QNED Structure and Manufacturing Technology Analysis Report

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Contents

Summary

- This report is an analysis of 41 open patents related to QNED (quantum dot nanorod LED) developed by Samsung Display. The contents described in this report were selected and structured to be used for QNED manufacturing.
- The main content of this report is an analysis of QNED's structure and manufacturing process, nanorod LED manufacturing technology and structure, and nanorod LED alignment technology that composes pixels.
- TFT and QD (quantum dot) -CF (color filter) parts of QNED's structure and manufacturing technology were prepared with reference to QD-OLED structure and manufacturing technology.
- The nanorod LED used in QNED manufacturing is a blue light emitting LED. Nanorod LED is a GaN-made LED and is a nano-class device with a size of <1um x 10um. In order to enhance the effect of aligning the nanorod LED, the nanorod LED surface may be treated with an insulating film and an orientation group.
- In the patent filed by Samsung Display, all TFT structures are expressed in a 2Tr1C structure, but at least three transistors (Tr) are required for current-driven TFTs. QD-OLED uses 3Tr1C structure.
- The method of aligning the nanorod LED within the pixel is by using a dielectrophoretic force. The nanorod LEDs in the ink jetted solution are aligned by the waveform applied to the electrodes.
- There are two types of pixel electrode structures: circular and rectangular. The published patent does not explain which form is the main structure. However, QNED's pixel electrode is presumed to be circular, since the dielectrophoretic force shows excellent arrangement characteristics at the circular electrode. Nanorod LED alignment electrode and drive use the same electrode.
- Pixel includes a light extraction structure and a reflection structure to effectively use the light emitted from the nanorod LED.

1. QNED Overview

1.1 Next-generation Large-size Display Structure Comparison

- Currently commercial TV displays include a regular LCD using a-Si TFT, a high-end LCD using QD (quantum dot) material based on a-Si TFT-LCD, and a WRGB OLED using white OLED and color filter (CF). There are micro LEDs manufactured as micrometer-sized LEDs.
- As a display being developed as a next-generation display, there is an LCD that increases the contrast ratio by using a mini LED as a light source for a back light unit (BLU), and QD-OLED (OLED display is called QD Display) that converts the color of blue OLED to QD. And there is also QNED (quantum dot nanorod LED) using nano-sized blue LED and QD.

Comparison of features for each large-size display

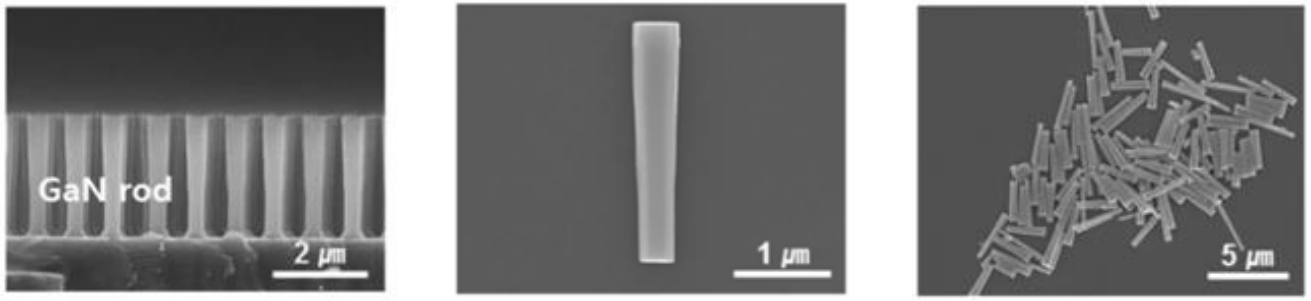
Technology	LCD			OLED		LED	
	TFT-LCD	TFT-LCD + QD	TFT-LCD + mini LED	WRGB OLED	QD-OLED	Micro LED	QNED
Technology property	BLU + CF	blue BLU + QDEF + CF	Mini-LED BLU + CF	White OLED + CF	blue OLED + QD CF	LED	Nanorod LED + QD + CF
Back Plane	a-Si TFT	Oxide TFT					
Emission	Non self-emission			Self-emission			
Emission Material	white LED	blue LED	Mini-LED	WOLED	blue OLED	RGB LED	blue LED
Driving	Voltage driving			Current driving			

