Application demonstration of polarization-analyzing CMOS image sensor and performance improvement using 65 nm standard CMOS process

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Introduction

We have been developing polarization-analyzing CMOS image sensor with monolithically embedded polarizer [1, 2, 3]. Figure 1 shows structure of the polarization-analyzing pixel. In the last workshop, we reported a performance improvement in polarization measurement using multiple pixel arrays [4]. In this work, we report an application demonstration of the polarization-analyzing CMOS image sensor fabricated with 0.35 μm standard CMOS technology. We configured a miniaturized in-line polarimeter for optical measurement of chemical solution. Functionality of the fabricated device was successfully demonstrated for model chemical reaction. We are also working on an improvement polarization measurement function using a 65 nm standard CMOS process. A polarization-analyzing CMOS image sensor was fabricated and characterized with 65 nm standard CMOS technology.

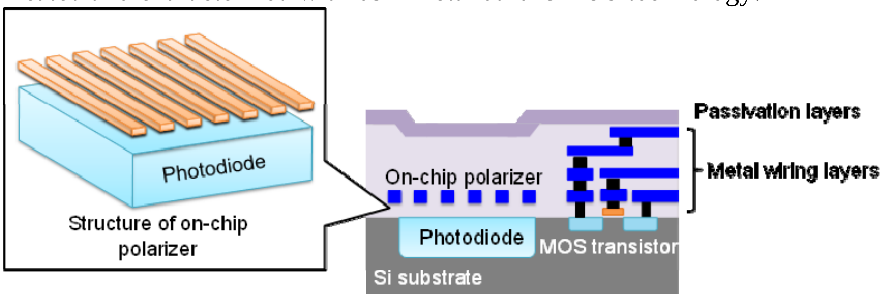


Figure 1: Structure of the polarization-analyzing pixel

Application demonstration of polarization-analyzing CMOS image sensor

Figure 2 shows layout of the polarization-analyzing CMOS image sensor with pixel arrangement of the polarization-analyzing pixel. The image sensor was designed with 0.35 μm process. Table I shows specifications of the sensor. We implemented 9 sets of polarization-analyzing pixel array that covers 0 - 179 deg. Combining with intra-frame and inter-frame averaging, we obtained accuracy better than 0.01 deg. in polarization angle measurement [5]. Table II shows experimentally obtained angular fluctuation in typical averaging conditions.

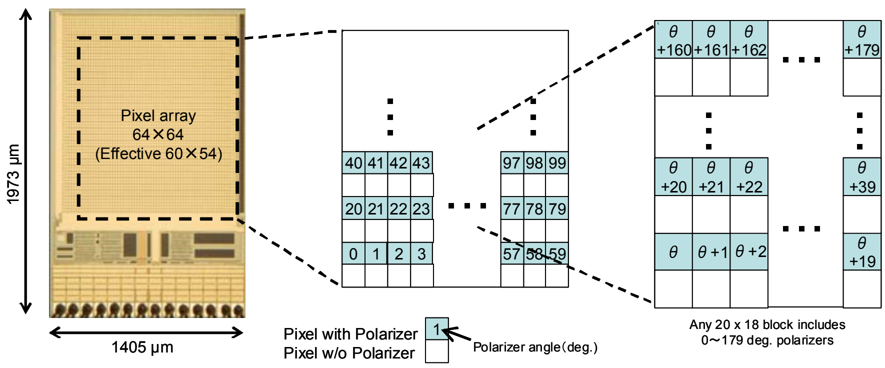


Figure 2: Layout with arrangement of the polarization-analyzing pixel

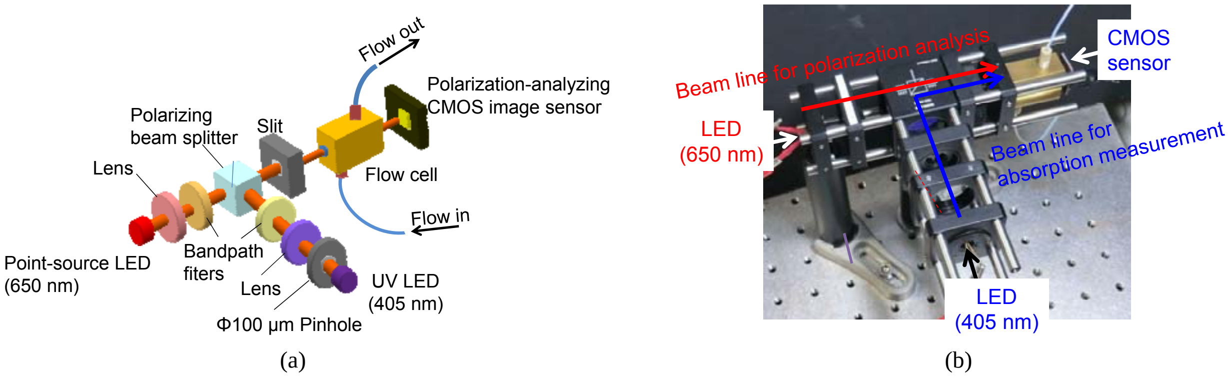
We designed an in-line optical measurement system dedicated for miniaturized chemical reactor. Figure 3 shows (a) structure and (b) photograph of the miniaturized in-line optical analyzing device equipped with the polarization-analyzing CMOS image sensor. The device was designed to monitor chemical products processed in a micro-flow reactor [5]. Chemical solution from the miniaturized chemical reactor is introduced into a flow cell for optical analysis. A polarized (650nm) and an unpolarized (405nm) light beam lines were coaxially aligned through the flow cell. The light beams that come through the chemical solution in the flow cell were detected by the polarization-analyzing CMOS image sensor. We can measure a polarization rotation to estimate the chirality of the chemical solution and single-wave (405nm) absorbance to monitor the chemical reaction.

