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Compact Triangulation Sensor Array Constructed by Folded Wafer

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1. Introduction

Optical metrology has the advantage of the high accuracy and non-contact measuring method, and will play an important role for realizing the intelligent machines. Small and light-weighted sensor will have many kinds of usage. The micromachining can supply a method for assisting the miniaturization and assembly. For combining with the separately prepared bulk elements, the alignment guide can be included in the structure realizing the passive alignment. Up to now, the fabrication technique for constructing the compact optical setup is not fully established. This is because the difficulty of the requirement from the optics. Since distance sensors are necessary to irradiate the light beam to the sample far from the sensor, the expansion of the beam diameter due to the diffraction strongly occurs. This limits the efficiency of the light power. For reducing the diffraction, the larger beam diameter (>ϕ100μm) is essentially necessary, and this requires the larger optical element (e.g., lens, mirror) and the structure (microoptical bench). In addition, the free-space optics needs three-dimensional structures, because the path of the light propagation follows the laws of optical propagation. Realizing the mm-level three-dimensional structure having the sub-μm level fabrication compatibility is still difficult.

LIGA process is a well-known MEMS technique for preparing the deep structure. The structure height of several hundred μm and sub-μm pattern accuracy can be obtained. Oka et al. realized the triangulation sensor [1]. The structure is 500 μm deep. The triangulation path is about 1cm. Although the deeper structure will improve the optical performance, it will increase the fabrication difficulty.

Recently we have proposed the wafer folding technique for preparing the deep three-dimensional structures [2]. Since segments of the wafer are connected each other, the relative position is fixed except for the folding motion. The folding angle is arbitrary. The elements on the wafer (mirror, photodiodes, alignment guides) can be designed using the planer photomask at an unfolded condition. In this study, the triangulation 2x2 sensor array is fabricated.

2. Process

Figure 1 shows the fabrication sequence. First, PSD, Al mirror, alignment pit, and V-groove are prepared on 200μm-thick Si substrate using the standard planer lithography (step 1). The photoresist is filled inside the V-groove (step 2). Heating at the temperature greater than the glass transition temperature (>155 ^{o}C), Si wafer is folded on the jig (step 3). The jig was separately prepared using the mechanical machining. The folding angle is decided by the jig allowing the arbitrary angle. The wafer is fixed on the jig for the rigidity before using as the sensor.

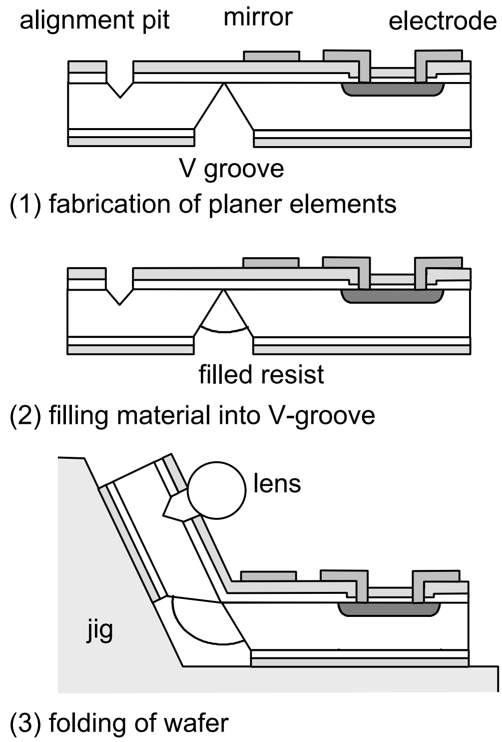

Fig. 1: Fabrication sequence.

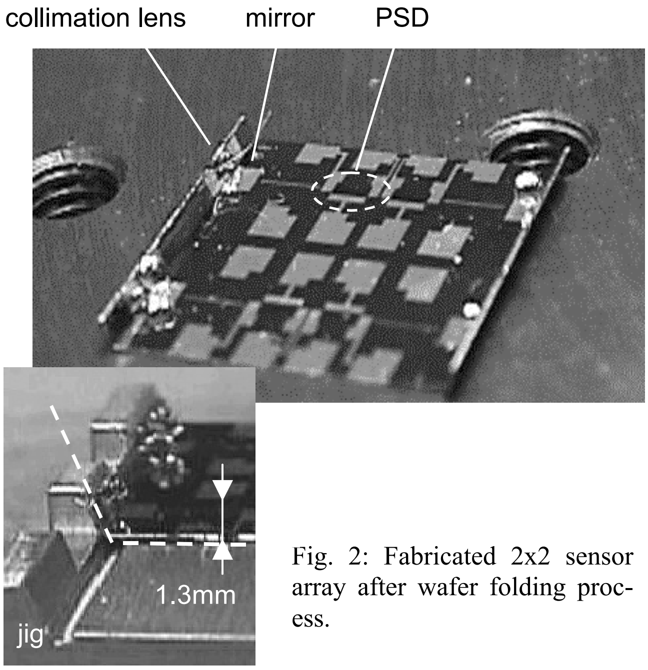

Fig. 2: Fabricated 2x2 sensor array after wafer folding process.

