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POSITION AND ATTITUDE MEASUREMENT FOR MICRO MANIPULATOR BY DIFFRACTED LIGHT PROVE

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Abstract – In the present study, we investigate the removal of extremely minute materials via a micro manipulator. This operation requires measurement and control of the position and attitude of the micro manipulator at a sub-micrometer level. Therefore, a miniature instrumentation sensor having six degrees-of-freedom is necessary. We devised a technology that measures the diffracted light from minute slits formed on the micro manipulator which enables the position and attitude to be measured in six degrees-of-freedom simultaneously using only one laser light.

In the present paper, we report the result of a trial production of minute slits formed by anisotropy etching at a high forming precision. We optimized the design of this minute slits based on Fraunhofer diffraction theory. In addition, we discuss the feasibility of the proposed technology as well as the experimental results of diffracted light distribution from these slits.

Keywords: MEMS, measurement, diffracted light

1. INTRODUCTION

In the present study, we investigate the removal of foreign materials (IC: ≥0,1 μm, LCD: ≥1 μm), which has a great influence on yield in IC and LCD production. We remove foreign materials using a micro manipulator constructed using MEMS (Micro Electro Mechanical Systems) technology. In order to operate this micro manipulator precisely, the position and attitude of the manipulator must be measured. However, the dimension of the micro manipulator is on the order of several millimeters, and so the six degrees-of-freedom instrumentation device should be compact.

Generally, this application of the micro manipulator resembles the installation and adjustment of a cantilever that is used as the probe of an Atomic Force Microscope (AFM). The cantilever is constructed using MEMS technology. The position of the cantilever is adjusted in two degrees-of-freedom, such as the inclination direction [1-2]. Concretely, the cantilever can be adjusted by three-point instrumentation technology using a laser. In the present study, the measurement of six degrees-of-freedom is required for the micro manipulator. However, the scale is such that there is insufficient space in which to install several displacement sensors. Moreover when removing foreign materials, the manipulator cannot be allowed to damage the surface of the substrate. Therefore, sub-micrometer scale instrumentation technology is required. Here, miniaturization and measurement in multiple degrees-of-freedom with high accuracy are important.

We propose herein a multiple degree-of-freedom position and attitude instrumentation system using diffracted light[3-4]. First, we produce a minute slit on the manipulator and measure the distribution of diffracted light divergence when a laser is used to illuminate the slit. Because this diffracted light distribution changes according to the attitude of the slit, instrumentation of six degree-of-freedom should be possible.

In this method, miniaturization can be expected due to the requirement of only one laser. Moreover, by using the diffracted light distribution, multiple degree-of-freedom position and attitude instrumentation will be realized even though only one light source is used.

We present the result of a trial production of minute slits using anisotropy etching, which allows precise formation. We optimized the design of this minute slits based on Fraunhofer diffraction theory. In addition, we discuss the feasibility of the proposed method based on experimental results obtained using a diffracted light distribution.

2. INSTRUMENTATION OF POSITION AND ATTITUDE BY HIGH-ORDER DIFFRACTED LIGHT

In the present method, we considered the light distribution diffracted from a minute slit. The diffracted light from a straight line distributes more strongly in the cross direction. When a laser is used to illuminate a minute slit, diffracted light appears in the cross direction in the shape of a sector. This intensity distribution is formulated as grating diffraction. Grating diffraction intensity is evaluated using the following formula [5].

$$I(\nu_x) = I_o \sin c^2 (d\nu_x) \frac{1-\cos(2\pi a N \nu_x)}{1-\cos(2\pi a \nu_x)} \tag{1}$$

I : intensity $\quad \nu_x : \dfrac{x}{\lambda R}$ $\quad \lambda$: wave length $\quad R$: distance

