# Technology of color filter materials for image sensor

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## Abstract

Image sensors are devices that are widely used for various kinds of camera modules. Their market size was greatly expanded by the increasing demand for Digital Still Cameras and mobile phone cameras. Especially the application for camera phones has been a major force to the further size reduction of sensors. The pixel size already reached 1.1um. Towards higher pixel numbers with smaller pixel size, on-chip color filters are considered a key-component, which defines the camera module performance.

In this paper, we will explain the technology of pigment type color filter materials, which is the key-technology for producing on-chip color filters. The paper gives an introduction of pattern size, spectrum, film thickness, and color uniformity, which are required for the further size reduction of image sensor devices and highlights technology of color filter materials for future high performance camera modules.

## History of color filters for image sensors

On-chip color filter consists of a micro lens, a color filter. The function of the micro lens is to efficiently deliver the light through the color filter to the photo diode and the function of the color filter is to obtain the color information of the light. FUJIFILM Electronic Materials Co. Ltd. (FFEM) registered a trademark for high functional pigment type color filter materials as “Color Mosaic ”(CM). FFEM develops and delivers those materials.

Table.1 CM Characteristic for each generation

| Generation | | LCD Type | 3rd Gene | 5th Gene | 7th Gene |
|---|---|---|---|---|---|
| Resolution | | 100～300um | 3.0um | 1.70um | 1.1um |
| Film Thickness | | 2.0um | 1.1um | 0.9um | 0.8um |
| Large Size Pigments ( n / Area) | Red | 10.7 | 2.2 | 1.1 | 1.0 |
| | Green | 6.4 | 1.3 | 1.2 | 1.7 |
| | Blue | 69.6 | 1.3 | 1.2 | 1.0 |
| Color Uniformity (n/Area) | Red | 10502 | 8892 | 3216 | 2017 |
| | Green | 25807 | 10625 | 1556 | 1000 |
| | Blue | 72709 | 39333 | 5139 | 5439 |
| Spectrum Concept | | For LCD | Color Error | ← | Color Error and SNR |

In the past, the dying method was applied for the color filter. However, from the process cost and light durability point of view, they are gradually transferred to the CM used at the LCD color filter. On the other hand, the material resolution for LCD was not enough to be used as image sensor color filter and a specialized development of color filter materials for the image sensors was needed. The expanding Digital Still Camera and mobile phone camera market was the driver for higher resolution and size reduction of the image sensors. Based on the market situation, the color filter materials were improved for higher resolution, thinner film thickness, fewer large size particle and better color uniformity characteristics. At a pixel size of 1.4um and below, the sensitivity of the photo diode got worse and a new set of RGB spectra was required to achieve a low color error and a high SNR (Signal-to-Noise Ratio) at the same time. The color spectra were reviewed and they are under process of development now. Table 1 shows the CM characteristics for each generation.

Characteristics and Technology required for CM for Image Sensors

1) CM basic characteristics and its components

CM is a negative type photosensitive material to be patterned with UV light. It consists of pigments to define the spectrum of the color filter, dispersant polymer for pigment dispersion, initiator to generate the radical for the polymerization reaction, monomer to be polymerized and an alkaline soluble polymer to control the development property.

The photo polymerization starts with the radicals generated when the initiator is exposed to UV light. When the radical gets in contact with the monomers, the polymerization starts and forms the high molecular weight polymer insoluble for the developer. The un-exposure area is not polymerized and is removed during the development process. As a result, the pattern profile is formed. The CM requires coating, pre-bake, exposure, development, rinse and post-bake.

2) Spectrum

Until 1.75um pixel size image sensors, a high SNR was not required and the spectrum design was only focusing on a low color error. As of 1.4um pixel size image sensors, both low color error and high SNR were required for the color filter. The spectra designed with conventional pigments cannot achieve the two characteristics at the same time and new pigments for red and new dye based magenta for pigment/dye hybrid blue are under development. The materials using these new colorants also apply the design to meet the material requirements as CM.

Fig. 2 shows the $5^{th}$ and new spectra CM. The blue spectrum achieved higher sensitivity and lower noise by increasing the peak transmittance by 10% and lowering transmittance below 5% at 540nm and 700nm wavelength. The red spectrum achieved lower noise and color error by erasing the hump at 530nm and shifting the slope to longer wavelengths. The green, using a combination of conventional pigments, achieved a higher sensitivity and lower noise by widening the mountain and lowering the bottom transmittance around 5%.

Fig. 3 shows the simulation result of SNR and color error with new spectra CM. With the combination of these 3 new spectra, it is estimated to achieve a high SNR while keeping the color error characteristics constant.

