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Sensor assembly method using Si-interposer with trenches for 3-D binocular range sensors

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Abstract

We devised an alignment method of two image sensors using a Si-interposer with trenches. The trench was formed using deep-reactive ion etching (RIE) equipment. We produced the 3-D range sensor using the method in our experiment and confirmed that sufficient alignment accuracy was realized.

1. Introduction

The three-dimensional (3-D) range sensor with a high speed more than 30 frames per second is used in, for example, automotive collision-avoidance systems, monitors for security, and game console interfaces. Active-type 3-D range sensors based on methods such as the time of flight (TOF) method or pattern irradiation method have been developed [1][2]. However, the detection range is relatively narrow and they are limited to indoor use. The reason is that in those methods, distance is measured using the reflection of the modulated light, and the detection signal attenuates in inverse proportion to the square of the distance and is influenced by environmental light. On the other hand, passive-type 3-D binocular range sensors have no such restriction. However, it is necessary to separate two cameras by several to several tens of centimeters or more depending on the detection range, and there are problems of large size and high cost [3].

We developed single-chip 3-D binocular range sensors by integrating two image sensors and a parallax calculation circuit [4][5]. However, the distance between the two sensors is 2 mm, and it is necessary to use the binocular optical lens shown in Figure 1. The special lens projects one of two images of the object-lens separated by 4 cm onto each image sensor via a prism. It has been confirmed that the 3-D binocular range sensor LSI can detect objects within the range of about 3 m with the use of this special lens. However, such a special optic lens has the problem that the equipment is large and expensive. On the other hand, accurate horizontal alignment of the two image sensors is required they are separated.

We propose a method of the precise horizontal alignment of the two separated image sensors. This technology can expand the detection range without the need for a special optical lens and preserve the small size and low cost of the device.

2. Trench Si-Interposer

To expand the detection range of the 3-D binocular range sensor, two image sensors must be installed at a remote positions. In addition, horizontal alignment of high precision is indispensable for the placement of the two image sensors. Therefore, we developed a Si-interposer with trenches. As shown in Figures 2 and 3, using deep-reactive ion etching (RIE) equipment, two trenches are formed at the position of image sensor installation in the Si-interposer. The size of these trenches is 7.1 mm × 5.6 mm and they have depths as shown in Figure 2: 100 μm and 150 μm. The deeper trench is provided to catch excess adhesive. Because each image sensor is installed along the sidewall of a trench, accurate alignment is possible. The required alignment precision is calculated in pixel size and the number of lateral pixels as shown in Figure 4. Because the pixel size of the image sensor is 11 μm × 11 μm, and the number of lateral pixels is 320, a precision better than the relative angle θ of 0.179 degrees is required in the alignment.

$$\theta < 0.179° = \tan^{-1}(11/3520)$$

3. 3-D Binocular Range Sensor Assembly using Trench

This 3-D binocular range sensor module is assembled on the Si-interposer with two image-sensor LSIs, a parallax-detection LSI, and a control LSI (ASIC). These configurations are shown in Figure 5. The micrograph of the module is shown in Figure 6. The size of this Si-interposer is 90.0 mm × 13.3 mm. The distance between the two image sensors aligned with the two trenches is 80.0 mm.

The image-sensor LSI has 320 × 240 pixels, and outputs signals to the parallax-detection LSI in 8 time divisions 40 signal lines for every 320 pixels. The LSI is fabricated by a 0.35μm CMOS process, and the chip size is 5.8 mm × 4.3 mm. The parallax-detection LSI performs correlation calculation by parallel processing every 320 pixels and outputs parallax information in which correlation between the left and right images is strongly detected. The LSI is fabricated by a 0.35μm CMOS process, and the chip size is 8.3 mm × 3.0 mm. The control LSI outputs operation signals to the two image-sensor LSI and the parallax-detection LSI. The LSI is fabricated by a 0.35μm CMOS process, and the chip size is 10.0 mm × 4.0 mm.

These four LSIs are assembled in a trench Si-interposer. Since accurate alignment is required for the two image-sensor LSIs, the sidewalls of the trenches are used as positioning guides for the chip. The 3-D range sensor used in this evaluation experiment is equipped with two normal optic lenses in the module and also included a USB interface.

4. Measurement Result

Table 1 shows the measured sensor alignment angle for three 3-D range sensor modules produced experimentally. In this table, each installation angle of the two image-sensor LSIs along the trench sidewall and the relative angles of two trench sidewalls on the Si-interposer and the relative angles of two image-sensor LSIs calculated using those values are shown. All the measured relative angles of image-sensor LSIs were less than 0.179 degrees. This measurement result confirmed that sufficient precision of alignment was achieved.