$I_o : (\dfrac{A}{\lambda R})^2 d^2$ $\quad A$: amplitude $\quad d$: slit width

a : span of slits $\quad N$: *slit number*

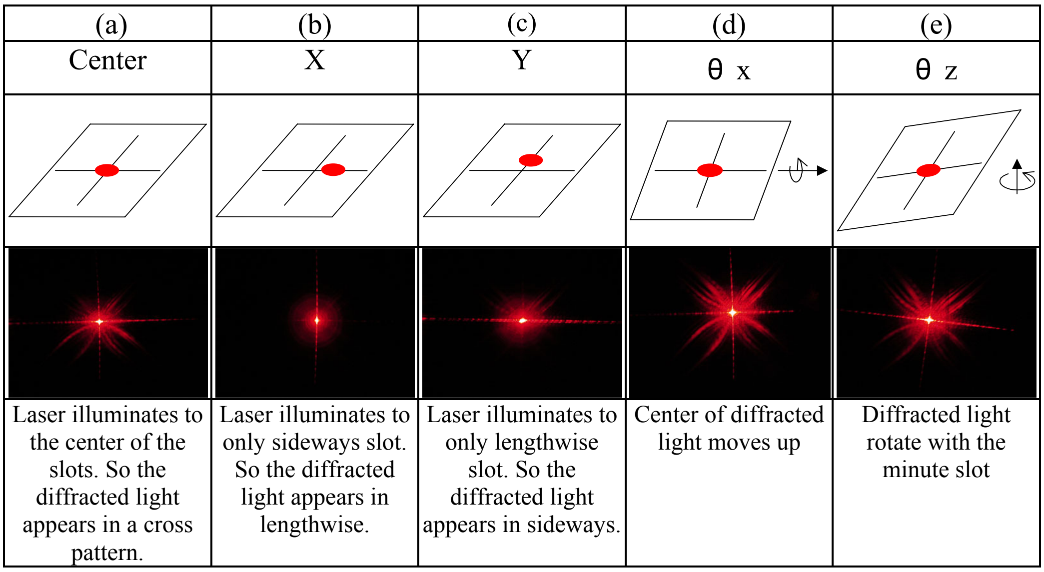


Fig.1 Changes of diffracted light

The diffraction intensity as calculated using (1) changes corresponding to the relative position and attitude between the laser illuminated spot and the minute slit. We therefore decided to detect the gradation of diffraction intensity using more than one sensor. By comparing various combinations of the detected intensities, we should be able to measure the position and attitude of the slit.

Fig.1 shows the diffracted light distribution observed on the diffusion board. We constructed two minute slits at right angles to each other. These minute slits illuminated by a laser beam (He-Ne laser, Wavelength: 633 nm, Spot diameter: approximately 1 mm). The diffracted light from the minute slit is made visible via a diffusion board. In six degrees-of-freedom, θy is not shown because its value was obtained in another evaluation. Moreover, z is not shown because the differences are too small to be observed via the naked eye. Thus, we proved that instrumentation of a multiple degree-of-freedom micro manipulator is possible if the configuration of the detectors is constructed properly (Fig.2). Fig.3 shows the specification of measurement. We therefore decided to examine the precision in detail.

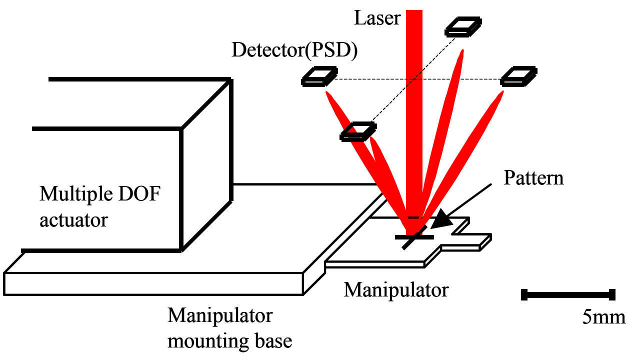


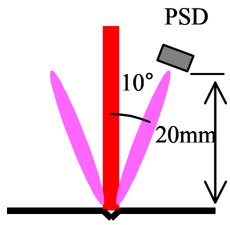
Fig.2 Schematic diagram of instrumentation

Required detection precision

(Specification from manipulator design)

x	1μm
y	1μm
z	1μm
θx	0.1°
θy	0.1°
θz	1°

x	1μm
y	1μm
z	0.2μm
θx	35μm
θy	35μm



Displacement of spot position on PSD

Fig.3 Specification of measurement

3. EVALUATION RESULTS OF ANGLE MEASUREMENT

Fig.4 shows the schematic diagram of this experimental device. Using this device, the angle precision was evaluated as shown Fig.5. This experimental results satisfied the target accuracy (0.1°) in the direction of side:V. But in the case of side:H accuracy is not enough. Because distribution of diffracted light is not sharp figure. So PSD can't detect the movement precisely. So we improved the profile of diffracted light prove using grating diffraction (1).

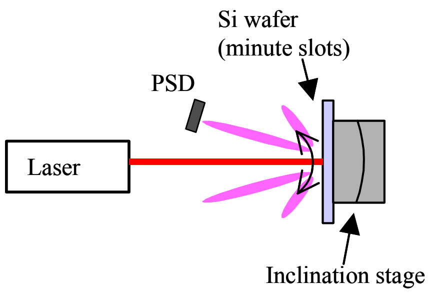
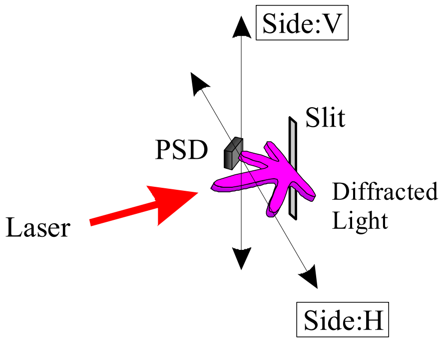


