IGZO-based Identification Tags Communicating with Everyday Touchscreens

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Abstract

In this work, we demonstrate a capacitive coupled data transfer with flexible thin-film electronics using touchscreen as ubiquitous reader interface. The capacitive communication to the touchscreen is proven using a 64-bit metal-oxide thin-film capacitive-coupled identification tag. The tag is powered by a thin film battery or thin-film photovoltaic cell that is converting the light of the screen. The thin-film integrated tag has on-chip monolithic electrodes (0.8cm^2), and the integrated circuit employs 409 transistors and dissipates only 140nW of power at 600mV supply voltage. The asynchronous data rate of the chip is up to 35bps, strictly limited by the touchscreen readout electronics.

Author Keywords

RFID; Capacitive; TFT; touchscreen; mobile; flexible; metal-oxide; IGZO; identification; tag; touch; IoE; internet-of-everything; IoT

1. Introduction

The Internet-of-Things (IoT) era has been enabled by millions of high-end devices that are connected to the cloud by WIFI, BLE or 4G/5G. Equipping lower-value everyday items with a wireless communication chip at sufficiently low cost may pave the way to the Internet-of-Everything (IoE). Thin-film transistor (TFT) technologies on plastic substrate offer many advantages to the next-generation IoE family. A very thin, flexible and low-cost radio-frequency identification (RFID) tag can be disguised in thin paper (150µm) and plastic tickets, official letters, certified documents, game and payment cards, but also in other thin or curved objects (1–6).

For short-range communication protocols (RFID/NFC) a dedicated reader, that is serving as a hub connecting the tag-enabled items to the cloud, is needed (1–3). NFC enabled phones or tablets already integrate NFC-dedicated hardware, adding-up the cost. However, the number of NFC-enabled devices is much smaller compared to the omnipresence of touchscreens available on smart devices. Capacitive-coupled touchscreen tags (CT-tag) do not require a specific reader hardware, which would make them the true enabler for IoE (7). In this work, we demonstrate a TFT-based CT-tag that communicates electrically with the capacitive touchscreens, paving the way for the IoE era.

Recently capacitive very thin and monolithic integrated thin-film identification tags (5,6) were demonstrated using a custom-built reader. The integration of capacitive touchscreens to everyday devices introduces an unexpected object ID reader on these devices (Fig.1). A touchscreen can be considered nowadays as a, not initially foreseen, reader for non-human objects, that is populating every corner (7,8). Moreover, capacitive communication offers besides security due to the touch-range communication, but also lower cost due to the monolithic integrated antenna that alleviates assembly cost as well.

The next section of the paper describes briefly the metal-oxide thin-film transistor technology on polyimide substrates and provides details on the uniformity graphs and statistics for key technology parameters. Subsequently, the CT-tag system and its various building blocks and circuit operation are presented and analyzed. Finally, the experimental results of the full tag system and its established communication to multiple touchscreens are shown and discussed.

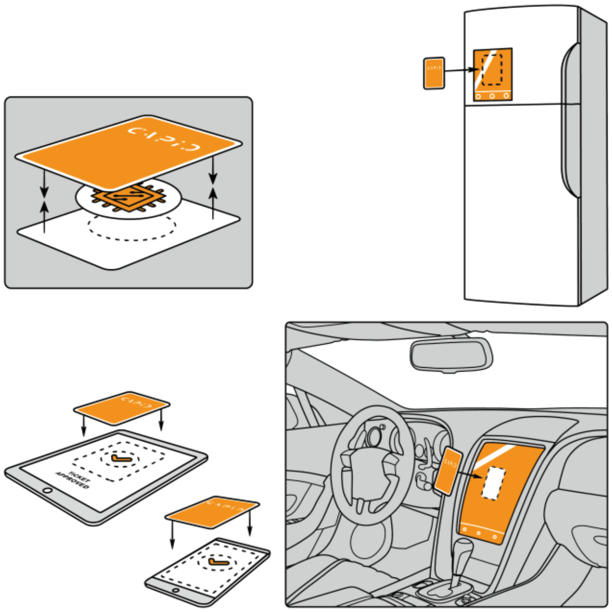

Figure 1. Application cases of c-touch tags integrated in cards.

