Design of a linkable self-encoding CMOS image sensor for a compact lensless camera with an ultra-wide field of view

Fuki Hosokawa[1], Keiichiro Kagawa[2], Kiyotaka Sasagawa[3], Jun Ohta[3], Tomoya Nakamura[4]
1 Graduate School of Instituted Science and Technology, Shizuoka University
3-5-1 Johoku, Hamamatsu, Shizuoka, 432-8011 Japan
2 Research Institute of Electronics, Shizuoka University
3-5-1 Johoku, Hamamatsu, Shizuoka, 432-8011 Japan
3 Nara Institute of Science and Technology
8916-5 Takayamacho, Ikoma, Nara, 630-0192 Japan
4 SANKEN, Osaka University
8-1 Mihogaoka, Ibaraki, Osaka, 567-0047 Japan
E-mail: kagawa@idl.rie.shizuoka.ac.jp

Abstract We are developing a compact lensless camera based on a CMOS image sensor that works as an encoding mask. The image sensor is approximately 5 mm square in size and is equipped with a lot of through holes randomly placed in the pixel array. Six image sensors can be combined to build a cubic ultra-wide field-of-view camera. A pair of image sensors that face each other generate a spatially multiplexed optical image on the other side. They are linked via a serial communication interface, and one of them is selected to read images by a unique ID assigned to each image sensor.

Keywords: lensless camera, coded imaging, ultra-wide field of view

1. Introduction

Conventional wide-field cameras use multiple or special lens systems [1], limiting the camera body's miniaturization. In this study, we aim at realizing a very small wide-field camera based on a lensless camera that utilizes a randomly placed pinhole array to reduce the thickness of the camera system down to a few millimeters. Instead of using multi-component bulky lenses like conventional wide-field cameras, most lensless cameras use a coded mask to modulate the amplitude [2] or phase [3] of light. With the amplitude mask, incident light through the multiple pinholes in the mask forms a spatially multiplexed image on the image sensor. The captured image looks extremely blurry and no image of the scene is visible. However, based on the compressive sensing theory that exploits the sparsity of signal, it becomes possible to recover the original image of the scene using a pre-measured point spread function.

In this study, an image sensor with a lot of holes in the pixel array is used as an amplitude mask [4]. Thus, the image sensor works as both an image sensor and a coded mask at the same time. By placing multiple image sensors a pair of which faces each other, all-round cameras will be embodied.

Table 1. Specifications of the proposed CMOS image sensor

Chip size	4.8 × 4.8 mm^2
Number of pixels	65 (H) × 61 (V)
Number of pinholes	630
Pixel size	56 × 56 μm^2
Pinhole size	40 × 40 μm^2

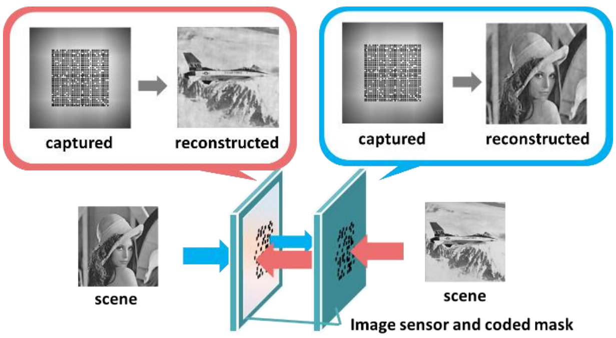

Fig. 1. Configuration of the proposed lensless imaging system

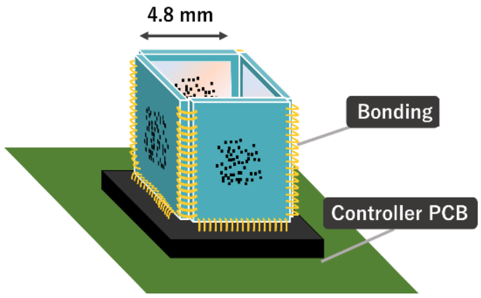

Fig. 2. An example of assembled four image sensors for omnidirectional viewing.

2. Design of linkable image sensor

Fig. 2 illustrates the concept of the omnidirectional camera with the proposed CMOS image sensors. The image sensors are linked together for communication. The following functions are required for linking multiple image sensors to work together.

- Control signals for image shooting and readout are shared among the sensors.
- A unique ID can be assigned to each image sensor to specify one of them for image readout and testing.