Source: UBI Research DB

2. Nanorod LED Structure and Manufacturing Process

2.1 What is Nanorod LED?

- Nanorod LED is a LED whose length is less than 10um and the rod diameter is less than 1um.
- The nanorod LED used in QNED is made of GaN that emits only blue light.
- When an electric field is applied to both ends of the nanorod LED, the nanorod LED emits light while the electron-hole pair is combined in the active layer.
- Nanorod LED is composed of an active layer (MQW, multi-quantum wall) between p-type and n-type conductive semiconductor layers, and a metal electrode for contact is formed on the top layer of the p-type conductive semiconductor.
- An insulating layer is formed on the outside of the nanorod LED, and the side part is electrically insulated.



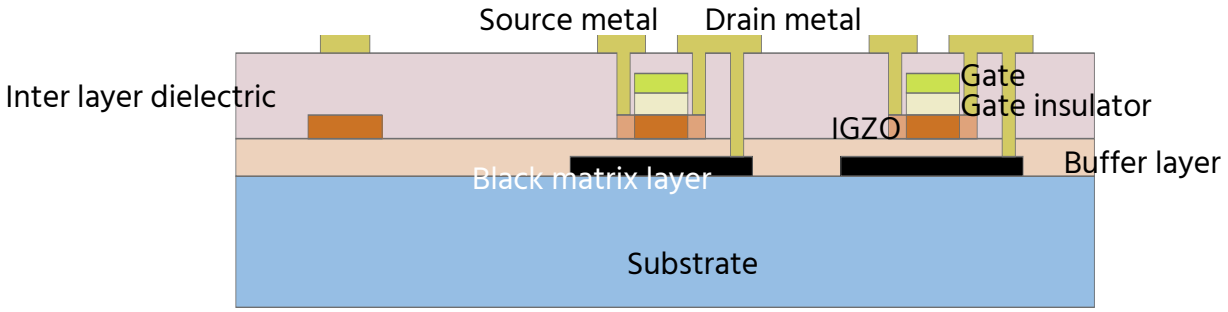
Park HK, Yoon SW, Eo YJ, et al. Horizontally assembled green InGaN nanorod LEDs: scalable polarized surface emitting LEDs using electric-field assisted assembly. Sci Rep. 2016;6:28312. doi:10.1038/srep28312

3. TFT Structure and Manufacturing Process

3.1 Expected TFT Structure

- **Expected structure of Oxide TFT for QNED**
  - Current-driven displays require at least 2 transistor / 1 capacitor per pixel (switching, driving transistor).
  - Since the OLED for mobile devices is difficult to use an external compensation circuit due to the limited space of the set, a 7 transistor / 1 capacitor structure is used because all the internal compensation circuits are integrated on the substrate.
  - For large set products such as TVs, there is a lot of space for a drive IC, so an external compensation method is used rather than an internal compensation method that is difficult to manufacture.
  - Although the 2Tr1C structure is shown in the cross-section structure of the QNED patent filed by Samsung Display, it is expected to be a 3Tr1C structure (switching, driving, signal compensation transistor).

