

Color simulation and demonstration of perovskite nanocrystal filters for wide color gamut displays

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Abstract: In this study, we define spectral parameters of perovskite nanocrystals to improve LCD color gamut, replacing color filters (CFs) with perovskite based subpixels. The optimization of the CFs has been enhanced 15.8% (98.43% of Rec.2020) in simulation and 13.8% experimentally, with 97.37% color gamut coverage.

Introduction

Mimicking the existing colors in nature is the main aim for display technology in terms of the quality. Recently color filters with colloidal quantum dots have been introduced in order to address the low performance of the commercially available color filters stemming from their wide transmission spectra and the crosstalk [1]. On the other hand, the perovskite nanocrystals are promising agents thanks to their narrow emission spectra and high photoluminescence efficiency with better performance than semiconductor quantum dots [2,3,4]. In this study, we simulate and analyze the effect of commercial CFs on wide color gamut displays and propose a design with a patterned perovskite layer instead of CFs. Thus, the drawback of CFs will be eliminated and subpixels based on nano emitters will provide purer colors and wider color gamut.

Method

In our structure, we assumed a design with blue InGaN LED as main backlight source which excites red and green perovskite nanocrystals. These perovskites can potentially be implemented onto substrate as subpixels by inkjet printing etc. and blue subpixel will transmit the blue backlight directly to the other side of that layer. Then, using long wavelength pass dichroic filters (LPDF) only for red and green subpixels, we can eliminate blue light from red and green spectra which provides achieving pure RGB colors separately [5]. Controlling currents on thin film transistor (TFT), it is possible adjust the intensities of emitters for desired colors on display.

In order to broaden the color gamut, appropriate parameter values, peak emission wavelength and FWHM, for each emitter have to be investigated and optimized. Additionally, a reference white

point, around D65 (0.3127, 0.3290), has to be defined for the integration of proposed parameters to the television technology. Considering the announced peak emission wavelengths in ITU-R BT.2020, appropriate FWHM parameters of emitters have been investigated [6]. Additionally, intensities are included to the simulation for white. Furthermore, we calculated CIEDE2000 which is a color difference metric that compares the color difference scale between reference color and test color. Having a CIEDE2000 value less than 1 means that the difference can not be recognized by human eye. It is critical to match a color gamut with a referenced one for a successful enhancement.

Results

Conventional backlight technology including color filters have been simulated for 500-600nm and 600-700nm peak emission wavelength ranges with 15-60nm emission FWHM values using 0.5% intensity sensitivity for green and red emitters. A blue InGaN led emitting at 465.5nm with 25nm FWHM is used as backlight source both for simulation and experimental study. Maximum achievable Rec.2020 coverage ratio with commercially available color filters was 86.85%. On the other hand it is found out that, 10nm FWHM for three primaries covers 98.96% of Rec.2020 color gamut. Thus, it is clear that quantum dots (QDs) will not be sufficient to cover Rec.2020 due to spectral width, which is potentially around 30nm, therefore we adjust our simulation region for FWHM starting from 15nm which is applicable for perovskite nanocrystals. Color gamut by perovskite nanocrystals investigated using 500-550nm and 600-700nm peak emission wavelength and 15-40nm FWHM ranges for green and red perovskite emitters, respectively.

Table 1. Spectral parameters of simulation result for achieved maximum percentage of Rec.2020 color gamut.

	R	G	B
Peak emission wavelength (nm)	633	530	463
FWHM (nm)	18	15	25
Intensity (%)	42	37	20

In Table 1, spectral parameters of simulation result, covering 98.43% of Rec.2020 is presented. Using those values, white point is obtained at (0.3143, 0.3291). Thus, the coverage ratio is increased from 87% to 98%. In other words, around 16% enhancement was achieved. Increasing the ratio up to 100% may be possible by using ultra narrow emitters, i.e. nanoplatelets with less than 10nm spectral width [7,8,9].

In Figure 1, color gamuts of Rec.2020 and simulation results, are given along with the emission spectra of conventional white light (commercial color filter applied) and simulated white (perovskite layer instead of CFs), with commercial color filter spectra (inset)

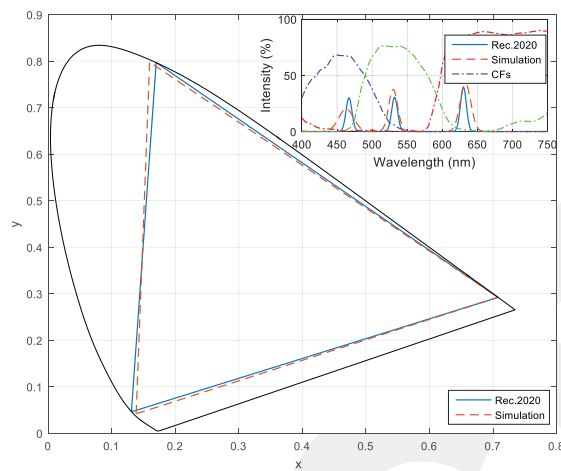


Figure 1 Color gamuts of Rec.2020 and simulation result, (inset) Emission spectra of referenced Rec.2020, simulation result and commercial CFs.

We also calculated CIEDE2000 color difference among referenced Rec.2020 color gamut's and our experimentally achieved color gamut's corners. As can be seen in Table 2, the differences are quite high as expected. The main reason for those results is the spectral width. In reference, the FWHM values are 10nm and perovskite nanocrystals are not well appropriate to achieve that much narrow values. However, using nanoplatelets, it may be possible to reach a value less than 1 for CIEDE2000.

Table 2. CIEDE2000 values between corner primaries of referenced Rec.2020 color gamut and simulation results.

	Red	Green	Blue
CIEDE2000	13.5	17.5	5.3

As a demonstration, we synthesized green and red perovskites considering our simulation results to check their performance. All inorganic cesium lead bromide (CsPbBr_3) perovskite nanocrystals were synthesized by using hot injection method and slightly modified from literature recipes.

After a purification process, the perovskite nanocrystals in hexane were mixed with a controlled amount of anion exchange PbI_2 solution in hexane. After the desired color was achieved,

addition of anion exchange solution was terminated. Finally, the quantum dot solutions were mixed with PMMA – hexane solutions and films were prepared by drop casting method.

Exciting those nanocrystals by blue LED, we achieved red and green emission at 644nm with 36nm FWHM and at 531nm with 20nm FWHM, respectively.

Using the achieved color performance values of synthesized materials, we obtained 97.37% of Rec.2020 color gamut coverage which possess around 14% enhancement compared to the conventional backlight system. In Table 3, the results of CIEDE2000 is given.

Table 3. CIEDE2000 values between corner primaries of referenced Rec.2020 color gamut and experimental results.

	Red	Green	Blue
CIEDE2000	17.4	19.3	11.2

Conclusion

In this work, we first time simulated and analysed performance of perovskite nanocrystals for display technologies. Replacing color filters with perovskites in subpixel level enhances the drawbacks on wide color gamut displays. In simulation, using 15nm as the narrowest perovskite spectral width, the ratio of enhancement is 15.8%. We calculated color differences between Rec.2020 and experimental results for each primary pairs. Using ultra narrow emitters will create better results in terms of CIEDE2000 with less than 10nm FWHM values. We also synthesized perovskites considering our simulation work and about 13.8% improvement achieved experimentally.

We believe that our study will open a new window to use of perovskites as promising materials for wide color display applications.

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