For sharing signals among the image sensors, the pads for the signals are laid out as shown in Fig. 3. The rectangles in the same color are for the same signal. To specify the image sensor to operate through the serial communication interface, we designed the circuit to configure the ID in post-processing. As shown in Fig. 4, the input of the buffer is connected to the power supply or the ground. The ID is configured by cutting either of the lines to the power supply or the ground, for example by laser processing. The ID is 3-bit long in order to link six sensors at most.

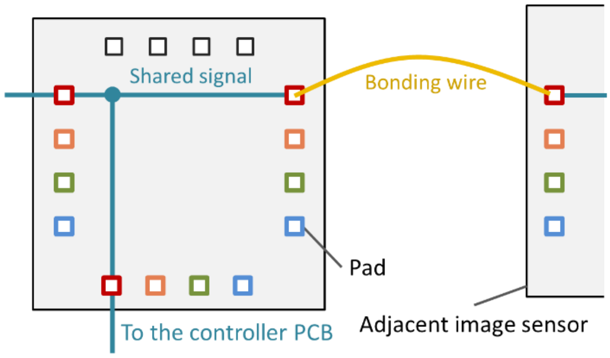

Fig. 3. Pad arrangement to link sensors

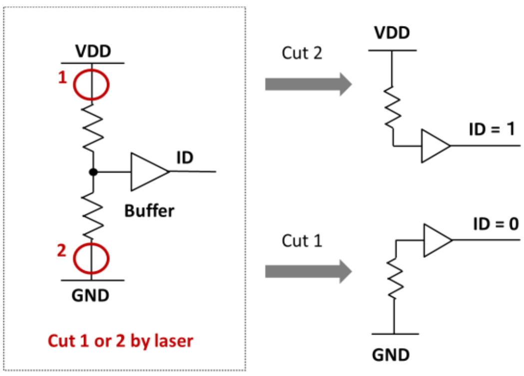

Fig. 4. The circuit to configure an ID. Position 1 or 2 is cut in post-process

3. Forming pinholes through the CMOS image sensor

Pinholes were formed on the previous prototype image sensor whose specifications are shown in Table 1. The image sensor was thinned by polishing. Then, the etching mask was formed on it by photolithography. Finally, the pinholes were made by deep reactive ion etching [5].

The coded mask's thickness affects the camera's field of view. Fig. 5 shows the relationship between the thickness of the image sensor and the geometric limit of the field of view. Since the thickness of the prototype image sensor was several hundred µm, the field of view was expected to be very narrow. Therefore, the image sensor was thinned down to about 65 µm. Fig. 6 is a microphotograph of the image sensor after the pinhole formation. The pinhole area is shown in bright green.

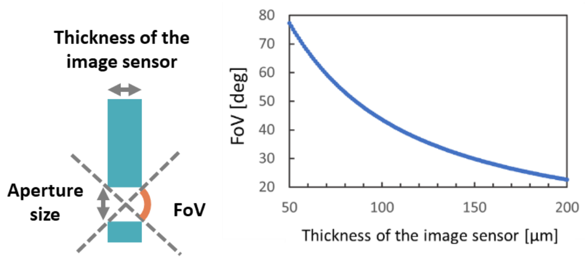

Fig. 5. Relationship between the thickness of the image sensor and the geometric limit of the field of view

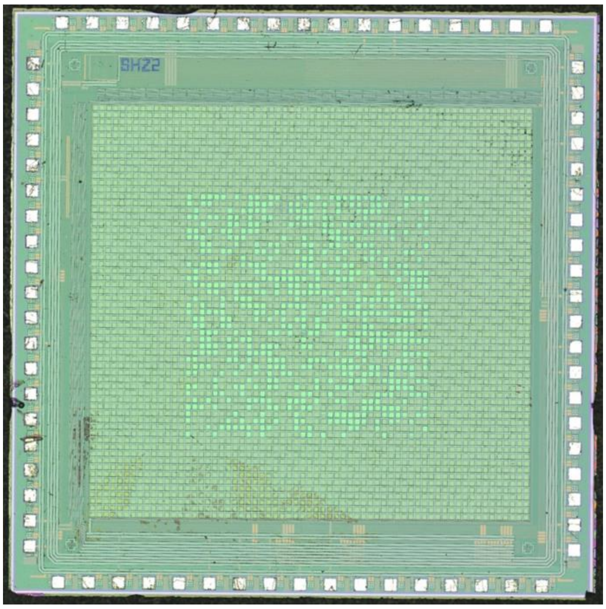

Fig. 6. Microphotograph of the post-processed CMOS image sensor with pinholes

4. Conclusion

We designed a linkable CMOS image sensor for a compact lensless camera with an ultra-wide field of view. The image sensor was thinned by polishing and pinholes were formed by deep reactive ion etching.

Acknowledgments

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