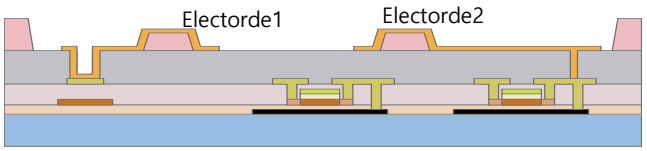
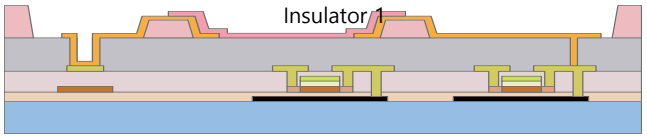
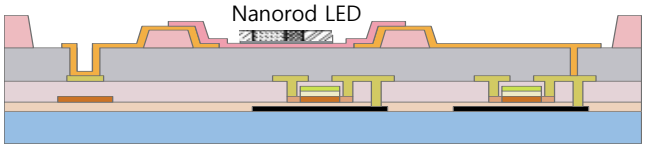
Expected structure of Oxide TFT for QNED



Source: UBI Research DB

4.2 Pixel Manufacturing Process

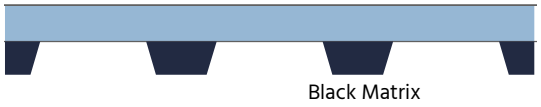
Pixel manufacturing process

Process	
	Electrode formation
	Insulation layer 1 formation
	Nanorod LED align

Source: UBI Research DB

5.2 QD-CF Manufacturing Process

QD-CF manufacturing process

Process	
	Glass cleaning
	BM formation
	Red CF formation
	Green CF formation

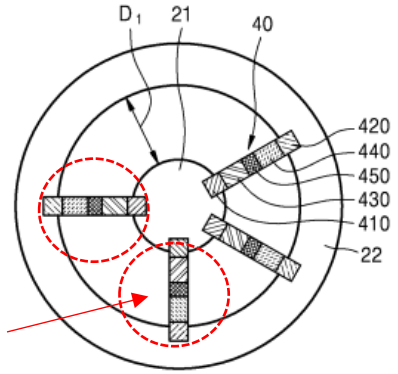
Source: UBI Research DB

7.2 Characteristics by Electrode Structure

- **Circular electrode arrangement structure**
  - The circular arrangement has a higher degree of freedom in arrangement than the rectangular arrangement, which can increase the density of nanorod LEDs.
  - When the alignment voltage is applied, an asymmetric electric field can be formed to focus the alignment direction of the nanorod LED.

Example of nanorod LED placement and degrees of freedom on a circular electrode

The red circle is the area of the minimum radius of rotation required when the nanorod LEDs are aligned by the dielectrophoretic force.