2. The TFT Technology

The dual-gate self-aligned (DGSA) thin-film-transistor architecture on a GEN1 polyimide (PI) substrate (Fig.2) (9) is used to fabricate the CT-tags. On a temporary glass carrier with a 15µm thick PI film, a humidity barrier is deposited and afterwards, 130nm of MoCr is deposited followed by the 200nm PECVD SiO$_2$ deposition as a BGate dielectric. Next, a thin layer IGZO is DC sputtered and patterned to define the active semiconductor area. Subsequently, 200nm PECVD SiO_2 is deposited as a gate dielectric at a deposition temperature of 250°C. Afterwards, 130nm MoCr is added as gate-metal. The gate/dielectric stack is patterned within the same process step. 200nm PECVD SiNx is deposited as intermetal dielectric and hydrogen dope the IGZO in the contact area. The contact holes for the Source-Drain (SD) contacts are opened and MoCr/Al/MoCr is deposited and patterned to define the SD-contacts. The stack is passivated by thick organic layer and 130nm MoCr is deposited and patterned. The last step in the TFT process is a final anneal at 165°C. All process steps in the backplane process stay below a thermal budget of 350°C.

In Fig. 3 the extracted effective dual gate mobility (µ) (due to dual-gate structure) and threshold voltage (V_T) from experimental data of 20/5 (µm/µm) dual-gate IGZO are shown across $150mm^2$ on the wafer for the 200nm gate dielectric. The median V_T is 0.75V and the median μ=$32.3cm^2/Vs$. Moreover, the standard deviation of V_T is only 160mV, the standard deviation of µ is $1.1cm^2/Vs$ across $150mm^2$.

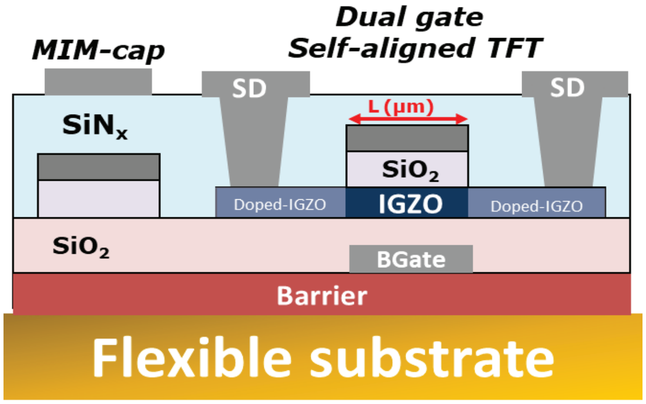

Figure 2. Cross-section of dual-gate self-aligned metal oxide TFT and Metal-Insulator-Metal (MIM) capacitor on flexible polyimide substrate.

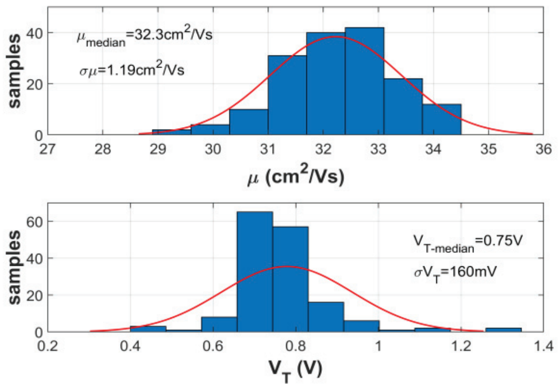

Figure 3. Extracted effective mobility (µ) (due to dual-gate structure) and threshold voltage (V_T) from experimental data of 164 20/5 (µm/µm) Dual Gate IGZO TFTs over $150mm^2$.