Fig.2 $5^{th}$ Gene and New Spectra

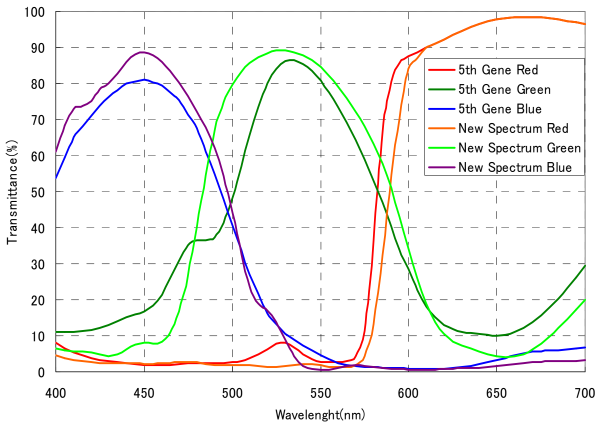
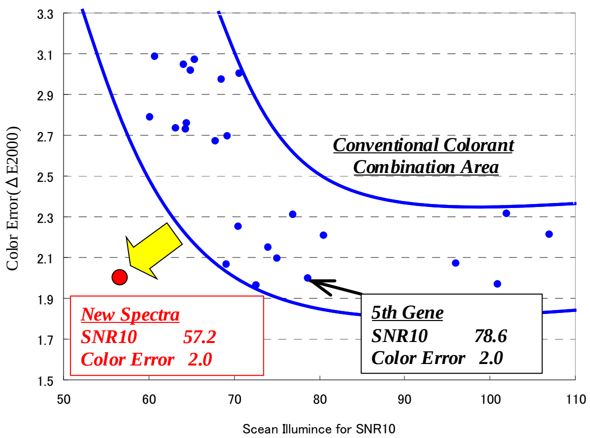



Fig.3 SNR10 and Color Error

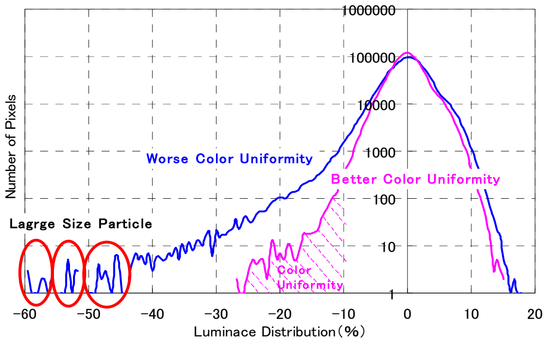



3) Large Size Pigments and Color Uniformity

The measurement result of large size pigments and color uniformity is shown in Fig. 4. The methodology of this measurement is to capture with a CCD sensor the microscope image of the CM coated on glass. The noncontiguous parts of lower luminance area of the luminance distribution can be attributed to large size pigments. The integral part of the lower luminance area is defined as color uniformity. From customer's data, these two characteristics were well correlated to the black defect (Kuro-kizu). New pigment dispersion liquid including pigment, dispersion polymer and solvent were developed to reduce the number of large size pigments and to improve color uniformity.

The numbers of large size pigments were also reduced by an additional process during the pigment dispersion manufacturing process. For the color uniformity, everything including pigment production process, pigment milling process, dispersion process and dispersant polymer was restructured and improved.

Fig.4 The measurement result of Large size pigments and Color Uniformity




4) Higher Resolution

Fig. 5 shows the trend to smaller pixel sizes. To satisfy the demand for smaller pixel size for image sensors, higher resolution CM is needed. Higher resolution requires smaller pigment size and improved development properties of the CM. The approaches needed for smaller pigment size have already been described in the paragraph about color uniformity. Improved development properties were obtained by implementing alkaline solubility as a function to raw materials that were not equipped with that function before. Fig. 6 shows the green bayer resolution profile at 3$^{rd}$, 5$^{th}$ and 7$^{th}$ generation.

With the trend to smaller pixel size, the vertical profiles are required to allow pixel shrinkage. The transmittance control of CM at exposure wavelength area (365nm) is needed. Especially, the higher transmittance at 365nm area tends to be footing due to scattered light from the substrate, which causes the poor resolution. This was improved by controlling the transmittance for i-line wavelengths with an i-line absorber.