TABLE I: Specifications of polarization-analyzing CMOS image sensor

Technology	0.35 μm 2 poly 4 metal standard CMOS
Pixel number	64×64 (Effective 60×54)
Pixel configuration	3Tr - APS
Embedded polarizer	Line / Space = 0.6 μm / 0.6 μm
Pixel size	20 μm × 20 μm
Photodiode size	10 μm × 10 μm
Operation voltage	3.3 V
Chip size	1405 μm × 1973 μm

TABLE II: Experimentally obtained angular fluctuations

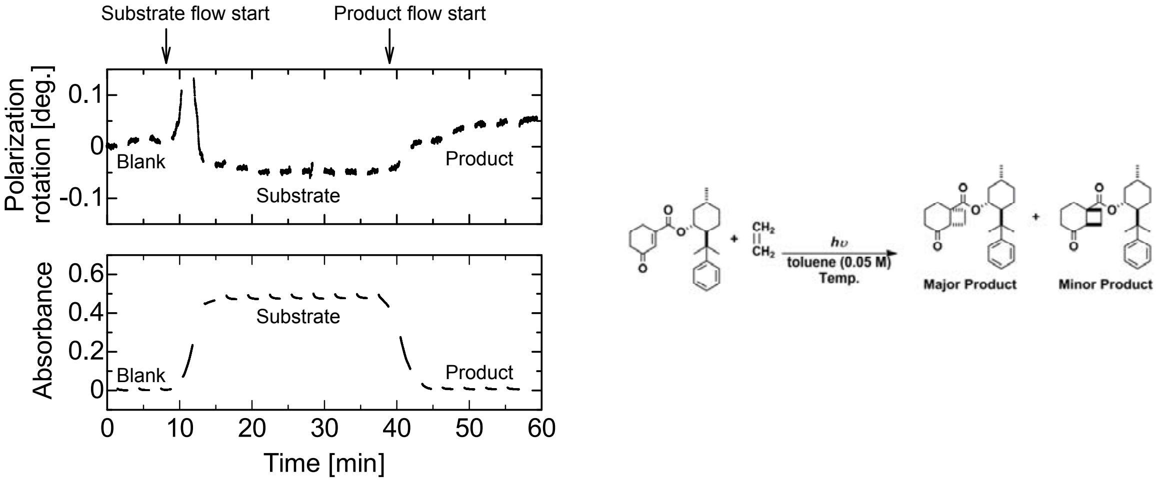
	Without Intra-frame averaging	With Intra-frame averaging
No inter-frame averaging	0.0160°	0.0061°
10 inter-frame averaging	0.0067°	0.0031°
100 inter-frame averaging	0.0036°	00022°



(a) (b)

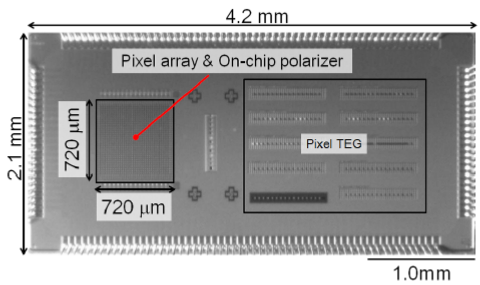
Figure 3: (a) Structure and (b) photograph of the miniaturized in-line optical analyzing device with the polarization-analyzing CMOS image sensor

Figure 4 (a) shows a measurement results obtained for blank / substrate / product solutions for a model reaction that is shown in Fig. 4(b). Since the current CMOS image sensor does not have a color filter, we have to separate the two types of measurements in a time-sharing manner. The light sources are operated alternatively to perform the two kinds of measurements alternatively. The switching interval was 90s. In Fig. 4(a), clear transitions between the blank / substrate solutions (at 10 min) and substrate / product solutions (40 min) were observed in both the optical rotation and absorption traces. This result proves the basic feasibility of the present in-line dual-functional optical analyzing device.



