OLED Opportunity in Healthcare With the Pulse Oximeter

The emergence of ultra-thin, flexible, and bright OLED devices has ignited tremendous interest in their potential as a light source in pulse oximetry, a well-established method to monitor pulse rate and blood oxygen level.

by Chang-Hyun Kim

THE CURRENT COVID-19 PANDEMIC HAS RENEWED worldwide interest in personal healthcare issues. Even before that, an ever-increasing demand for healthy and sustainable life has been a traditional motivation for developing a range of precision biosensors and health monitors in service of the general public, which in most cases was realized thanks to the timely development of high-performance electronics. Although the biotech area still seems not-so-directly relevant to the display industry, several advanced sensing platforms reported from academic groups suggest strong evidence that these two worlds can effectively collaborate for the common good.

What Is Pulse Oximetry?

Pulse oximetry is a ubiquitous, non-invasive, and exceptionally reliable medical method to measure pulse rate and arterial blood oxygenation. It generally couples two LEDs having different peak emission wavelengths (normally one at red, the other at infrared [IR]) with a broadband photodiode (PD). This platform measures the real-time intensity of two LED-generated light beams that transmit through a body part and get collected at the PD. Because of the pulsating part of arterial blood, the transmitted light has a certain periodic shape, from which the heart rate is estimated. In addition, the use of two wavelengths is intended for quantifying the ratio between oxy- and deoxy-hemoglobin (HbO₂ and Hb), which respond differently to each of these excitation wavelengths. Therefore, signal processing that relies on a mathematical model can provide the value of the blood oxygen level (SpO₂ level).

While pulse oximeters most generally have been deployed in hospitals as a relatively bulky fingertip attachment (often with wire connections to external displays and/or power sources), there is a clear need to make them more compact and mobile for practical use at home or integration into our favorite wearable devices.

Embracing OLED as a Light Source

This is where OLEDs may be helpful as an attractive element to transform future pulse oximeters. As they come into technological maturity, OLEDs are ultra-thin, extremely lightweight, conformably flexible, and highly energy efficient. Thus, they can be an excellent replacement for inorganic LEDs, especially in manufacturing wearable- and portable-type pulse oximeters. Ideally, the detecting device also is made of organic photo-sensitive semiconductors, so that both OLEDs and organic photodiodes (OPDs) can be integrated with maximum process advantages and the most favorable form factors.

A research group at the University of California, Berkeley...
reported in 2014 their first all-organic optoelectronic sensor for pulse oximetry (Fig. 1). These researchers harmoniously used three organic devices: a green OLED, a red OLED, and an OPD sensitive to both colors. They noted that the conventional near-IR (NIR) source can be replaced by a green emitter because of the similar optical response. These lighting and detecting devices were prepared by low-cost, low-temperature coating and printing techniques, which are known strengths of organic electronic materials. The developed oximeter sensor was able to offer a high-precision measurement, as shown by errors of only 1 and 2 percent for pulse rate and oxygen level, respectively.

The conventional pulse oximeters are a “transmittance” type, in that the LEDs and PD are positioned on the opposite sides of the measurement sample. It requires a sufficiently strong light source to ensure deep penetration, yet the collection of light is relatively straightforward if its in-body propagation is sufficiently directional (which generally is the case).

On the other hand, it may have a fundamental drawback, which is the limitation in a measurement spot (generally restricted to fingers, toes, or earlobes) because a thicker body part will not adequately support light transmission. In 2018, a research group at the Korea Advanced Institute of Science and Technology (KAIST) reported on a “reflectance” type of organic pulse oximetry sensing patch.

As Fig. 2 shows, the entire platform comprising OLEDs and OPD now sits on a single plastic sheet, greatly improving the flexible and wearable form factor. The reflectance oximeter should send and collect the light at the same physical height and relies on optical changes during body reflectance. Therefore, it has an advantage of an overall smaller volume and can eventually have fewer limitations on the sensing position. However, the working mechanism based on the surface reflectance implies apparent challenges in control of light propagation depth and angles, and avoiding the optical interference between the individual light signals can be of critical importance.

**Engineering Perspectives and Where We Are Headed**

Conventional OLEDs—thanks to extremely intensive research for more than three decades—already are optimized sufficiently for displays. In contrast, there is still no established understanding about asserting what a good OLED is for pulse oximetry, and what are the necessary performance metrics. In addition, the entire operation relies on sophisticated electro-optic coupling between different elements,
so that system-level engineering is critically important. For instance, the OLEDs for a transmittance-type oximeter should naturally have a strong emission (in terms of brightness and power). At the same time, a hard limit for emission intensity generally does not exist, because a high-sensitivity PD and an amplifying readout circuitry may compensate for a low emission and/or transmission level.$^2$

Now is the time when interest surrounding the organic-based pulse oximeter, either in transmittance or reflectance mode, is on the rise within both the organic electronics and biomedical communities. While initial developments largely relied on the technological basis prepared by the established display fields, current and future developments seem to focus on dedicated efforts in making the materials, devices, and integrated systems more explicitly tailored for sensing applications. This can include the molecular synthesis targeted at optimum biological excitations, and new device geometries and circuit layouts to ensure the best coupling between a pulse oximeter’s functional blocks.

An example of the latter can be found in a 2019 article by the University of California, Berkeley Group (Fig. 3).$^4$ In this work, an advanced reflectance type of all-organic multichannel oximeter was demonstrated. In arranging the key components (red OLED, near-IR OLED, and common OPD) on the substrate, the researchers directly compared three different designs—namely rectangular, bracket, and circular geometries. Each of these shapes are supposed to provide different optical paths and active areas, to help observe the substantial changes in measurement signals.

What becomes apparent as this research progresses is that pulse oximeter is a new frontier in OLED-based display technologies—yet it also represents a robust, standard health-monitoring system with high commercial value. Thus, despite there being only a handful of research demonstrations reported to date, we can expect a considerable surge in research and development on it in the near future. An entirely remote, functionally diversified, and fully integrated OLED pulse oximeter can be a major goal of such activities, which may increase the market performances even further of prevailing OLED technologies. An apparent challenge for such an integrated platform is to expand fabrication yields while minimizing energy and manufacturing costs. $^5$

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