Research on the Integration Technology of In-Screen Ambient Light Sensor for Wearable Applications

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Abstract:

In this paper, we demonstrated the ambient light sensor(ALS) integrate into TFT LCD which use in the Wearable Applications. To address the compact nature of wearable devices, we have re-engineered the ambient light sensor to fit their dimensions and incorporated an algorithm within the synchronization software to enhance the accuracy of ambient light brightness detection. Additionally, we have researched a new feature that optimizes backlight longevity by leveraging the capabilities of the ambient light sensor.

Author Keywords:

Ambient Light Sensor, TFT-LCD, Wearable Application, Long life of backlight

1. Introduction:

In recent years, there has been an increasing number of production for wearable applications that have begun to add ambient light sensor to adjust the screen brightness more appropriately for the ambient brightness under different ambient brightness conditions. The conventional scheme involves creating an aperture in the front of the display to accommodate an ambient light sensor at a designated location, enabling it to measure the surrounding light intensity and adjust the screen brightness accordingly. However, this method presents several drawbacks. Firstly, achieving a true full-screen experience is impeded by the necessity of positioning a hole for the sensor that is one reason, there are some wearable applications don't have an automatic screen brightness adjustment function, Simultaneously, the constrained internal space of wearable devices poses a challenge for incorporating light sensors, leading many product specifications to overlook their integration. Secondly, comprising an external ALS[1] and its associated circuitry leads to increased production costs, in the consideration of low-cost solutions, many products give up the addition of light sensors.

In light of the traditional solutions previously discussed, we have developed an innovative approach that accommodates the compact dimensions of wearable devices while integrating Ambient Light Sensing directly into the display. In our hardware design, we leverage the photoelectric effect of Thin-Film Transistors (TFTs), utilizing them as photosensitive sensors to measure ambient light intensity. By analyzing the leakage current generated when light interacts with TFTs and observing how this current varies with light intensity, we collect data on leakage current levels and convert these measurements into corresponding brightness values through a sophisticated algorithm. Furthermore, to address the constraints posed by limited size and minimal front-facing space in wearable products, we have re-engineered a smaller TFT-based light sensor that meets detection requirements without necessitating openings on the device's front surface. This solution preserves a seamless screen experience.

Simultaneously, to enhance user experience, we have introduced a novel algorithm customized for wearable applications. This algorithm comprises two components: a temperature compensation mechanism and a backlight compensation mechanism. The temperature compensation component mitigates inaccuracies arising from prolonged usage or elevated outdoor temperatures, while the backlight compensation component primarily addresses discrepancies caused by ambient lighting conditions.

Meanwhile, during our ALS development, we discovered that low-cost and long-life backlight is widely demanded by a wide range of wearable customers and other customers. We redesigned the existing ALS to fulfill the need for a long-life backlight using in-screen ALS and then expanded the application of ALS.

2. Hardware Design：

In the field of Hardware Design, extensive research has demonstrated that compact size and full-screen functionality are two critical components of wearable products. Regarding compact size, when designing the ambient light sensor, it is essential to identify the smallest possible dimensions for the sensor. The principle of integrated light sensing within screens plays a crucial role to help us to reduce the size of the sensor.

Thus, I will introduce the principle firstly, we utilize the brightness from a light source based on the photoelectric characteristics of thin-film transistors and measure the leakage current generated by light exposure on these TFTs. The stronger the light, the greater the leakage current. By detecting the size of the leakage current, establish the relationship between current and light, convert the current into illumination, and then convert it into electrical signal, control the backlight current and voltage. However, a single TFT does not produce sufficient current for collection by an ADC[2] (analog-to-digital converter) in TDDI (Touch and Display Driver Integration) IC (Integrated Circuit).

This presents an initial challenge: single TFT leakage currents typically operate at nanometer levels while ADC sampling ranges predominantly span 0-10V, therefore, multiple sets of TFTs must be employed to achieve current amplification, which consequently increases sensor dimensions. To ascertain the most suitable and accurate sensors for wearable applications, we propose a novel design of the TFT sensor, which adopts the design scheme of source pole sharing. When multiple TFTs are paralleled, the source poles of two adjacent TFTs are used in the same part, making the entire TFT module area smaller, as shown in Figure 1.

