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Back-illuminated CMOS Image Sensor Having Both Infrared Absorbing and Blocking Pixels in a Single Chip

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Abstract

Back-illuminated CMOS image sensor containing both IR pass and IR cut pixel in a single chip was developed using 1.12μm pixels. The IR cut pixel was implemented by integrating IR cut filter into a pixel. The in-chip IR cut filter is composed of TiO_2-SiO_2 multilayer films, which are common materials for making light preventing filters. The normalized QE spectra of IR cut pixels showed excellent IR blocking ability in the range of 650-1000nm, whereas IR pass pixels showed high IR response in IR range. These experimental results reveal the possibility of implementing IR and visible (IR cut) sensor in one chip.

1. Introduction

Recently, various application fields for CMOS image sensor have emerged a lot, such as Time-of-Flight (ToF) sensor [1], automotive sensor [2], and IR detecting sensor [3]. Since the IR sensor and conventional image sensor have different wavelength ranges to detect, pixel structure modification [3] or sensor configuration modification is necessary. One of the important changes is the removal of IR cut filter. For the conventional RGB sensor, IR cut filter is necessary because the IR light causes the RGB signal distortion. On the other hand, for the IR detecting sensor, removal of the IR cut filter is essential. Because of this reason, it is difficult to implement RGB (visible) sensor and IR sensor in one chip. In this paper, we present back-illuminated CMOS image sensor containing both IR pass and IR cut pixel in a single chip using 1.12μm pixel. The IR cut filter was integrated directly into a pixel in order to remove the external IR cut filter. The IR blocking ability of both IR pass and IR cut pixel was analyzed by quantum efficiency (QE) spectra of both pixels.

2. Results and discussion

The principle of an integrated inorganic IR cut filter is to reflect a specific wavelength region by stacking a pair of two different oxide layers having different refractive indices repeatedly, which is a common method to fabricate a light blocking filter [4]. The light blocking capability and wavelength range of these IR cut filters are determined by the difference in refractive indices of the two paired layers and the number of pairs. Figure 1 shows the vertical SEM image of IR cut filter which is integrated into a pixel. The IR cut filter was deposited between the pixel aperture and the micro lens with the film thickness of 4μm. In this study, 11 pairs of titanium dioxide (TiO_2) and silicon dioxide (SiO_2) layers deposited by e-beam evaporation method were used. For the sufficient IR preventing ability for CMOS image sensor, IR light in the wavelength range of 650nm-1000nm should be blocked. We combined two different types of multilayer films composed of TiO_2 and SiO_2 to achieve this property. As shown in the SEM image, it can be seen that two types of multilayer film with different TiO_2 and SiO_2 thickness were combined at the top of pixel aperture. Type-1 and type-2 films were composed of same materials but different layer thickness and number of pairs.

Figure 2(a) indicates a simulated transmittance graph of type-1, type-2 and type-3 multilayer films, which is the combination of type-1 and type-2 films. In the case of type-1 film, light wavelength above 650nm was effectively blocked, but the transmittance increased at the longer wavelength range above 850nm. On the other hand, the type-2 film had high transmittance up to 800nm and the wavelength light in the 800-1000nm range was effectively blocked. Therefore, by integrating the two films, it is possible to block the near IR light of 650nm-1000nm. The transmittance of type-3 film confirmed that the corresponding near IR light was effectively prevented. Meanwhile, the blocking capability of the IR cut filter depends on the number of pairs of layers. As shown in the simulated transmittance according to the number of pairs in Figure 2(b), the blocking capability was strengthened as the number of pairs increased. Consequently, the film consisting 16 pairs was developed, which showed sufficient IR blocking ability.

Figure 3(a) demonstrates a vertical SEM image of a pixel structure that contains both IR pass and IR cut pixels in one chip. This pixel structure confirmed the possibility of implementing an IR pass and IR cut (visible) sensor in a single chip. Figure 3(b) shows the normalized QE spectra of the IR pass and IR cut pixels fabricated in one chip. As can be seen from this result, the IR cut pixels showed an excellent IR blocking capability in the range of 650nm-1000nm, which is equivalent to that of conventional in-chip IR cut filter. Meanwhile, the IR cut filter of IR absorbing pixels was removed by a dry-etch process usually used in semiconductor fields. The etch process of IR cut filter is important because it could directly affects the pixel performance since the pixels are just beneath the IR cut filter. Figure 3(c) shows a dark histogram of pixels which the IR cut filter was normally and over etched, respectively. The dark histogram of over etched pixels indicates that improper etch could increase the white spot and deteriorate the pixel performance.

Figure 4 shows the photographic images taken with conventional pixel with/without conventional IR cut filter and those taken with the pixels consisting IR pass and IR cut pixels. The photos were taken using both visible and 940nm-IR light source. The photo taken with partial IR pass and IR cut pixel region indicates that the in-chip IR cut filter operates well and shows equivalent light preventing ability compared to the conventional IR cut filter.