3. Tag Design Considerations

In Fig.4 the overall block schematic diagram of the CT-tag system is outlined (power source, logic generator, clock generator, modulator and touchscreen). The formed interface is an artificial capacitor between the transparent metal lines of the touchscreen and the electrodes of the CT-tag. The glass of the touchscreen combined to the PI of the tag or paper/plastic of (gaming) cards forms the dielectric of the artificial capacitor. The roughness of aforementioned materials adds air as well in the dielectric mix, impeding the communication coupling. Due to the complexity and diversity of capacitive touchscreens (10) and their electronics (11,12), the communication method of our CT-tag device was verified over a variety of touchscreens from different brands (Apple, Huawei, Samsung). All the above increase the complexity of the overall targeted system that is analyzed in the following.

The power of the tag can be provided either by a thin-film battery (TFBAT) or photovoltaic cell (TFPV) capturing light from the screen. TFBAT are available from 1.5V (13) whereas the TFPV open circuit voltage starts typically at 0.6V (14). We have demonstrated the operation of c-touch for both power sources.

The most power-hungry block is 64-bit logic generator, which contains 324 DGSA TFTs, forming 7 latches, 23 inverters (Fig.4 (b)), 10 3-input NOR gates and 24 2-input NOR gates. The logic is creating a continuous stream of predefined bit-sequence. We implemented improved methods to synthesize the code generator resulting in similar numbers of TFT as earlier for 12-bit code generators (6). This is depicted also in the power dissipation of the block and the full tag. The logic gate style used is dual-gate single supply pseudo-cmos shown in Fig.4 (b).

The clock generator is a 19-stage ring oscillator (RO, Fig.4 (c)) and directly controls the data transmission rate to the touchscreen. From experiments on various touchscreens with off-the-shelf build lab emulator, it is concluded that the touch event sampling rate is typically limited to only 60 events/sec using electrodes of 8x6mm (7). The same speed is confirmed by swiping a finger on a touchscreen. This readout speed is setting a very low clock speed specification (Hz) to the clock generator of the tag. To meet the slow speed challenge, we increased the TFT channel lengths of the 19-stage RO to 200µm and 400µm, and we also introduced an extra capacitor to the output stage of the RO. In addition, the same RO is designed to be used for both power levels: battery (~0.6-0.8V) and PV (>1.5V).

The modulator (T_{MOD}) is driven by the output of the logic generator and is controlling the second electrode. T_{MOD} is connecting and disconnecting the second electrode to the first electrode and to the ground. The very low off-current of the IGZO technology is leveraged by the modulator since modern readout electronics are very sensitive to charge changes (11,12).

4. Experimental Results

Fig. 5 shows photos of the CT-tag. In Fig.5 (a) and (b) the tag is powered by respectively a flexible TFBAT and a TFPV, transmitting its code to two different touchscreens (Samsung S8 and iPhone 8). In Fig. 5 (c) a zoom into the CT-tag and the created touch event is shown. The touch event is illustrated by two lines perpendicular to each other (touch event lines). The CT-tag is creating a swipe from the first electrode to the other and the coordinates are processed by the app to decode the transmitted code (Fig.7). Fig.5 (d) shows the integration of a roll of tags into gaming cards.

In Fig. 6 the performance of the various blocks of tag is analyzed.