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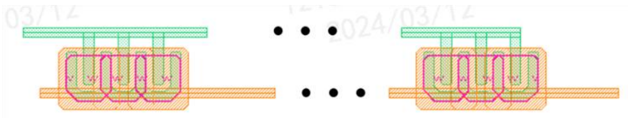

Figure 1: novel new ALS TFT sensor design

Furthermore, there exists a second issue: an ADC is necessary to convert analog signals into digital formats. Consequently, a resistor is incorporated into the flexible printed circuit (FPC) module to transform leakage currents into voltage readings. This resistance is strategically placed between the ground and the drain of each TFT. Selecting appropriate resistance values must consider our earlier challenges regarding leakage currents, the selection of resistance is generally several MΩ. The voltage across this sampling resistor is detected and subsequently converted into digital signals via ADC within TDDI ICs. The corresponding illuminance level is then determined through an ALS algorithm with real-time feedback provided to the host system.

Additionally, there arises a third problem concerning how to mitigate external factors affecting accuracy—such as backlighting conditions—leading us to categorize sensors into Group W and Group D classifications. The primary distinction lies in that Group W sensors exclude any Black Matrix(BM) cover while primarily measuring ambient light intensity. Conversely, Group D serves as a reference group used for assessing various influencing factors such as backlight intensity and temperature variations—data, which informs subsequent software optimization efforts, discussed later in this paper.

Following our analysis regarding optimal numbers of added TFTs and suitable sensor structures, we identified two ideal sizes: one measuring 3.5mm in length and another at 1.7mm in length—with both configurations maintaining a width of 35μm. Extensive experimentation under controlled conditions confirmed that both sensor sizes fulfill diverse customer requirements while ensuring accuracy in collected brightness measurements.

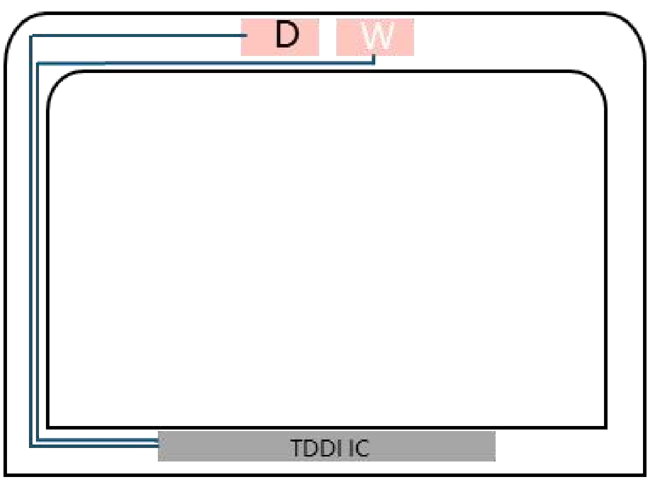

Figure 2: Overall design of wearing ALS

When selecting the sensor size, the positioning of the sensor is also a critical consideration, as it highlights the advantages of integrating an Ambient Light Sensor within the display. Given that most wearable devices feature bezels less than 1mm, incorporating traditional external ALS would compromise the integrity of the front screen. This necessitates creating openings for additional sensors, which undermines the seamless display experience sought by many customers. In contrast, an integrated ALS design within the screen only requires augmenting the Thin-Film Transistor utilized as an ALS sensor and adding corresponding circuit lines in the Visible Area (VA) area outside of the Active Area (AA). Because the sensor is small and can be placed between the VA and AA area, the customer can choose to place it in any position or place it currently recommended DP (Data Pad) side, as shown in Figure 2. This shows that the integration of ALS in the screen can not only bring customers a full-screen experience but also bring more freedom of location choice.

3. Software Optimization

Before delving into software optimization, we initially tested the non-interference of the software. As depicted in Figure 3, the accuracy of the two ALS designs tested and the feedback under varying ambient light exhibited a marked disparity compared with the test results of the illuminometer under an ambient light of 300Lux. The difference between Type A and Type B exceeded 40%, and at 1200Lux ambient illumination, the difference surpassed 20%. Through extensive data analysis, the primary reasons for the discrepancy are as follows:

(1). The spectral response of the TFT Sensor is not in line with that of the human eye, and the light intensity is nonlinear.