3. Conclusion

Back-illuminated CMOS image sensor containing both IR pass and IR cut pixels in one chip was successfully developed using 1.12μm pixels. The IR cut pixels were implemented by integrating IR cut filter into a pixel. The in-chip IR cut filter was composed of TiO_2-SiO_2 multilayer films, which was deposited by e-beam evaporation method. The normalized QE spectra of IR cut pixels showed excellent IR preventing ability at the range of 650-1000nm, whereas IR pass pixels showed high IR response in IR range. From this result, there is a possibility of implementing IR and visible sensor in a single chip.

Acknowledgements

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References

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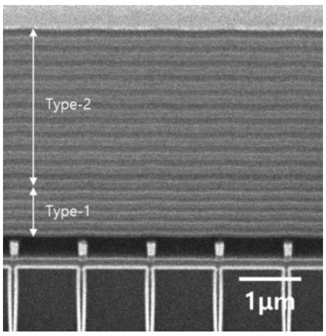

Fig. 1 Vertical SEM images of in-chip IR cut filter integrated into a 1.12μm pixel.

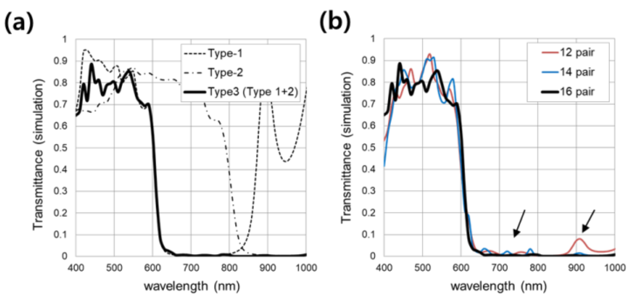

Fig. 2 Simulated transmittance graphs of (a) type-1, type-2, and type-3 (combination of type-1 and 2) in-chip IR filter and (b) type-3 IR cut filter in terms of the number of pairs.

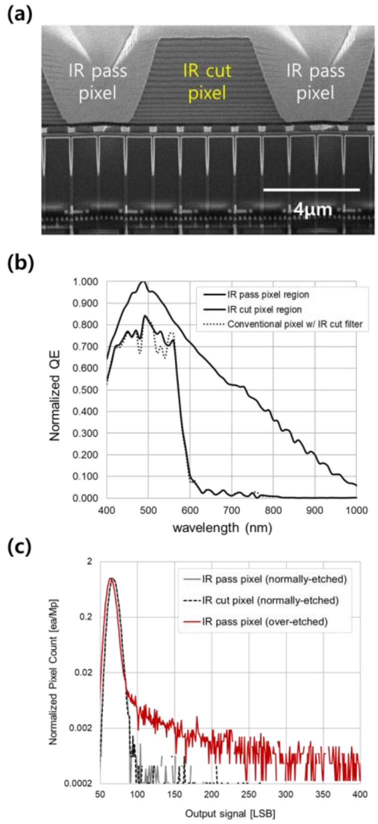

Fig. 3 (a) Vertical SEM images of pixel structure consists of both IR pass and IR cut region on one chip. (b) Normalized QE spectra of IR pass and IR cut pixel region compared with pixel having conventional IR cut filter. (c) Normalized dark histogram of normally etched and over etched IR pass/cut pixel.

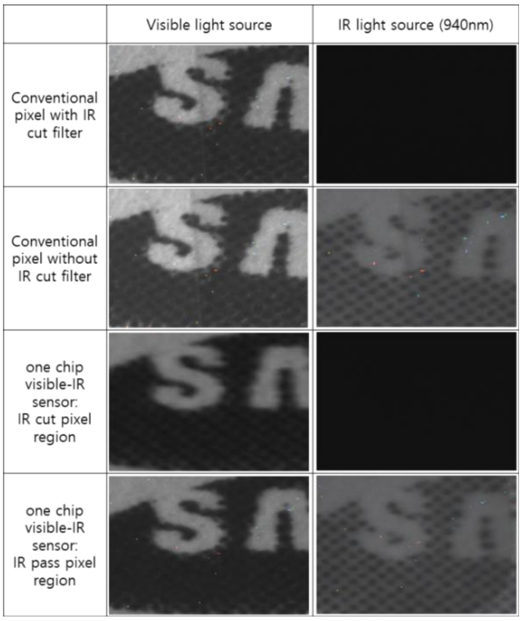

Fig. 4 Photographic images taken by conventional image sensor with conventional IR cut filter and sensor consists of both IR pass and IR cut pixel region without any external IR cut filter. The photos were taken with visible and 940nm-IR light source.