Fig.4 Angle measurement experiment



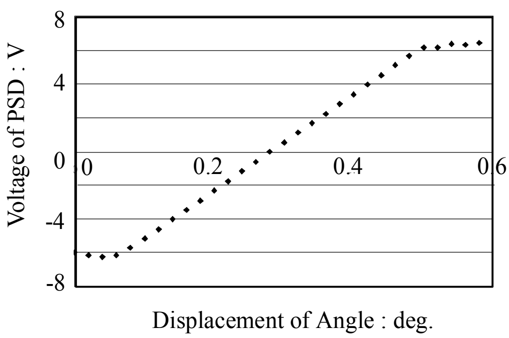


Fig.5 Angle displacement measurement precision

4. OPTIMIZATION OF MINUTE SLITS USING FRAUNHOFER DIFFRACTION EQUATION

Fig.7 shows the parameters of Fraunhofer diffraction equation. We paid attention to 3 parameters, such as width of minute slots, span of minute slots and number of minute slots. These parameters effect the distribution of diffracted light like this as shows in Fig.8. If width of minute slots is narrower, the intensity of diffracted light is generally higher. We can use the 1st order of diffracted light as light probe. So this is effective to improve the S/N. And if the span of minute slits is narrower, the span of light prove is wider. This span of optical-prove means the measurement range. Because PSD can recognize the only one optical-probe. So if there are two or more number of optical probe in PSD plane, we can't get proper optical-probe position. And if number of slots is lager, shape of optical-probe is made to be sharp. So we can expect the high precise measurement of optical-probe displacement.

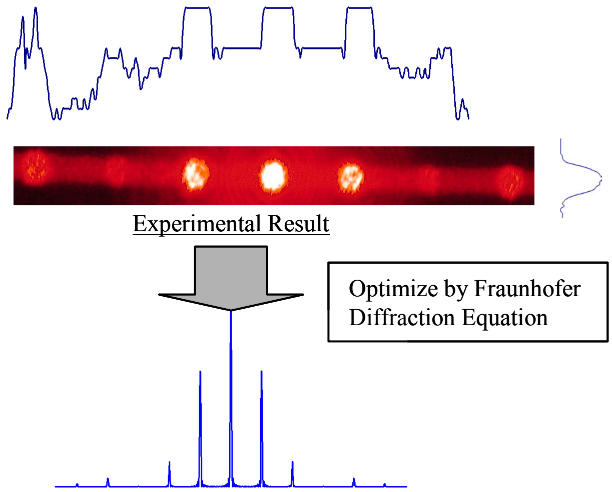
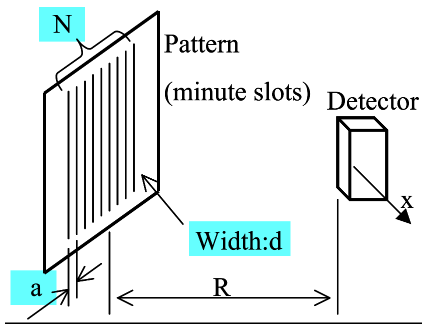


Fig.6 Distribution of diffracted light at Side: V



R	Distance from pattern to detector
A	Amplitude of laser lay
λ	Wave length of laser lay
x	Coordinate
D	Width of minute slots
a	Span of minutes slots
N	Number of minute slots

Fig.7 Parameters of Fraunhofer diffraction equation

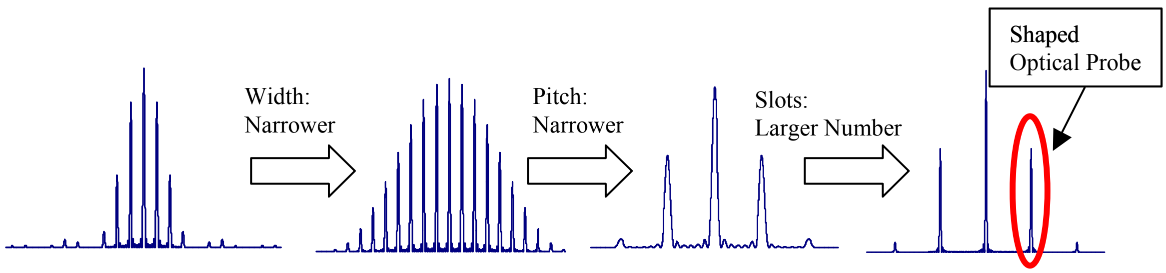


Fig.8 Effect of selected parameters to distribution of diffracted light

Fig.9 shows an example of numerical analysis result. N means the number of slit. This example shows the effect of number of slit. As we mentioned before, the shape of optical-probe can be made to be sharp figure.As this result, slit number and width and span can optimize the figure of optical-probe. Fig.10 shows the experimental results of diffracted light distribution. This Fraunhofer diffraction model is for transmissive slits. And in this proposed method, this slit pattern is reflective type. But we can confirm that this Fraunhofer diffraction equation can be adaptable for this proposed method in optimization.