(2). Because the TFT sensor is positioned within the screen and above the backlight, two influences of the backlight will be exerted in this case. Firstly, the impact of the backlight on the accuracy after passing through the sensor from the bottom, that is, the impact of the backlight itself on the ALS. Secondly, when the module is in a dark state, the ALS also detects the emitted light, and these two factors constitute one of the main reasons for the difference in the aforementioned data.

(3). In different temperatures, it will also bring about differences in accuracy. From the test, comparing 20°C and 40°C under 1000LUX ambient light, the difference is greater than 5%. The influence of these three parts poses the greatest challenge to accuracy.

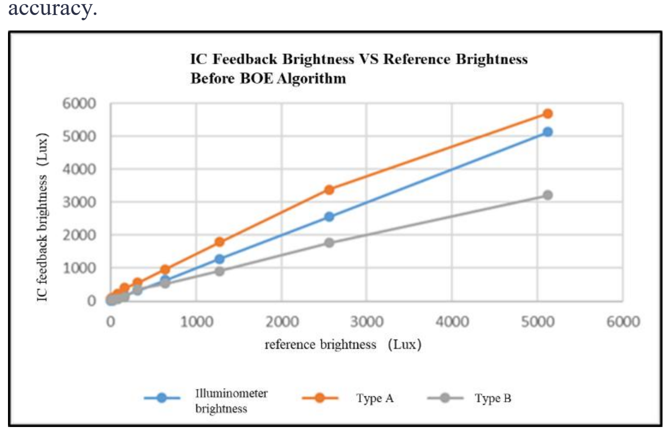

Figure 3: Brightness accuracy before algorithm intervention

To address the influence of backlight and temperature on accuracy, the BOE ALS algorithm was incorporated to rectify the raw data collected by the IC prior to its conversion into brightness information. Firstly, the impact of backlight cannot be corrected through a standardized algorithm. We discovered via testing that different brightness conditions resulting from the brightness of the backlight and the corresponding temperature vary. Hence, we adopt algorithm segmentation. Different brightness segments correspond to distinct brightness levels. For instance, we divided 0 - 5000LUX into 13 segments. The specific segmentation strategy can also be customized according to customer requirements. For example, if some customers only focus on the brightness adjustment of levels 3 - 5, then we will reduce the segments to minimize the amount of data to be processed and assist customers in completing dimming at a lower cost. If customers use it in outdoor wear, we will make more detailed adjustments for customers in high brightness to provide a dimming strategy more suitable for the usage habits of users in the outdoor environment. For the algorithm itself, we will apply the main formula in each segment:

$$Y=F(x)=X(\boldsymbol{L\_j},\boldsymbol{I\_j},\ \boldsymbol{X\_B},\ \boldsymbol{X\_W}) \qquad (1)$$

For adjustment, encompassing the parts that mitigate the impact of backlight and the parts that reduce the impact of temperature. After integrating this algorithm and the corresponding company, the accuracy will be significantly enhanced. Utilizing the same test methods and conditions mentioned above, the accuracy of type A and type B will increase from 40% to 9% at 300LUX. The accuracy will rise from 20% to 5% at 1200LUX. The Figure 4 showed result of our test.

