Towards Perovskite LED Displays

Cheng Chang, Chen Zou, Mark Odendahl and Lih Y. Lin
Department of Electrical and Computer Engineering
University of Washington
Seattle, USA
cchang36@uw.edu, chenzou@uw.edu, merko@uw.edu, lylin@uw.edu

***Abstract*— We present a perovskite LED array fabricated by photolithography. The LED pixels in this array can be independently driven. The work demonstrates the potential of perovskite devices for next-generation displays.**

***Keywords*— perovskites, LED, independently driven, display screen**

I. Introduction

Perovskite light emitting diodes (LEDs) are promising light emitting devices for their high color purity, tunable emission wavelength, compatibility with deformable substrates and low fabrication cost [1]. During the past five years, perovskite LED external quantum efficiency (EQE) has increased from 0.0125% to 28.2% [2]. However, photolithographic patterning techniques for perovskite devices are still quite limited due to the materials' incompatibility with most solvents used in the process. Most of the demonstrated techniques are limited in the range of perovskite materials, thus constrain the potential of perovskite LEDs for display applications. In this work, we use a novel dry lift-off process involving traditional photolithography to build a perovskite LED array [3]. During the process, the perovskite layer is not exposed to any solvents for photolithography, therefore the process is compatible with all kinds of perovskite materials. Each pixel in the array is controlled individually by a cross-link electrode matrix. With further optimization and integration, an all-color perovskite LED display with high resolution can be achieved.

II. Device fabrication And Results

A. Fabrication work flow

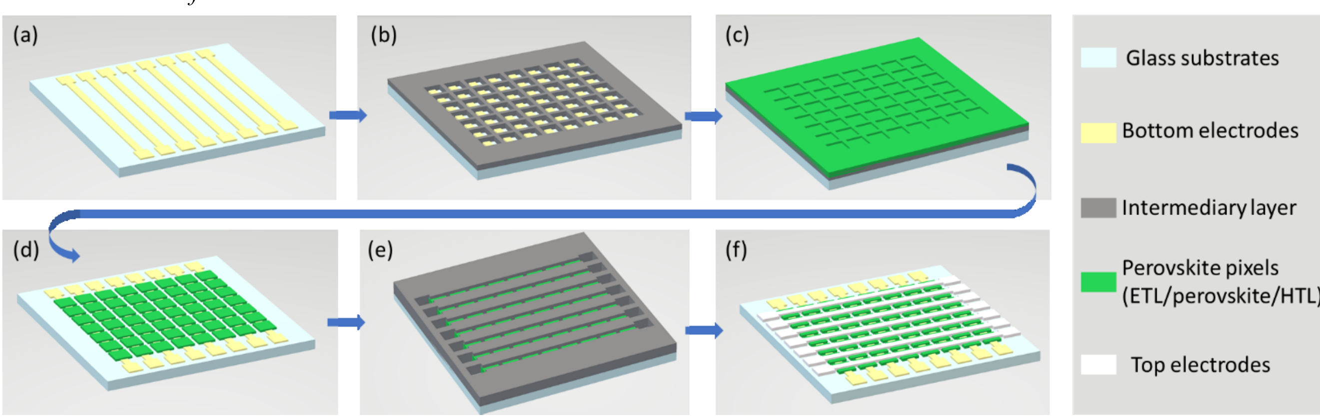

Fig. 1. Fabrication process of the perovskite LED array. (a) Deposit patterned bottom electrodes on substrate. (b) Pattern an intermediary layer of parylene-C on top of the electrode. (c) Spin-coat emission layers (HTL/perovskites/ETL) on the intermediary layer. (d) Lift off the intermediary layer and patterned pixels are formed. (e) Deposit and pattern another intermediary layer for the top electrode patterns. (f) Deposit the top electrode and lift-off the intermediary layer.

The fabrication work flow of the perovskite LED array is shown in Figure 1. First as shown in Figure 1(a), a layer of indium tin oxide (ITO) is deposit on the substrate in a desired pattern as bottom electrodes. Due to the fact that perovskites dissolve in most polar solvents including photolithographic developers, an intermediary layer of parylene-C is used to pattern and protect the perovskites [3]. This intermediary layer is first etched with patterns by photolithography (Figure 1(b)). Then, hole transporting layer (HTL)/perovskite layer/electron transporting layer (ETL) are deposited on top of the intermediary layer in sequence (Figure 1(c)). After that, the intermediary layer is lifted off mechanically, leaving the patterned perovskite LED pixels on the bottom electrodes as shown in Figure 1(d). Since perovskite LED pixels are still vulnerable during the fabrication, another intermediary layer is used to cover the perovskites and then patterned as shown in Figure 1(e). The top electrodes are deposited and patterned through the same process as described above. With careful alignment, the top and bottom electrodes can cross-link all the perovskite LED pixels and form a display array with individually addressable pixels (Figure 1(f)).

