Inorganic Electroluminescent Display Technology: Current Status and Future Development

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The development of inorganic electroluminescent display technology was initiated about 50 years ago. In 1974, scientists from Sharp Corporation demonstrated the world first flat panel display capable to show video images using the so-called Thin Film Electroluminescent (TFEL) technology. Since then, inorganic EL became the focus of display engineers around the world till the late 1980s. With its robust all-solid-state structure, wide viewing angle, wide operating temperature range and fast response time, TFEL technology was successfully commercialized for military, space, medical and industrial applications. However, despite the early success in commercialization, great difficulties were encountered in the development of large size and full color TFEL.

The development of thick dielectric electroluminescent (TDEL) technology started in 1991. The original scope is to use screen printed thick film dielectric to replace thin film dielectrics in TFEL, thus to improve the device reliability under high voltage driving and to improve the production yield for manufacturing cost reduction. After nearly 14 years of research and development, the structure of inorganic EL display devices has been changed dramatically from the well known TFEL.

High Dielectric Constant Thick Film Dielectric

Different from TFEL, TDEL is made with a screen printed metal electrode and thick film dielectric layer. The printing process is similar to that used in producing hybrid electronic circuitries. This thick film dielectric layer protects the display devices from electrical breakdowns, also provides an optically diffusive reflecting surface for the phosphor layer to enhance the light out-coupling. The thick film materials used in TDEL are similar to those used in hybrid circuits and capacitors, but the paste formulation has been modified especially for display applications. In large area TDEL display, glass substrate is used. Therefore, the paste system including the solvent, frit and binders has to be carefully chosen to ensure the quality of the thick dielectric layer and easy processing.

Inorganic EL Phosphor

In the development of inorganic EL phosphor, for a long time the focus had been the binary sulfides such as ZnS, CaS and BaS. Although efficient, high luminance yellow and green EL phosphors were known for many years, the development of full color inorganic EL display was very slow due to the lack of suitable color phosphors, especially for blue. The major breakthrough was the discovery of $BaAl_2S_4$:Eu blue ternary sulfide phosphor at Meiji University led by Professor Miura in 1999, it has been the primary EL phosphor material for the full color EL display development since then. In TDEL, $BaAl_2S_4$:Eu now is the only phosphor used in the display. It has high efficiency and high luminance, and even more importantly, has good color saturation.

With future mass production in mind, many efforts have been put into the development of the deposition processes of $BaAl_2S_4$:Eu suitable for manufacturing. Although this phosphor material was originally developed with e-beam evaporation, in order to achieve good uniformity in large area with high throughput, a reactive sputtering deposition process has been developed for production. Compare to e-beam evaporation, this sputtering process offers the same or better phosphor performance in terms of luminance, color saturation and stability, with much improved deposition repeatability and the ease of process control.

Color by Blue

The development of full color TDEL started with color by white (CBW) approach. The white emitter was a layered ZnS:Mn amber phosphor with a SrS:Ce cyan phosphor. Red, green and blue primaries were filtered from the white emission of the phosphor. Although the fabrication processes were simple, but CBW was inherently inefficient as it required filtering of the white primary emission.

In order to improve the display luminance for commercial TV application, patterned phosphor process was then developed. The patterned phosphor process was able to produce very high performance displays, with luminance in excess of 300 cd/m^2 and excellent color gamut. However, the process used in make the display required three phosphor depositions and a variety of patterning steps, and with three different emitters, matching threshold voltages and achieving acceptable color uniformity across all grayscales was challenging.

In early 2003, iFire started development work on a new display architecture, called color by blue (CBB), which is based on secondary emission of conversion phosphors. In the CBB device, only the blue phosphor was used to generate light. In order to get necessary red and green primaries, color conversion materials were screen printed on the top surface of the column electrodes, where they absorbed the blue light from the $BaAl_2S_4$:Eu blue phosphor, and re-emitted red and green light. This system has many advantages. Only a single phosphor deposition step is required, and no phosphor patterning is required, so the process is shorter and simpler. Because the light is generated by only one phosphor material, there is no threshold voltage matching to be considered, and the gamma and other electro-optical characteristics of all pixels are identical. Most importantly, the CBB system separates the luminance generation mechanism from the color generation mechanism, which allows very uniform color.

Current Status and Future Development

Using screen printed thick film dielectrics, sputtered $BaAl_2S_4$:Eu blue phosphor and CBB color conversion system, both 17" diagonal (480x640x3) and 34" diagonal (678x1280x3) full color TDEL prototype displays have been successfully developed at iFire's laboratories.

iFire has formed a joint development alliance with Dai Nippon Printing (DNP) and Sanyo to further advance TDEL technology. With the rapid improvement in both the performance and size of the technology, a decision was made to start the transition from R&D to commercial production. By late July 2005, a USD $35 million 34" TDEL development line will be completed. With the help of DNP, it is anticipated that 34" module engineering samples will be made by the end of 2005. iFire intends to work together in a joint venture with one or more manufacturing partners to produce modules in commercial volumes starting in 2007.