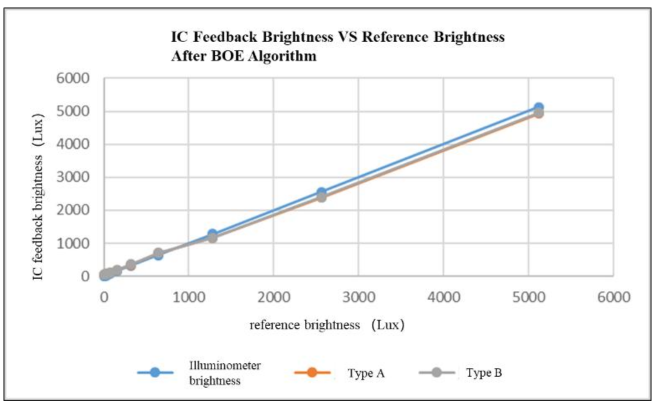

Figure 4: Brightness accuracy after algorithm intervention

4. DEMO：

Based on the current algorithm and hardware design, we have also developed a demo suitable for testing. Currently, we have conducted corresponding tests on the accuracy and response time that customers are most concerned about, and the obtained results are presented in the following Table 1. The three most critical data points are: the detectable accuracy is 2 Lux, and the response time of the host segment is 150ms. Of course, if the customer demands a larger amount of data, we can also enhance this speed by adjusting the algorithm and hardware, and reduce it to within 100ms. Finally, almost all customers are particularly concerned about the accuracy of the brightness detection above 1000 Lux; we improved the accuracy to less than 5% to meet the requirements of wearable users for the optimal brightness of the screen display when used outdoors. Later, we will also develop a demo that can be displayed as shown in Figure 5 and Figure 6.

Table1: ALS Demo Specification

	Item	Specification
ALS Spec	Sensor Postion	DPO
	FOV	45°
	Illumination Range	0~12000Lux
	Detection Accuracy	2Lux
	Accuracy	5~20Lux: 50% 20~100Lux: 20% 100~500Lux：10% 500~1000Lux：10% 1000~12000Lux：5%
	Interface Standard	I^2C
	Data Refresh Time	150ms
	Operating Voltage	±6/1.8V

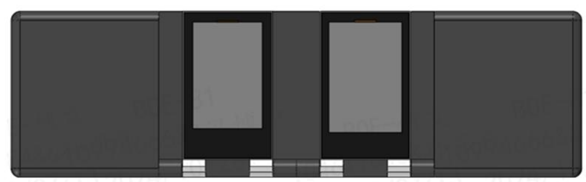

Figure5: Fold state of BOE Demo

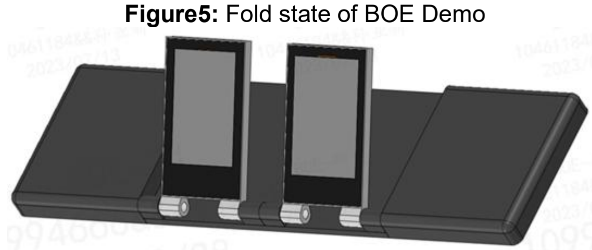

Figure 6: Spread state of BOE Demo

5. New application direction for ALS:

while designing a new ALS sensor suitable for wearable devices, we identified that the backlight lifespan is also a constituent that demands attention. As the majority of wearable products need to be employed outdoors, such as sports watches, there will be numerous application scenarios for outdoor usage, and the maximum brightness of the backlight will be activated to meet the normal utilization of users. Nevertheless, with the prolongation of the usage cycle, the lifespan of LED lamps will become a significant adjustment factor. From the data viewpoint, the majority of LED lamps commence to exhibit brightness attenuation at 1000 hours, and the attenuation reaches 90% of the standard brightness at 10000 hours. We acknowledge that the solution featuring a long backlight lifespan and low-cost LED lights is also a scenario where our ALS can demonstrate its capabilities. As the product's usage time extends, the display effect of the product is significantly diminished. Therefore, to address this issue, we propose a method to adjust the current and voltage of the backlight LED to achieve consistent brightness of the product. To realize the adaptive adjustment of current and voltage, the backlight ALS design of the integrated panel is put forward, and the light sense TFT is added to the panel border to realize the backlight brightness induction.

