then be capacitively (wirelessly) coupled to an IC for readout; for efficient transfer, capacitive readout is used due to the limitation in operating frequency imposed by the low a-Si TFT  $f_t$  of  $\sim 1\text{MHz}$  (as a result of low mobility and large parasitic capacitances). Such a structure, however, results in large AC amplitudes at the modulator output nodes, of which only a small fraction is representative of the actual strain-induced T3 current change. In addition, the intrinsic drain current drop due to TFT threshold voltage shift is also mirrored directly in this AC amplitude. To overcome these two issues, an additional TFT differential pair (T4/5) is used (also driven by sinusoidal inputs), whose outputs are connected to the outputs of the primary differential-pair structure, to cancel

the sensor-independent signal. This additional differential pair uses an orthogonally laid-out strain-invariant reference TFT as its tail current source (T6). Assuming TFTs T6 and T3 are fairly well current-matched and experience similar  $V_t$  drift, the effect of this drift on the output AC signal of the TFTs is mitigated.

Using the described architecture, readout can be achieved from multiple TFT sensors by selectively gating each TFT sensor into the Gilbert-cell tail using a series of TFT access switches. In the complete system with a co-designed CMOS IC, non-contact TFT strain sensing on a cantilever-like structure is achieved up to 1000 microstrain ( $10^{-6} \Delta L/L$ ), with resolution of  $\sim 25$  microstrain.

[1] Y. Hu, et al., VLSI Symposium, June 2013 (in press)

[2] W. Rieutort-Louis, et al., PVSC, June 2013 (in press)

[3] T. Someya, et al., MRS Bulletin, vol. 33, pp. 690–696, July 2008

[4] P. Servati, et al., Appl. Phys. Lett., vol. 86, 033504, Jan. 2005

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