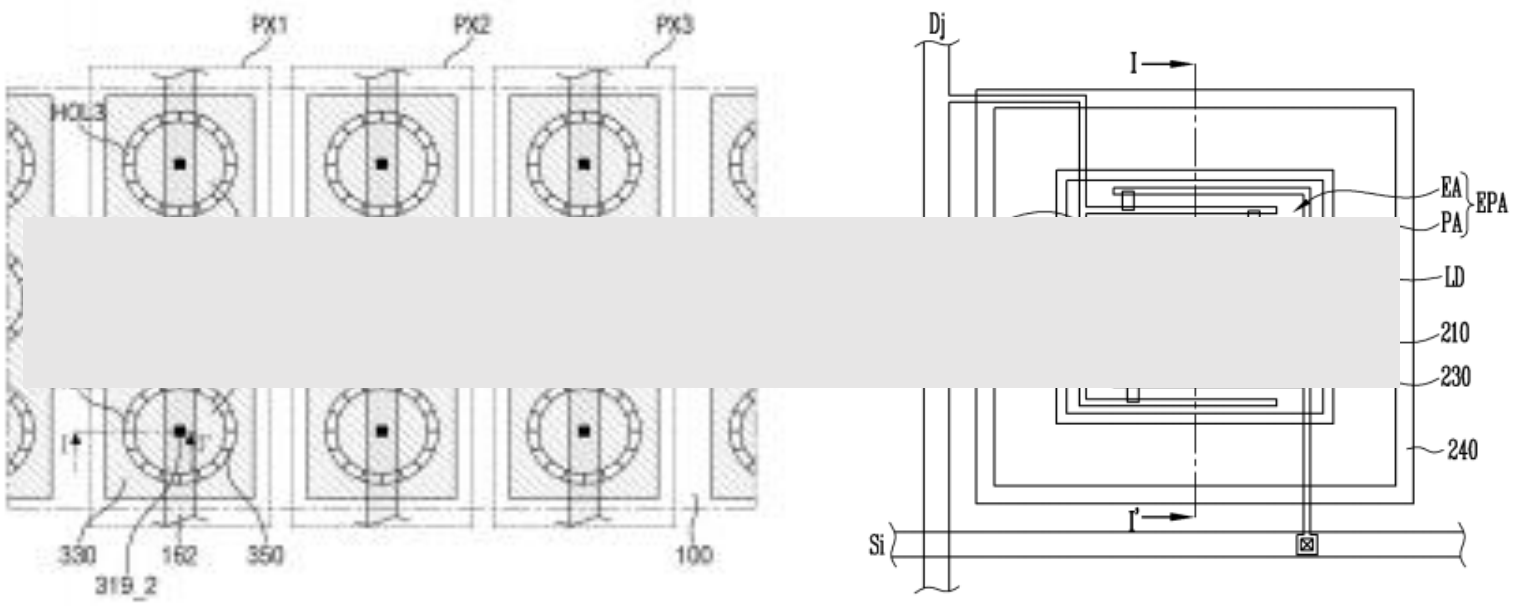
Circular electrode arrangement

7. Pixel Electrode Structure Analysis

7.1 Electrode Structure

- **Electrode arrangement structure of round and rectangular type**
  - In Samsung Display's patent, QNED's electrode structure can be classified into two types: circular and rectangular.
  - The placement and orientation of the nanorod LEDs are determined according to the shape of the electrode, and the arrangement quantity of the nanorod LEDs is determined.

