# Reflective Displays and Green Technology

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Keywords: Electronic paper, reflective displays, low power, sunlight readable, video rate

**ABSTRACT**

*Displays continue to improve performance. In particular, color reproduction and peak brightness are target for display development. But with better performance, power economy is difficult to maintain. Signage panels have to compete with sunlight, and still have to display a wide color gamut. A typical display will use ~ 500W / m2 during daytime, and not much less during night time, and since public displays are conquering more and more space in our outside world (advertising, smart cities, etc.) this continued growth becomes impossible to perpetuate. Unfortunately, reflective display technology and e-paper so far weren't able to fill in the gap, but if the dream of smart cities is to become reality, it will have to do so.*

## 1 Introduction

The advantages of reflective displays have been known since the advent of LCD watches and calculators. Where the historic LED-based pocket calculators of the 70's only lasted hours on a battery, it's LCD counterparts lived virtually forever.

And this hasn't changed. Where OLED based smart watches have battery lives of one or two days, even with the screen mostly off, LCD based reflective or transflective smartwatches can run up to a month on a single charge.

Also, reflective LCD based smart watches are easy to read in direct sunlight, where OLED or backlit LCDs suffer.

Therefore, it should be easy to decide that reflective is the way to go.

But there is a catch. OLED and emissive LCDs boast excellent color reproduction, compared to the reflective LCD's pastel tints. In dim environments, OLED and transmissive LCDs are easily visible and retain all of their luster, and contrasts in the 1000's. These are difficult acts to follow for most reflective technologies. Or are they?

## 2 Reflective display properties

### 2.1 Contrast contradiction

One of the things most often heard is that reflective displays "only have contrasts between 10 and 20", while emissive / transmissive displays have contrasts sometimes reaching millions. This is often misconstrued as a requirement for high image quality. However, this can be proven untrue. In a normally lit environment, display surfaces (even the best OLED screens) reflect 1 – 2% of the incident light. This means that if the screen brightness is approximately equal to ambient illumination, the maximum contrast that can be achieved is 100:1.

There is, however, another reason why emissive / transmissive displays need high contrasts: Black state. As shown above, black state is not important in a normally lit environment, Black transmission will always be below the surface reflection level. But as ambient luminance decreases, residual transmission will play an increasingly important role: If the display backlight level remains largely unchanged between high and low ambient illumination,

**Figure 1: Black state of LCD panel**

the display backlight will have to be able to display a white state equal to the average ambient. This means a white state of around 1000 Cd / m2 for a brightly lit environment. In a dark environment it is at the same time required that the display provides a black state that is inconspicuous ("true black"?), so that means 1 – 5% of the ambient white level. This could be as low as 0.1 Cd / m2. (outdoor, evening).

This implies a contrast of 1000 / 0.001 = 1000000!

Reflective displays don't suffer from this. The black state is a fixed percentage of the illumination, so it will reach good white as well as good black while retaining the aforementioned 20:1 contrast.

### 2.2 Color rendering

Reflective displays have historically used RGB color rendering. As has been demonstrated on many occasions, this color rendering system works very well for emissive / transmissive systems, but is absolutely unsuitable for reflective displays.

The use of subtractive (CMY) color rendering yields much better results, as has been reported previously [1] and can eventually lead to a color reproduction very similar to the one that can be achieved by OLED or Q-dot LCD.

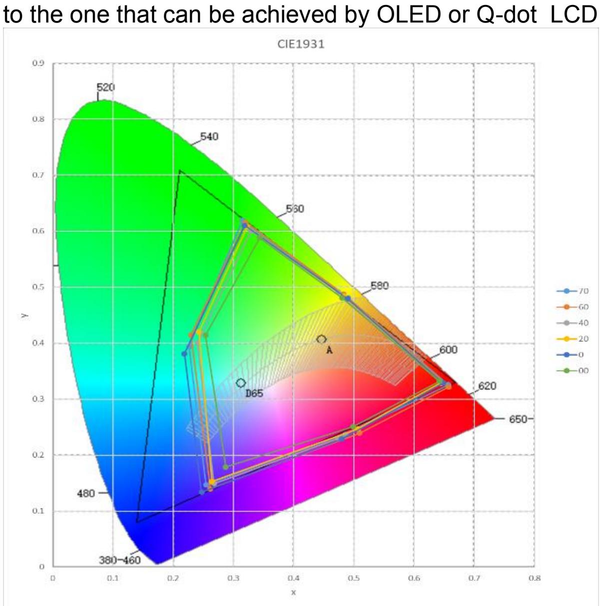


**Figure 2 Chromaticity for current electrowetting displays**

Requirement here would be the development of dyes with excellent wide band-pass properties, and very little absorption in the pass-region. Once this is realized, color rendering close to REC-2020 would be possible for CMY based color.

