https://doi.org/10.2352/EI.2022.34.7.ISS-201
This work is licensed under the Creative Commons Attribution 4.0 International License.
To view a copy of this license, visit http://creativecommons.org/licenses/by/4.0/.

The Study and Analysis of Using CMY Color Filter Arrays for 0.8 um CMOS Image Sensors

Po-Hsiang Wang [†, (a)], An-Li Kuo[†], Ta-Yung Ni, Hao-Wei Liu, Yu-Chi Chang, Ching-Chiang Wu, Ken Wu.

VisEra Technologies Company, No12, Dusing Rd.1, Hsinchu Science Park, Taiwan (30078)
[†] These two authers contrubuted equally, [(a)]
E-mail: Pohsiang_Wang@viseratech.com
Tel. : +886-3-7835270
Fax. : +886-3-6662858

Digital color cameras detect scenes through color filter array (CFA) of mosaic patterns. Among existing filter arrays, the CMY color filter set is one commonly used in commercial CMOS image sensors (CIS), where the subtractive colors such as cyan, magenta and yellow are used (Figure 1). These color filters generally suffered from lower color fidelity than their counterpart RGB color filters particularly in high illuminating scenes, as demultiplexing RGB values from captured CMY values generates noise. However, these broad-band CMY filters are also more light efficient than those narrow-band RGB filters, making them a more desirable choice for low-illuminating conditions such as dark/night scenes or for the photon constraining small-pixel image sensors.

Here we have fabricated and tested small pixel CIS using CMY color filters with a photodiode (PD) cell pitch of 0.8 μm (Figure 2). Each cell of the CIS was an assembly of a microlens (ML) above the composite metal grid (CMG) that is filled with a color filter material (either in cyan, magenta, or yellow arranged in a way according to the pattern in Figure 1a). The Quad-Bayer pixel structure (i.e. 4C) demonstrated here allows for the pixel to operate in normal, dual-exposure and binning modes for extended dynamic range and improved contrast in both daylight and low-light scenes; but the CFA arrangement in practical application is not limited to this structure.

Since the spectral sensitivity and overall performance is determined by the combination of the transmittance of the color filter material and the quantum efficiency (QE) of the substrate, the normalized QE we shown here were direct measurements made on the 0.8 μm small pixels using a RGB CFA (Figure 3) in comparison to a CMY CFA (Figure 4). These normalized QE curves would be useful for judging the color accuracy and noise evaluation. In Figure 5, we compare the CIS performance between RGB and CMY CFAs as in photon transfer curves. Also in Figure 6-8, X-Rite ColorChecker images captured by CIS with both RGB and CMY CFAs are shown as the raw images, images after demosaicing and color-corrected demosaicing images, respectively. Specifically through the analysis of Imatest®, we have found the minimum color errors (ΔE_{00}) for RGB and CMY CFAs to be 4.73 and 4.46 with a SNR of 48.2 dB and 43.8 dB respectively, which shows that the color performance and noise level were comparable for both CFAs. Moreover, when we further calculate the raw SNR from QE curves (Fig. 3 and 4) under a simulated D65 light source using a matlab® code developed by ourselves, we found the CMY CFA delivers a better sensitivity compared to the RGB CFA, with an averaged 12% signal improvement over RGB CFAs at a common 100 lux condition and a dramatic 38% improvement under the illumination condition of only 10 lux (Figure 9). These experiments and analysis confirm the possibility of CIS signal improvement for either low lux or small pixel conditions by using a CMY CFA.

Since the color performance and signal sensitivity were affected not only by the pigments used for color filters but also by the detailed structure designs and CFA arrangement of the pixel itself, we tends to further optimize the combination for both the color filter materials and the pixel designs for an improved pixel performance. Our efforts will improve CIS performance under low light conditions and have applications in astrophotography, low phototoxicity bioimaging, as well as general photography during dawn and dusk.

Keywords—CIS, CFA, color accuracy, noise evaluation, quantum efficiency, de-mosaic, color-correction.

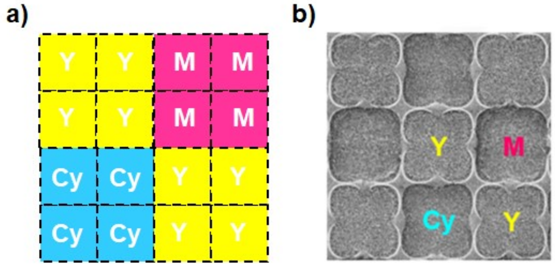

Figure 1. A typical CYYM color filter array with cyan (Cy), magenta (M), and yellow (Y) color pigments in a) a Quad-Bayer pixel arrangement and b) the CIS viewing with a SEM.