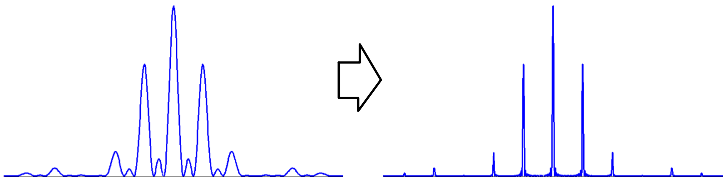


Fig.9 Improvement of Diffracted Optical Prove.

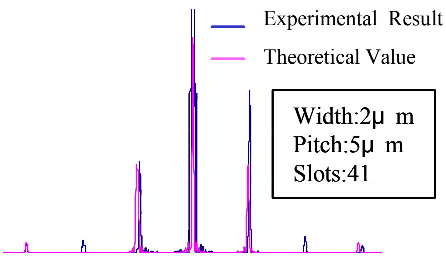


Fig.10 Experimental result of distribution of diffracted light

5. EXPERIMENTAL RESULT OF HORIZONTAL DISPLACEMENT MEASUREMENT

Fig.11 shows the schematic diagram of experimental device for horizontal displacement. In this experiment, we used the CCD camera as detector. Because we wanted to know the profile of optical-probe. So, in this experiment, the position of optical-probe was calculated as barycenter of an pixcel-area of CCD. The precision is 0.5 μm and this results satisfy the target value.

6. CONCLUSIONS

The purpose of the present study was high-accuracy instrumentation of a six degree-of-freedom micro manipulator. We devised a method by which to measure the diffracted light distribution from minute slits on the micro manipulator surface.

1. Measurement of six degrees-of-freedom via the diffracted light distribution appearing from perpendicular minute slits was performed.
2. We confirmed that changes in the diffracted light distribution correspond to the position and the attitude of the slit.
3. This minute slits is optimized by Fraunhofer diffracted equation.

Using this optimized minute slits, we can confirm that experimental results of displacement measurement precision satisfy the target specification. Now we proceed the next experiment. In this study, we are checking the 6 DOF displacement measurement precision.

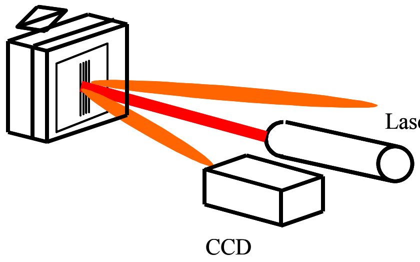


Fig.11 Experimental device for horizontal displacement measurement

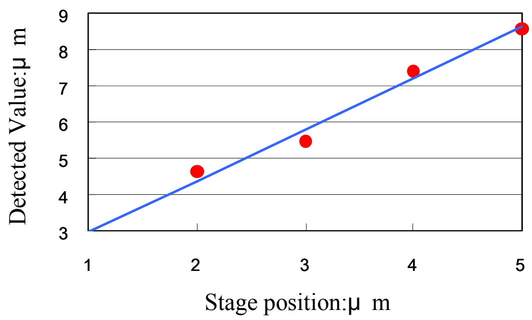


Fig.12 Experimental result of horizontal displacement measurement

REFERENCES

[1] G.. Binning, C. F. Quate and Ch. Gerber, Phys. Rev. Lett., 56, p.930 ,1986.
[2] M. Shiba, K. Fukuda, Y. Hira and H, Sato, “Study on Wafer Inclination Measurement Technique using Linear Grating Coupler”, Journal of the Japan Society for Precision Engineering, Vol.61, No.6, pp.859-863 ,1995.
[3]Y.Yokomizo,I.Ishimaru,G.Hashiguchi,Y.Mihara,"Proposal of Positioning Method for Nano-particle manipurator",Proc. of 2002 Japan-USA Symposium on Flexible Automation,pp363-366(2002)
[4] Y.Yokomizo,H.Kobayashi,I.Ishimaru,G.Hashiguchi,"6 DOF Instrumentation technology for MEMS ",Extended abstracts The Optical Society of Japan,pp24-25(2002)
[5] M. Born and E. Wolf, “Principles of Optics”, TOKAI UNIVERSITY PRESS, pp.583-589,1975.

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