Figure 2 shows the image of the sensor substrate. The left and right side segments are folded up realizing the 1.3mm deep structure. The folding angle is 70 degrees. The ball lenses (ϕ1.5 and 0.8 mm) are fixed using the glue. On this wafer 2x2 sensor array is prepared. Now the LD chip is not integrated because the main aim of this study is confirming the validity. Elements (etching pit for aligning the collimation lens, mirror, and PSD) are placed on a straight line. The folding motion is near to the simple rotation. The in-plane (parasitic) rotation during the wafer folding is about 0.03 degrees [2]. The imaging lens is placed on the wafer. The wafer bonding technique will be combined in future.

3. Results

The experimental setup is shown in Fig. 3. The sample is vertically moved using the z-axis stage. The movement is measured using the contact type encoder. The can-type LD is separately positioned near to the collimation lens. The whole 2x2 sensor array unit size can be 20x18x8mm.

Figure 4 shows a typical signal using the white paper as the sample, which is considered to have the uniform scattering performance. The sample height from the sensor changes 17-30 mm. Circles are current signals obtained from two electrodes of PSD. The detected photocurrent is a few μA when 1.6 mW laser spot is incident on the sample surface. When the sample is near to the sensor, the light is collected on the PSD near to the right electrode giving the larger signal at channel 2. When the sample becomes far, the spot moves to the left electrode giving the larger signal at channel 1. The peak value obtained from channel 1 is smaller compared to that from channel 2. This will relate to the change of the collected light power due to the change of effective NA. Although the sample displacement is small, the imaging condition significantly changes, since the original size is small. The normalized signal (difference divided by sum of two signals) is expressed as the solid (black and gray color) curves showing the S-shaped curve. The data are obtained when the sample moves the round trip showing the repeatability of the value. Between two peaks of photocurrent signals from channels 1 and 2 between 20 and 24 mm, the normalized signal (corresponding to the spot position) shows the rounded curve, which is in good agreement with the curve estimated from the geometrical relation.

The accuracy of the sensor is examined. Figure 5 shows the difference between the experimental data and the fitted curve. The 4-degree of polynomial is used for fitting the data. Since the normalized signal has kinks outside of the dynamic range, the fitting is carried out at each region. The data dispersion of ±1% against the dynamic range of 4mm (from 21.5 to 25.5 mm) is confirmed.

4. Conclusions

The triangulation distance sensor is fabricated using the folded wafer. The fabrication is fundamentally batch process having the feasibility of preparing the sensor array. The confirmed sensor has the dynamic range of a few mm and % level noise. The multipoint displacement measurement is confirmed to be possible using 2 sensors in the array.

The facilities used for this research include the Venture Business Laboratory at Tohoku University.

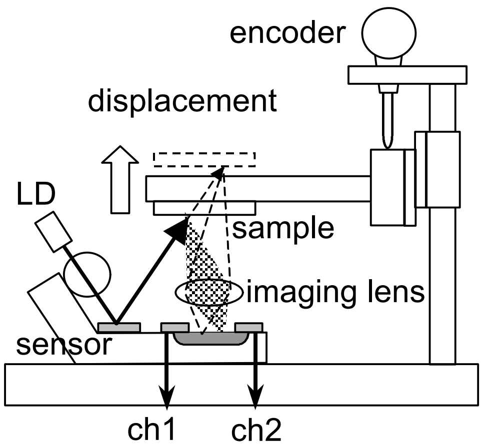

Fig. 3: Experimental setup.

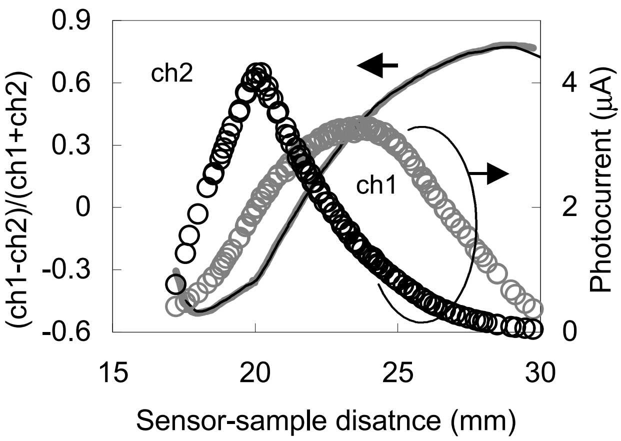

Fig. 4: Typical sensor signal when white paper is used as the sample.

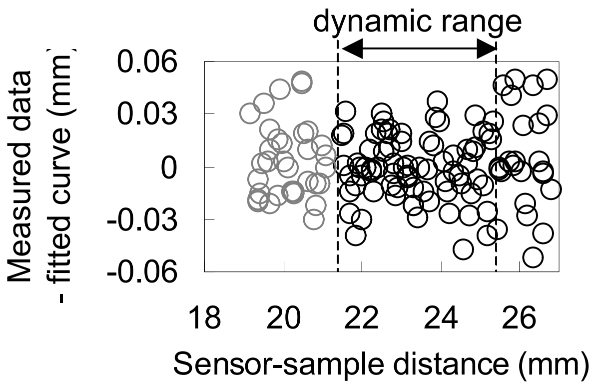

Fig. 5: Dispersion of measured data from the fitted curve.

References

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[2] M. Ishimori, J.-H. Song, M. Sasaki, K. Hane, Jpn. J. Appl. Phys. Part 1, vol. 42 (2003) pp. 4063-4066.