### 2.3 Reflectance / brightness

Key property, next to contrast and color rendering would, of course, be reflectance. Any reflective display would need to have the appearance of a sheet of paper (in the “white” state”), which puts a very strict requirement on the technology: In principle no losses allowed.

**Figure 3: Some examples of grayscale e-paper**

As it turns out, this is too much to ask for the moment. TFT panels have limited aperture, interfaces have significant Fresnel reflection, most thin film materials have some absorption. In order to reduce this, layers have to be individually optimized. As it turns out, this has all (to a more or lesser extent) already been done.

TFT aperture is difficult to change, but all layers existing in a TFT panel can be deposited as non-reflecting interfaces. Furthermore, the thickness of all absorbing layers can be minimized, thus leading to components that lose little more light than the aperture of the TFT panel would suggest. (we are reaching 90% aperture and more for 200 PPI panels).

The need for a triple layer for CMY color means each layer must be traversed twice (except for the final color layer, in the case of an in-cell reflector), so we should easily reach $0.9^5$ = 59% reflectance (in case of a 100% reflector..). Making use of reflectance characteristics of the reflector, the apparent reflectance over a large viewing area could easily be lifted to the required 100%.

### 2.4 Power

Technical objectives can be met. So why would we go through so much effort if we have a perfectly good solution? (OLED / LCD).

As it turns out, there is one compelling reason: If we continue the use of public displays in the city streets at the rate we have been doing in the past 5 years (and the “smart city” drive indicates this rate should accelerate), the total power used by our displays in these smart cities will soon exceed everything we need to keep the rest of the city running (lighting, offices, infrastructure) [2].


**Figure 4 Billboards in New York**

Example: New York City uses about 300 kWh per household, and counts ~3 million households (8 million population), accounting for ~ 900 GWh in energy. A billboard or other outdoor display consumes about 3000 kWh per square meter per year, so 900 GWh would support ~ 300,000 m2 display area. As it turns out there are some 2500 billboards in New York (digital or otherwise) accounting for just about this area.

If those would all turn digital, the power use would therefore already exceed that of all households together. And any kiosks, bus stops, stations and indoor signage and advertising, accounting for a similar energy use, have not even been counted yet. Therefore it is obvious that, if our objectives of digitization and smart cities are to be met, introduction of reflective color displays is imperative!

## 3 Device progress

### 3.1 Progress in current devices: Parallax, color, contrast

We have improved the displays shown previously [3] by adding a minimal black mask in positions where reflections were particularly disturbing (i.e. contributing to contrast reduction). Also, we implemented measures to reduce ITO transmission by removing unnecessary ITO as much as possible. Finally we reduced glass thickness to 0.15 mm which mostly eliminated any visible parallax. Finally we are in the process of designing an in-cell reflector that will return a mostly Gaussian reflection profile, accounting for approximately a factor of 2 gain, without affecting the appearance of diffuse reflection.

### 3.2 Results and discussion

It is now possible to manufacture display panels up to 20" (although a sensible size would be 10") with pixel sizes down to 150 um, with 70% NTSC chromaticity gamut area, 20:1 contrast and 50% (integrated in a 30 deg. cone around normal) reflectance. Remaining losses are continuously being eliminated and will soon lead to achieving the aforementioned 100% perceived reflectance.

## 4 Conclusions

After many years of limited progress, reflective displays have now found a way to challenge the supremacy of emissive and transmissive displays. Within a few years reflective color displays will start appearing in the world around us and their share will continue to climb in a low power, display centric world.

## 5 Acknowledgements

This project is supported by National Key R&D Program of China (No. 2016YFB0401501), Program for Guangdong Innovative and Entrepreneurial Teams (No. 2019BT02C241), Science and Technology Program of Guangzhou (No. 2019050001), Guangdong Natural Science Foundation (No. 2018A050501013), Program for Chang Jiang Scholars and Innovative Research Teams in Universities (No. IRT_17R40), MOE International Laboratory for Optical Information Technologies and the 111 Project

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