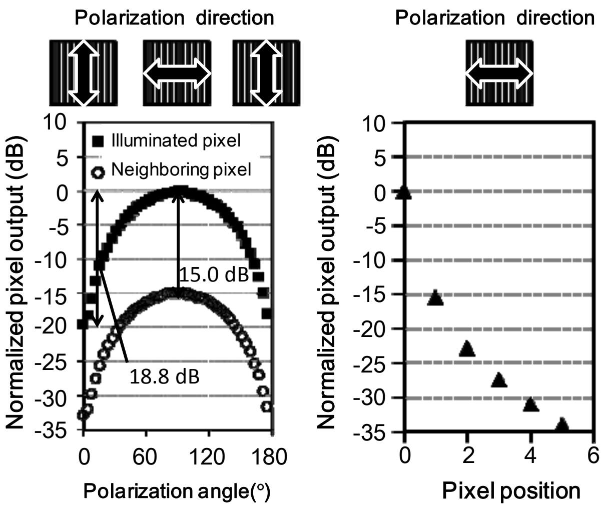
(a) (b)

Figure 4: (a) Demonstration results for (b) model chemical reaction [5]



Technology	65 nm standard CMOS
Wiring layers	7 (1 Al, 6 Cu)
Pixel configuration	3Tr - APS
Pixel size	20 μm × 20 μm
Fill factor	43.6 %
Pixel number	32×32
Operating Voltage	3.3 V

(Left) Figure 5: Layout of the polarization-analyzing CMOS image sensor fabricated with 65 nm process.
(Right) TABLE II: Specifications of polarization-analyzing CMOS image sensor with 65 nm technology

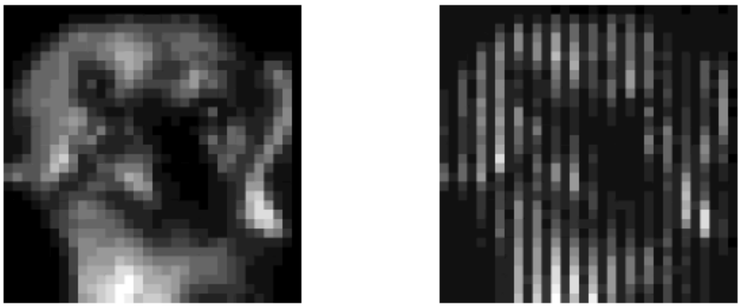


(a) (b)

Figure 6: (a) Polarization dependence of single-pixel sensitivity, and (b) positional dependence of the inter-pixel crosstalk signal

Polarization-analyzing CMOS image sensor using 65 nm technology

We are also working on performance improvement of the polarization analyzing pixel using finer device process. In the last workshop, we presented a polarization-analyzing pixel with 65 nm process [4, 6]. In this work, we designed a polarization-analyzing CMOS image sensor using 65 nm process. Figure 5 shows layout and Table II shows specifications of the image sensor. Figure 6(a) shows polarization dependence of the single-pixel sensitivity. The measurements were performed with single-pixel illumination. When we see the polarization dependence of the pixel (trace indicated as "Illuminated pixel"), the extinction ratio of the on-chip polarizer was 18.8 dB, which is significantly larger than that for 0.35 µm process (~3.3 dB) [2]. This improvement is attributed to the grid pitch smaller than the wavelength. However, it is found that crosstalk from the neighboring pixel limits the polarization selectivity of the pixel. In Fig. 6 (a), another polarization profile indicated as "Neighbour pixel" shows signal strength observed when the next pixel was illuminated by the polarized light. Although the single-pixel extinction ratio is 18.8 dB, the crosstalk from the next pixel is as large as -15 dB. Figure 6(b) shows the positional dependence of the crosstalk signal. These results suggest that we have to solve the crosstalk for accurate polarization imaging.



(a) (b)

Figure 7: Images captured (a) without and (b) with another off-chip polarizer between the sensor and an object.

We have performed preliminary polarization imaging using the sensor. Figure 7 shows typical images captured (a) without and (b) with additional off-chip polarizer between the sensor and an object. The images clearly show an effect of the on-chip polarizer as a polarization filter.

Conclusions

We have demonstrated an application feasibility of the polarization-analyzing CMOS image sensor with embedded wire-grid polarizers. We successfully demonstrated its functionality in *in-situ* optical measurements of the chemical solutions.

We also developed a polarization-analyzing CMOS image sensor using a 65 nm standard CMOS process. The extinction ratio of the on-chip polarizer was significantly larger than that for the previous results with 0.35 µm process. However, the inter-pixel crosstalk limits the polarization selectivity of the polarization-analyzing pixels. Currently, we are working on further characterization of the polarization-analyzing CMOS image sensor with 65 nm process.

Acknowledgements

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