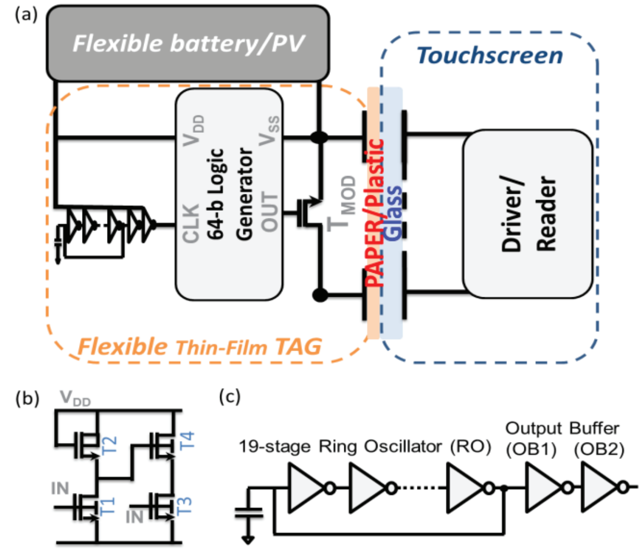

Figure 4. (a) The CT-tag system blocks and (b) the dual gate single supply pseudo-cmos logic style schematic used and (c) the 19-stage ring oscillator schematic.

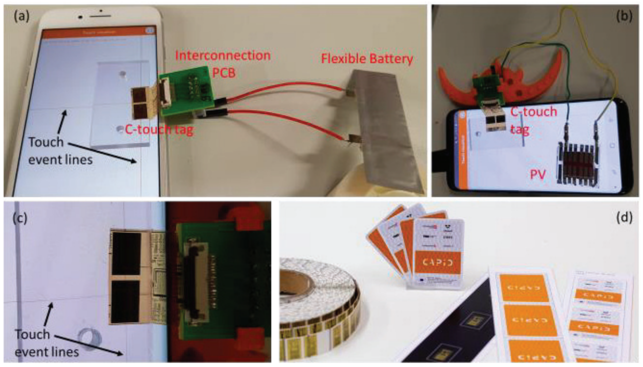

Figure 5. Photos of CT-tag placed on smartphone screen and powered by (a) a flexible battery (b) a TFPV and (c) a zoom of the CT-tag and the created touch event illustrated by the lines and (d) gaming cards with integrated tags and a roll of tags.

In Fig.6 (a) the measured power dissipation performance of the dual-gate 64-bt logic generator is shown in comparison to earlier 12-bit implementations using single gate logic (7). The power dissipation of the 64-bit logic chip is higher than the 12-bit of power at 0.6V. In Fig. 6 (b) the measured speed performance of various channel length (L) scaled ring oscillators are depicted. The 200μm channel length RO design is chosen because of the speed (<40Hz) at 2.5V. Moreover, the speed of the 400μm RO at 0.6V is impractical slow (1.2Hz). The other designs (L=10μm & 40μm) are too fast (>40Hz) for the readout electronics of the touchscreens as explained earlier. In the case of a 4V battery, the 400μm RO has to be chosen. In Fig.6 (c) the power performance of the perovskite TFPV cell is shown on a Samsung's S8 screen. Only one cell (12.5mm^2 footprint) is used to power the CT-tag when the screen brightness is at 25%. The TFPV is powered only by the light emitted by the display.

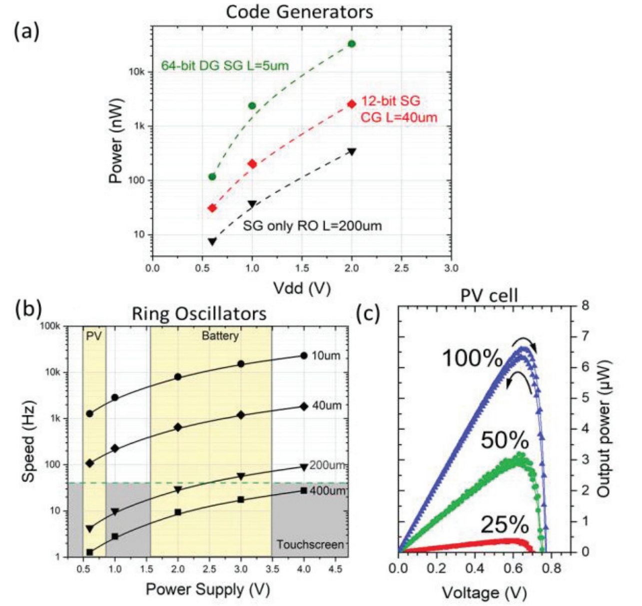

Figure 6. (a) The measured power dissipation of various logic generator designs and (b) ring oscillators speed response to the applied power supply voltage for various channels lengths and (c) the output power of the 12.5mm^2 TFPV cell for 3 different display brightness and the open-circuit voltage.