B. Results

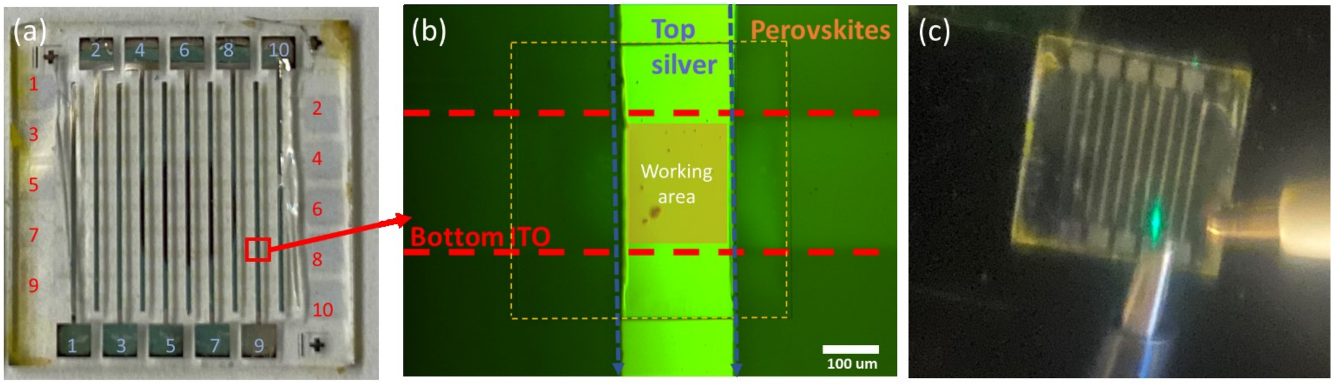

Fig. 2. (a) Fabricated device. The red square indicates the area for a single pixel. (b) A single pixel under microscope. The red and blue dash lines indicate the bottom and top electrodes. The dashed orange area is a perovskites pixel. (c) A single pixel working under an applied bias.

The whole device (in Figure 2(a)) is fabricated on a 15 mm × 15 mm glass substrate. There are 100 pixels controlled by 10 top electrodes (in column) and 10 bottom electrodes (in row) individually. The top and bottom electrodes are 200 um in width, which define the working pixels each with an area of 200 um×200 um, as shown in Figure 2(b). Figure 2(c) shows a single perovskite LED pixel turned on by applying the 8th top electrode column and 10th bottom electrode row with bias. By sweeping the on/off state of each electrode with a desired frequency, all the pixels can be turned on and off in certain sequence. An external circuit can be incorporated to selectively address multiple pixels simultaneously. By repeating the dry liftoff lithography process in Figure 1(c) and 1(d), different perovskite materials emitting different colors can be integrated together, forming a full-color display.

III. Conclusion And Future Work

In summary, we fabricated a perovskite LED utilizing photolithography with a dry lift-off process. Each pixel in the array can be controlled individually. The fabrication process only involves standard methods and has strong potential for mass production of perovskite LED displays.

Built upon the foundation of the method demonstrated, next we will pursue development and optimization in two directions. The first one is to further improve the resolution of each pixel. This can be fulfilled by reducing the sizes of electrodes and pixels, which is only limited by the resolution of photolithography. Figure 3(a) shows a LED array with 450 (15 × 30) pixels, each pixel's size is 100 um×100 um. By improving the accuracy and fineness during the fabrication, a perovskite micro-LED display with high resolution can be achieved.

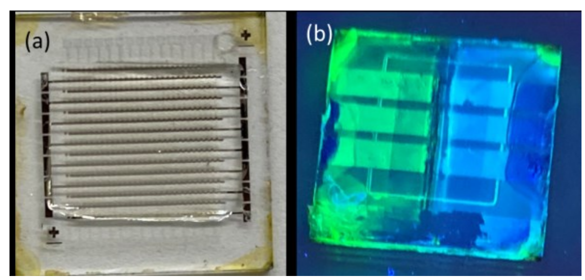

Figure 3. (a) A 15×30 display device with pixel size of 100 um ×100 um. (b) Dual-color perovskite device with green and blue perovskites integrated on one chip.

The other direction is to integrate multi-color perovskite light-emitting layers in a single array to achieve an all-color display [4][5]. This is also feasible with the current fabrication method by simply repeating the dry liftoff lithography process multi-times with different HTL/perovskite/ETL layers as discussed above. As shown in Figure 3(b), two kinds of perovskites emitting blue and green light can be deposited on the same device.

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