Trends in Organic Imaging Device Research

1. Introduction

We are doing research and development on a "Super Hi-Vision" next-generation broadcasting system that can achieve a high sense of presence by reproducing super-high-definition color video with 16 times the number of pixels of Hi-Vision (7,680 × 4,320 or about 33 megapixels) and multi-channel audio. To obtain high-definition color video, the cameras used for Super Hi-Vision video imaging use a color separation prism to split incoming light into three colors (blue, green and red) and direct the separated colors of light to three imaging devices. It is therefore necessary to reduce the size and weight of the imaging devices and the color separation prism to achieve a more compact Super Hi-Vision camera. However, the Super Hi-Vision imaging devices must have a very high pixel count of about 33 megapixels, and decreasing pixel size reduces device characteristics such as sensitivity and dynamic range. One way to solve that problem is to use a single color imaging device that doesn’t require a color separation prism (single device method). Current single imaging device systems, however, have lower sensitivity and resolution than the three-device systems, and so are not applicable for Super Hi-Vision cameras.

To reduce the size and weight of the Super Hi-Vision camera, we therefore took up the challenge of developing an “organic imaging device,” a single color imaging device based on a new concept in which light is split into the three primary colors and the charges produced by each primary color are read independently. A similar imaging device that uses the property that light of different colors penetrates a silicon substrate to different depths and has silicon photodiodes formed at different depths in the substrate for blue, green, and red light has been proposed⁵, but the organic imaging device is superior in principle to such devices in terms of sensitivity and color reproduction.

In this article, we explain the concept of the organic imaging device and report on the characteristics of a prototype organic photo-electric conversion film (referred to as simply ‘organic film’ below) that we fabricated as proof of concept as well as the progress in developing a prototype organic imaging device based on those results.

2. Overview of the organic imaging device

The current three-device color imaging method and the single device method are compared in Figure 1. The three-device method is superior in sensitivity, resolution and color reproduction and is used in virtually all broadcast TV cameras. However, the required color separation prism and three imaging devices limit camera compactness. Consumer video cameras and digital still cameras, on the other hand, mainly use the single-device method. In that method, however, minute three-color or four-color filters are arranged over the pixels of the single imaging device in a mosaic pattern to achieve color separation. Because no color separation prism is required and there is only one imaging device, the camera can be made small and lightweight. Nevertheless, the resolution is poorer than when a three-device method is used, and the light use efficiency (sensitivity) is low. However, if it were possible to form three layers corresponding to the three primary colors of light at different depths in the imaging device along the direction of light propagation and read an independent video signal from each layer,
then color images that have the same characteristics as images obtained by the three-device method could be obtained with a single device.

The concept of an organic imaging device that we are developing on the basis of that approach is illustrated in Figure 2. The organic imaging device has an alternating layer structure of three organic film and transparent circuit that read the signals from the each organic film. Because organic materials have the property of absorbing light in only specific wavelength regions, we turned attention to organic materials for candidate materials for the photo-electric conversion film of this device\(^2\). The materials must satisfy the following requirements to serve in devices.

1) Selective absorption and photo-electric conversion of light of three colors (blue, green, and red)
2) Complete transparency to light of colors not absorbed
3) High film resolution without division into pixels

3. Characteristics of organic films

3.1 Spectral sensitivity and transparency

Because the color of a material that absorbs only a particular color and is transparent to other colors will have the color complementary to the absorbed color, we searched for materials that are yellow, magenta, and cyan as films to serve as the respective organic film materials for the blue, green and red layers. Examples of materials that satisfy those conditions are coumarin 6 (C6) for blue, rhodammin 6G (R6G) for green, and zinc phthalocyanine (ZnPc) for red. We fabricated experimental cells in which those materials are sandwiched between electrodes and investigated their spectral sensitivity and spectral transparency\(^3\). The spectral sensitivities are presented in Figure 3 and the transmittances are presented in Figure 4. From Figure 3 we can see that photoelectric current that corresponds more or less to the three primary colors of light is obtained from the cells. In addition, Figure 4 shows that the C6 film absorbs blue light while transmitting 90% or more of the green and red light, and although the R6G and ZnPc films have somewhat low transparency for blue light, they are largely transparent to light in the wavelength regions outside of their respective regions of absorption. We thus verified that photo-electric conversion films that satisfy requirements 1) and 2) described in section 2 can be realized by selecting the organic materials appropriately, and that the structure stacked those films can separate the three primary colors in the direction of device depth and convert the light of those colors into electrical charge.

3.2 Resolution

To verify satisfaction of the third requirement described in section 2, we investigated the resolution of a prototype Hi-Vision imaging tube fabricated using dimethylquinacridone, which is sensitive to green light, as the photo-electric conversion film (Figure 5). The electrical charge generated by light in the operation of the imaging tube accumulated in the organic film in a maximum of 1/60 second. The organic film is not separated into pixels, so if the resolution of the film itself is not sufficient, the accumulated charge will disperse horizontally in the film and decrease the resolution. However, the obtained image has good resolution, as shown in Figure 6, so the organic film resolution is sufficiently high for at least Hi-Vision, which is to say that...
requirement 3) is satisfied\(^4\). This result shows that pixel separation is not needed when reading the charge generated in the organic film, and suggests that an aperture ratio\(^1\) of 100\% can be achieved with the organic imaging device.

4. Development of the organic imaging device

We know that selection of a suitable organic material makes it possible to obtain a high-resolution organic film that is sensitive to only one of the three primary colors and is transparent to other colors of light, as described in section 3. Those results have stimulated various current studies of stacking organic films.

Our prototype single color imaging device for basic experimentation on stacked organic films is shown in cross section in Figure 7. The organic film color signal is read by a thin-film transistor (TFT) circuit formed on a transparent substrate. The TFT uses amorphous silicon (a-Si) or polysilicon (poly-Si) as the transistor material is currently used widely in liquid crystal displays. However, a-Si and poly-Si are sensitive to colors of light that must be transmitted to lower layers, so light must be blocked from the transistor parts when used in this device and that decreases the efficiency of light use. We are therefore investigating use of zinc oxide (ZnO) TFTs for the color signal reading circuit, because ZnO is transparent to visible light (Figure 8).

5. Conclusion

We have outlined our development of an organic color imaging device that is aimed at realizing a compact Super Hi-Vision camera. The device separates light of the three primary colors along the depth direction of the device and reads the electrical charges produced by those colors as independent signals. We have verified the feasibility of stacking organic films that are specifically sensitive to the three primary colors and are currently proceeding with basic experiments with a prototype device.

Achieving a single-device color imaging device that has the same characteristics as a three-device system would improve the performance of consumer video cameras and digital still cameras\(^5\) as well as broadcast TV cameras, so we will continue to accelerate research and development for an early realization of an organic imaging device.

\(^1\) The proportion of the pixel area that actually contributes to photo-electrical conversion in an imaging device.
imaging device.

References