In Fig.7 (a) the readout of the 64-bit code of the CT-tag acquired from the touchscreen electronics is depicted. The CT-tag is powered at 0.8V and achieves 8b/s. In Fig.7 (b) the tag is powered at higher voltage (2.2V) and achieves faster speed (~35b/s). The power dissipated by the CT-tag is 33uW at 2.2V ensuring 700hrs of continuous operation using a typical TFBAT of 20mW. When the tag is powered by the perovskite TFPV at low brightness (25%) (as shown in Fig.6 (c)) it achieves a lower rate of 4b/s (Fig.7 (c)), as expected from Fig.4 (c). In Fig.7 (d) and (e) the CT-tag is connected to 1.5V TFBAT and placed on two different phones (iPhone8 and Huawei Y7) achieving a speed of ~19b/s. Experiments with paper in between the tag and the touchscreen show similar readings from the touchscreen. These graphs verify the operation of CT-tag for various speeds on different touchscreens. The speed can be adapted for a specific power source by redesigning the ring oscillator as concluded from Fig.6 (c).

5. Discussion and Conclusions

A capacitively coupled radio frequency identification tag is demonstrated, and its operation is verified on capacitive touchscreens of various mobiles. The very low power dissipation and low operation voltage of the 64-bit tag (140nW at 0.6V) enables powering by a 12.5mm^2 single-cell thin-film perovskite solar cell but also by thin-film batteries for up to 700 hrs continuous operation. The 4.5 billion mobile phones worldwide (15) and the extra touchscreen-enabled devices (cars, home appliances, smart surfaces/tables, etc) anticipated in the near future could provide a reader for this touchscreen-enabled tag and enable new functionalities. Mass-production of the newly proposed capacitive touchscreen tags may impact today's philosophy of the IoE .

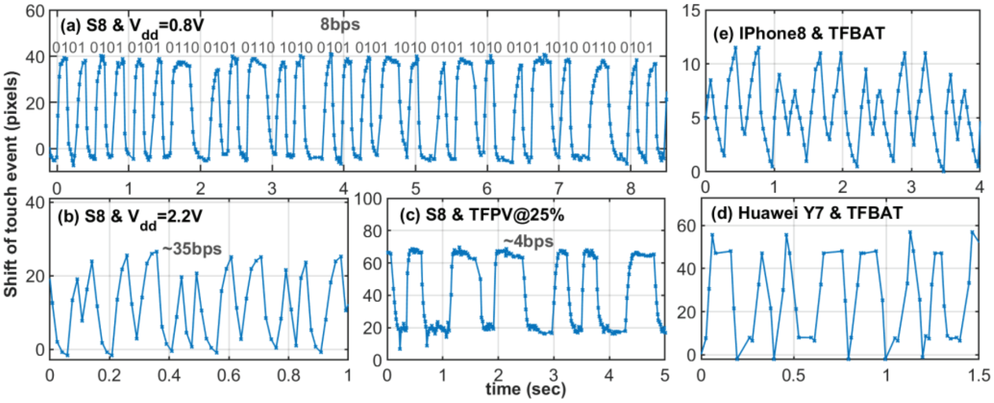

Figure 7. Extracted location data from experiments performed of CT-tags on the touch screen (a) of a Samsung S8 at V_{dd}=0.8V and (b) and at V_{dd}=2.2V and (c) powered by a TFPV at 0.6V at 25% brightness of the screen and on (d) iPhone 8 and (e) Huawei Y7 powered by TFBAT (1.5V).

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