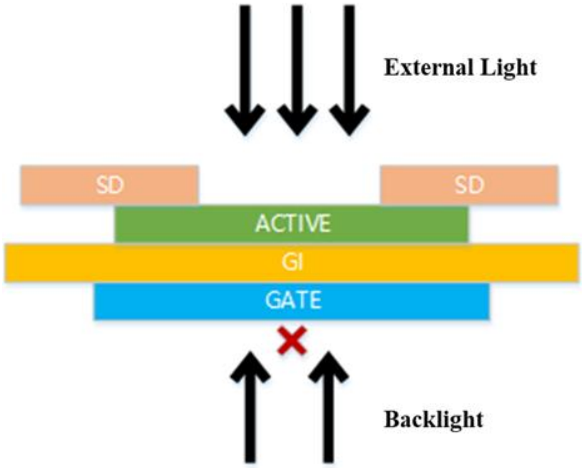

Figure 7: Front ALS sensor structure

Specifically, as depicted in Figure 7, ALS is integrated in the conventional screen, and TFT is composed of the SD layer, the Active layer, and the gate layer. To prevent leakage current caused by backlight irradiation on the Active layer, the design area of the gate should be larger than that of the active, and the channel location BM should be perforated. To realize that the sensor is oriented towards the back to collect the light emitted by the backlight, BM is added on the basis of the conventional design to block the external light. Simultaneously, to realize the brightness detection of the backlight, the size of the gate is reduced so that the Active area is larger than the gate and the backlight is effectively illuminated on the active, resulting in a large leakage current in the TFT. As shown in Figure 8.

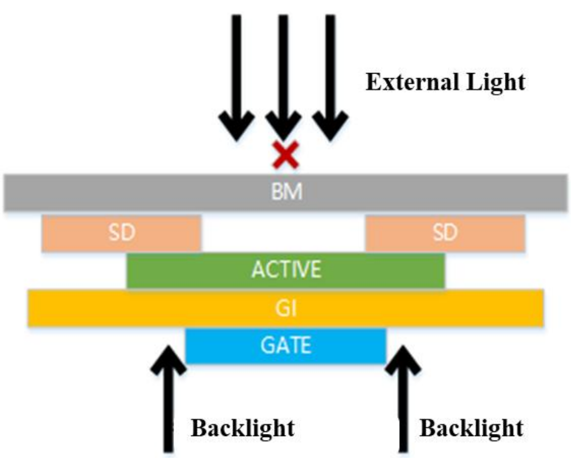

Figure 8: Backlight ALS sensor structure 1

As depicted in Figure 9, the overall design of TFT has been enhanced, and the gate is divided into two parts while its size is reduced. The middle part is completely hollowed out, enabling the active area to be exposed to more light. Consequently, the leakage current generated by a single TFT is larger under the same light conditions. Therefore, in the case of limited space, although the area of a single TFT in Scheme 1 is larger, under the same illumination, to achieve the leakage current of the same magnitude as Scheme 1, the number of parallel TFTs is smaller. Thus, the entire ALS occupies a smaller position, which is more conducive to space optimization and is more suitable for meeting the narrow frame requirements of customers.

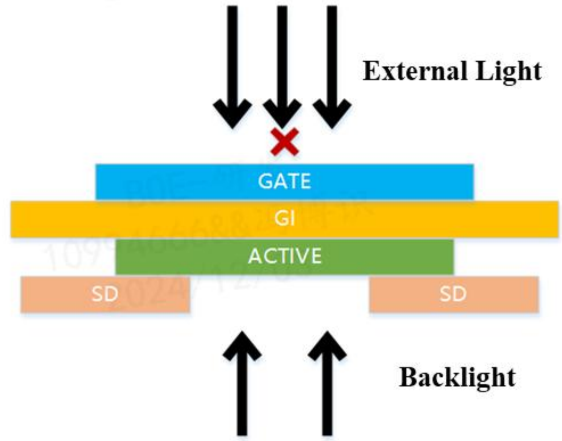

Figure 9: Backlight ALS sensor structure 2

Through the above improved ALS design scheme and the utilization of almost the same sampling scheme as described above, we can collect the brightness changes of the backlight, and then carry out corresponding brightness compensation as required, so as to fulfill the demand for the long life of the backlight.

6. Conclusion:

Our team has developed a novel Ambient Light Sensor, specifically engineered for wearable products. To ensure a full screen without increasing the width of the border, the ALS integrated within the screen is incorporated to achieve the detection of ambient light intensity. We implemented the pioneering BOE ALS algorithm to minimize the influence of backlight and temperature on detection accuracy, thereby significantly enhancing ambient light detection to a level that effectively meets customer requirements.

Simultaneously, we capitalized on our extensive expertise in positive ALS design to create an ALS that contributes prominently to prolonging the backlight lifespan. This improvement not only extends the durability of the backlight but also mitigates problems associated with reduced brightness when wearable devices are utilized outdoors for prolonged periods.

7. Reference:

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