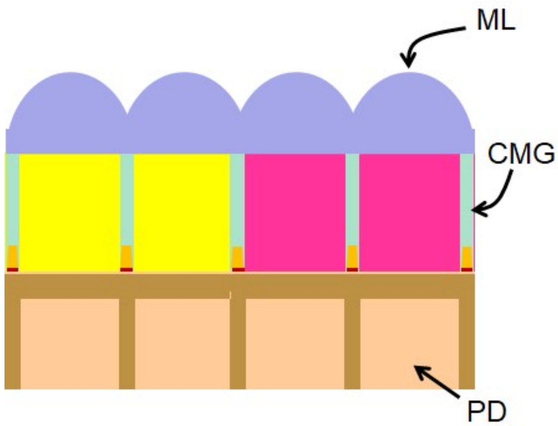

Figure 2. The schematics of the cross section of a typical pixel in 4C arrangement showing cells equipped with magenta and yellow color filters. Each pixel is contructed with a microlens (ML), a color filter, a photodiode (PD), and the composite metal grid (CMG).

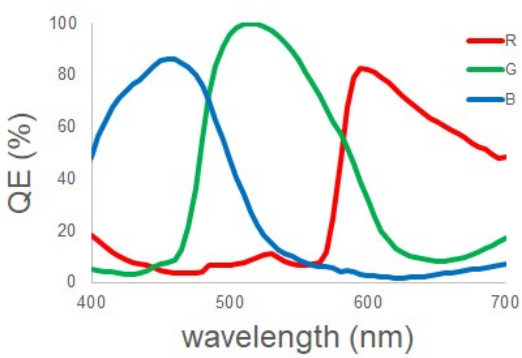

Figure 3. The normalized QE of a typical 0.8 μm CIS pixel with RGB color filters in a 4C arrangement.

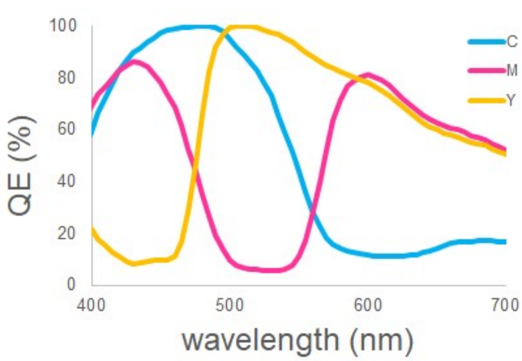

Figure 4. The normalized QE of a typical 0.8 μm CIS pixel with CMY color filters in a 4C arrangement.

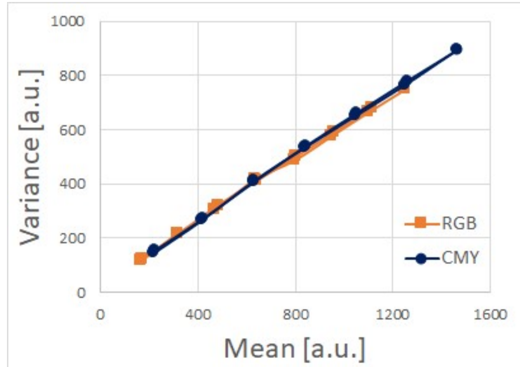

Figure 5. Comparison between RGB and CMY shown in photon transfer curves.

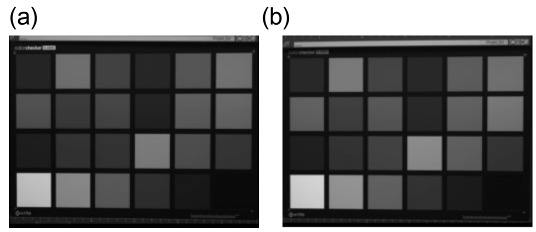

Figure 6. Raw images of (a) RGB and (b) CMY.

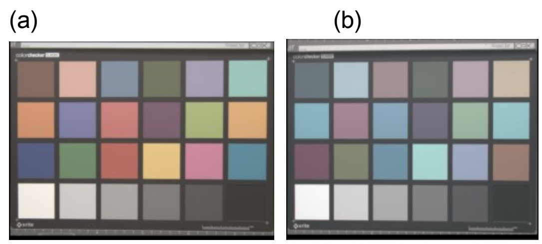

Figure 7. Demosaicing images of (a) RGB and (b) CMY.

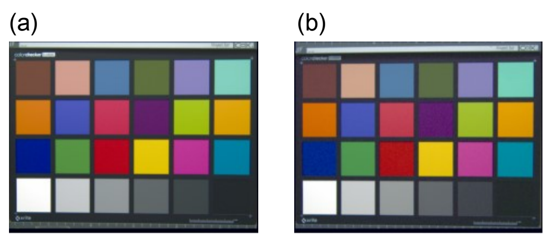

Figure 8. Color-corrected demosaicing images of (a) RGB and (b) CMY.

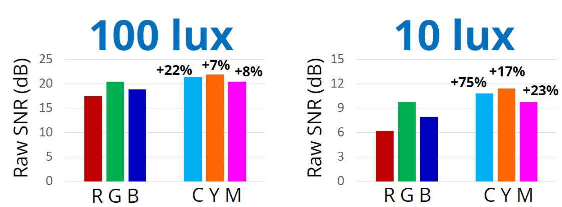

Figure 9. Simulated SNR from QE curves of both RGB and CMY under D65light source. The CMY shows better performance in low light condition by demonstrating much significantly higher raw SNR.