Figure 7 shows, an example of a distance detection result of the experiment using the 3-D range sensor. In this example, the distance to the object is approximately 3 m. Without using any special optical lens, stable distance detection was possible. Therefore, it was confirmed that the alignment method of two image-sensor LSIs using a trench Si-interposer was effective.

5. Conclusions

We devised an alignment method of two image sensors using a Si-interposer with trenches. We produced a 3-D range sensor using this method and confirmed that sufficient alignment precision could be realized. Furthermore, stable detection performance was confirmed by a distance detection experiment. This method allowed detection distance expansion without the need to use an expensive special optic lens. Because there are few manufacturing processes and the wiring density is low, the cost of the trench Si-interposer is much lower than that of a conventional LSI.

Acknowledgement

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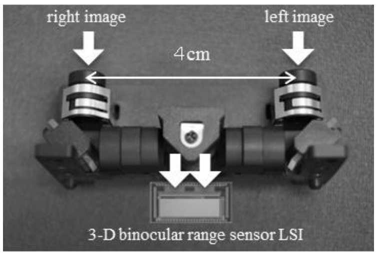

Fig. 1 Stereoscopic optical lens

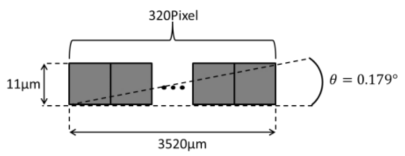

Fig. 4 Permissible maximum error of alignment

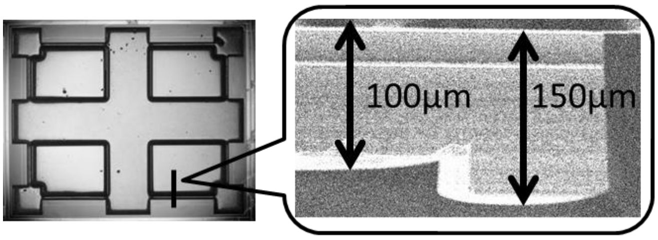

Fig. 2 Trench formed on Si-interposer

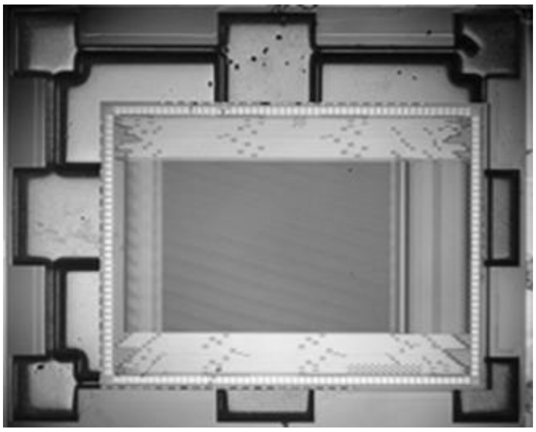

Fig. 3 Image-sensor LSI aligned using the trench

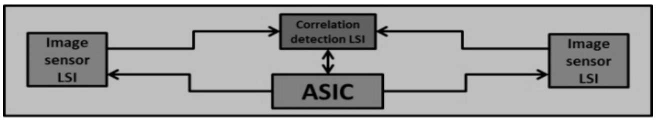

Fig. 5 3-D binocular range sensor module configuration

Fig. 6 Micrograph of the 3-D range sensor fabricated on the Si-interposer

Table 1 Measured accuracy of alignment

Relative angle of left imager	Relative angle of right imager	Relative angle of two trenchs	Relative angle of two imager LSI
-0.046 deg.	0.046 deg.	0.000 deg.	0.092 deg.
0.068 deg.	-0.007 deg.	0.001 deg.	0.074 deg.
0.025 deg.	-0.083 deg.	-0.001 deg.	0.109 deg.

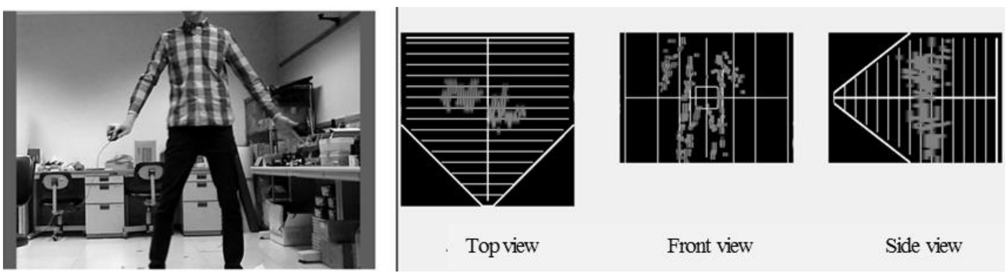

Fig. 7 Example of 3-D distance detection