Round and rectangular electrode arrangement



Circular electrode structure

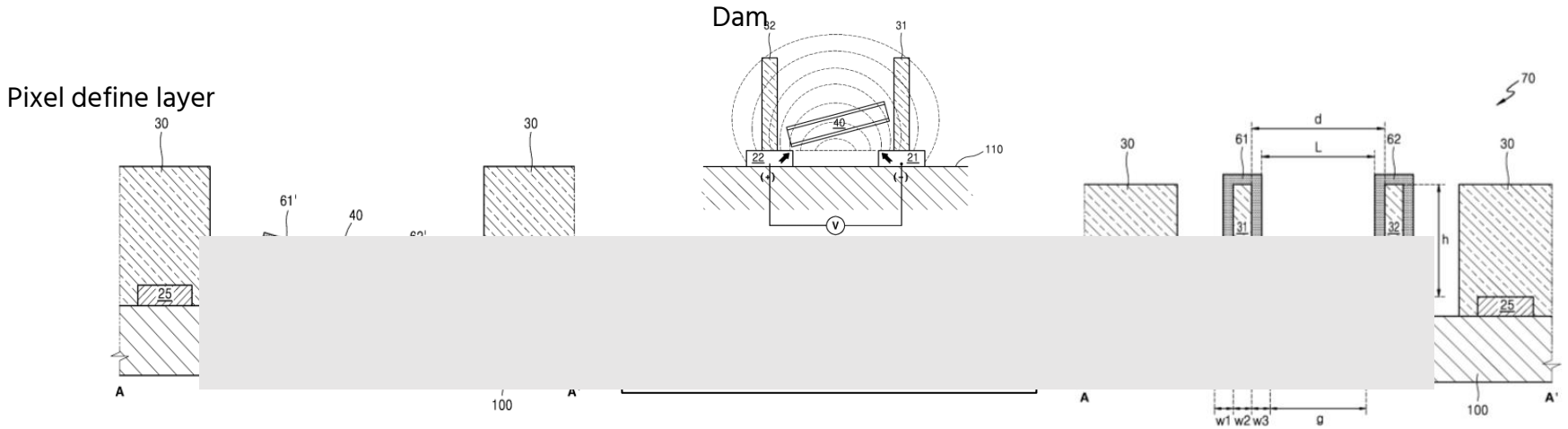
Rectangular electrode structure

9. Nanorod LED Count control Technology

9.3 Dam Structure for Nanorod LED Alignment

- When the separation distance (g) between the opposing electrodes is smaller than the length (L) of the nanorod LED, defects may occur when the nanorod LED contacts only one of the opposing electrodes by a dielectrophoretic force (DEP Force).
- Inside the individual pixel area surrounded by the pixel define layer, a dam surrounding the unit emission area can be precisely controlled to precisely align the position of the aligned nanorod LED, thereby enabling precise alignment.

Alignment type of nanorod LED according to the presence or absence of dam



If there is no dam structure, the alignment is misaligned without the restriction of the position of the nanorod LED

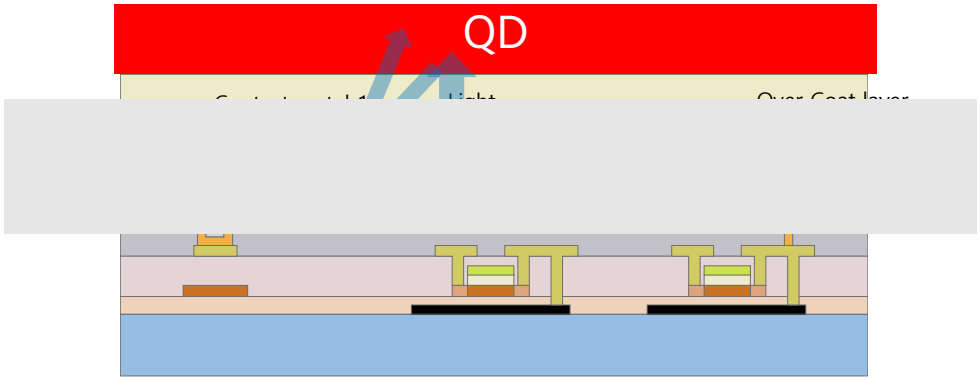
If there is a dam structure, alignment is made within the position limitation area of the nanorod LED

Source: Kipris.or.kr

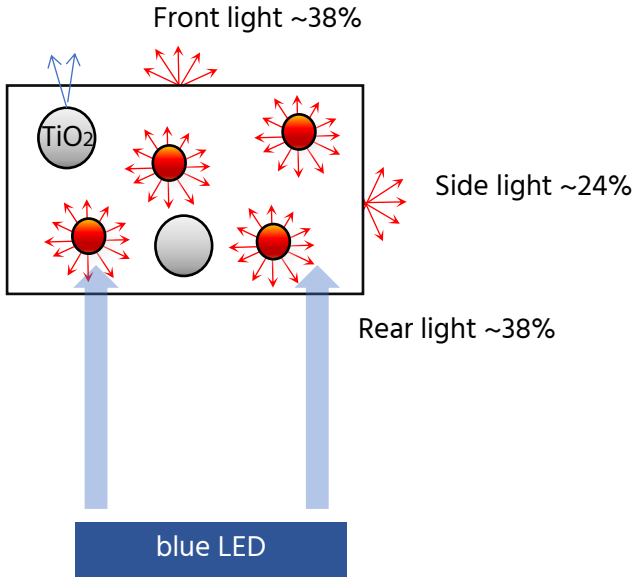
10. Light Extraction Structure and Reflective Layer

10.3 Reflective Layer

- Since light emitted from the Nanorod LED reaches the QD layer and is emitted, it is theoretically only 38% of the light exiting the front.
- In order to increase the light efficiency by recycling the light exiting the side or back to the front, the upper layer of the signal electrode is formed of a metal electrode (contact metal 1, contact metal 2) and used as a reflective layer.



< Reflective layer using metal electrodes >



< Quantum dot outgoing ratio according to the direction of light emission >

Source: UBI Research DB