Fig.5 Trend to smaller pixel Size

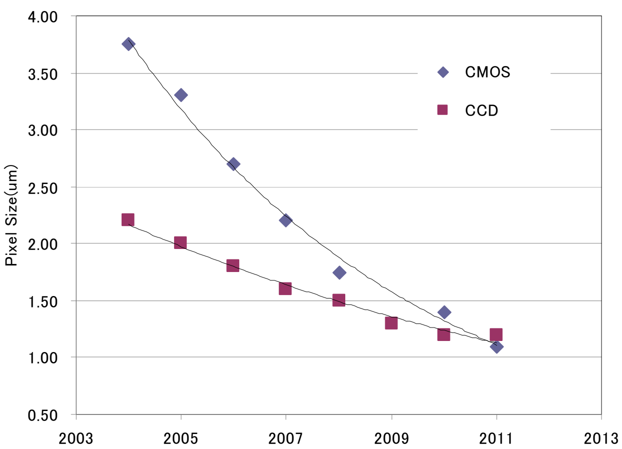
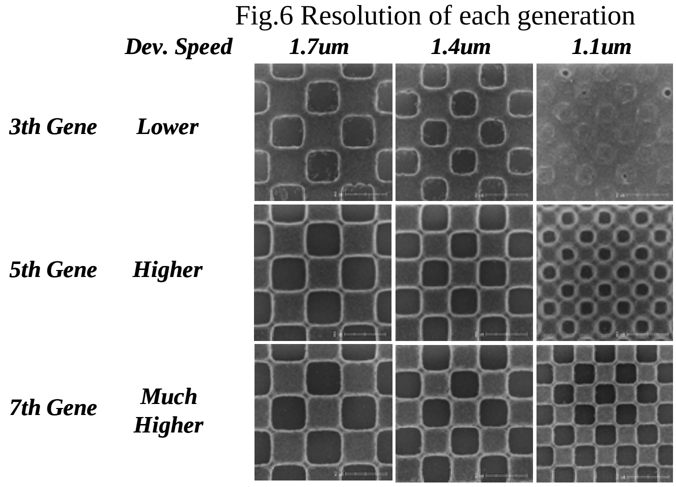



Fig.6 Resolution of each generation

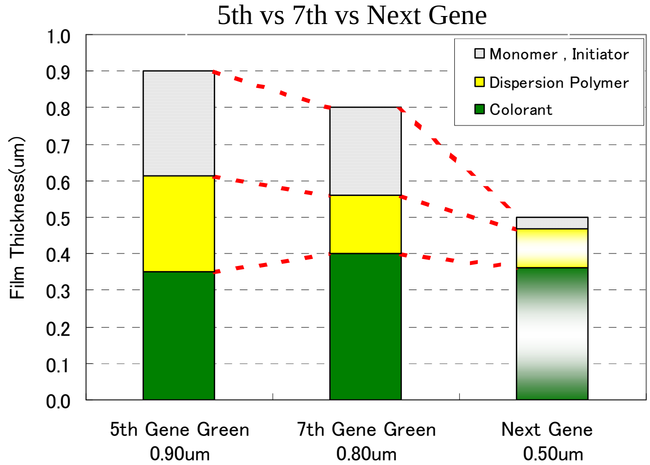



5) Thinner film thickness

Image sensors with a pixel size of 1.4um and below, suffered from the low sensitivity of the photo diode. To increase sensitivity, the structure of the image senor is changing from FSI (Front Side Illumination) to BSI (Back Side Illumination). However, for BSI the problem of cross talk needs to be solved and the CM film thickness is required to be reduced from 0.8um to 0.5um..

Fig.7 shows the CM film thickness and different raw material component for 5$^{th}$, 7$^{th}$ generation and 0.5um film

Fig.7 CM Composition Ratio
5th vs 7th vs Next Gene



thickness generation assumption.

With the increase of pigment ratio to achieve the 0.5um film thickness without changing the spectra, other materials such as monomer, initiator that are necessary to work as photo lithography materials cannot be added in the CM. Based on the situation, dry etching process is needed instead of lithography process. The thermal cross-linking type CM for dry etching process is under development as a next generation.

## CM Future technology for Image Sensor

New colorant and new process will be required for further spectrum improvement, higher resolution and thinner film thickness. Explore for new colorant is necessary as mentioned. New material design optimized for dry etching process is needed as well. With the dry etching process, pixel size below 0.9um is prospected.

For the further smaller pixel of image sensor, new image sensor such as Quantum Film, and Organic Conversion Layer are proposed. We would like to think together with the image sensor company about color filter and Color Mosaic for those new image sensors.

FFEM would like to cooperate with and contribute to the growth of image sensor business through high functional material (such as black material and refractive index material.)

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