Silicon Micromachined Two-Dimensional Galvano Optical Scanner

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***Abstract*— A new two-dimensional galvano optical scanner realized by silicon micromachining is proposed. To realize two-dimensional operation a silicon micromachined gimbal structure was introduced. It is possible to sense rotational angle using electromagnetic coupling between driving coil and fixed detecting coil.**

I. INTRODUCTION

Fabrication of small sized and sophisticated laser scanning system can be easily realized by silicon micromachining. Two dimensional operation is achieved by a gimbal structure fabricated by silicon etching. The surface of the reflecting mirror is placed at the same level with the rotational axis, allowing a steady reflecting point. Precise optical instrumentation can be realized using this scanner. Improvement of response time is also expected because of the reduced inertial mass of moving parts.

Electromagnetic actuation and electrostatic actuation are available. Various electromagnetic microactuators using silicon micromachining technique have been developed [1]-[6]. As electromagnetic actuation has the advantage of large deflection and linearity, electromagnetic driving and detection was choosen. When this scanner is driven by large current, heat generation may become a serious problem to be overcome.

II. PRINCIPLE

Fig.1 shows the principle of the proposed new scanner and built-in angle detector. The movement of the mirror is achieved by electromagnetic drive. Lorentz force is controlled easily by the direction and amplitude of the current flowing in the driving coil fabricated on the driving plate. The driving coil is also used for detecting the rotational angle.

Lorentz force vector **F** is given by :

$$\mathbf{F} = \boldsymbol{i} \times \mathbf{B}$$

where, $\boldsymbol{i}$ is current density vector and **B** is the magnetic flux density vector produced by permanent magnets. A torque T can be generated by the opposite directional Lorentz force on both sides of the torsion bar. The rotational angle ϕ is given by :

$$\phi = \mathrm{T} / k$$

where k, the spring constant of torsion, is expressed as :

$$k = \mathrm{G}\,\mathrm{Ip} / l.$$

G is shear modulus, Ip is the polar second moment of area

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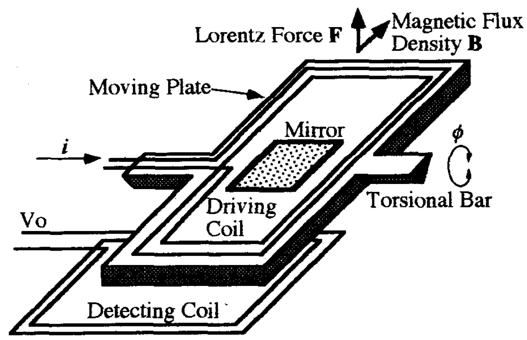

Fig.1 Principle of the proposed new scanner and built-in angle detector.

and l is the length of the torsion bar.

Resonant angular frequency ω is expressed by

$$\omega = \sqrt{k / \mathrm{J}}$$

where, J is the inertial momentum.

Neumann's formula of mutual inductance is expressed by

$$\mathrm{M} = \frac{\mu_0}{4\pi}\oint\oint\frac{ds_1 ds_2}{r}$$

where M is the mutual inductance between the driving coil and the detecting coil, μ_0 is vacuum permeability, ds_1 ds_2 are differential elements of driving coil and detecting coil and r is distance between ds_1 and ds_2. The Neumann's formula shows that mutual inductance depends on the distance between two coils. A high frequency detecting current is applied to the driving coil inducing a voltage Vo in the fixed detecting coil placed underneath.

III. FABRICATION

Fig.2 shows the structure of the two-dimensional galvano optical scanner. (100)-oriented, double side polished, 200μm thick silicon wafers and 200μm thick Pyrex glasses were used. Bulk silicon micromachining was performed by wet etching in hydrazine. Fig.3 show the phtograph of the fabricated device.

The both driving and detecting coils were formed thick (16μm) by electroplating of copper using photoresist as a mold in order to reduce the Joule heat generation. Coils are formed on the X-axis plate and Y-axis plate of the gimbal. The X-axis driving coil has 7 turns and a resistance of 5.2Ω. The Y-axis driving coil has 14 turns and a resistance of 7.4Ω. The X-axis and Y-axis detecting coils have 14 turns and a resistance of 10.4Ω. The line/space width of coils was 50μm.

Commercial Sm-Co magnets (DM-20, Seiko Electronic Components Ltd., Sendai, Japan) have a magnetization of 0.88T . Dimension of magnets were 6 x 4 x 2.5mm^3.

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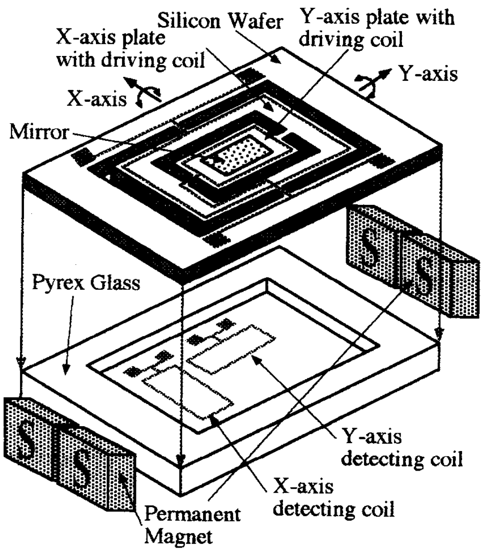

Fig.2 Structure of two-dimensional galvano optical scanner.

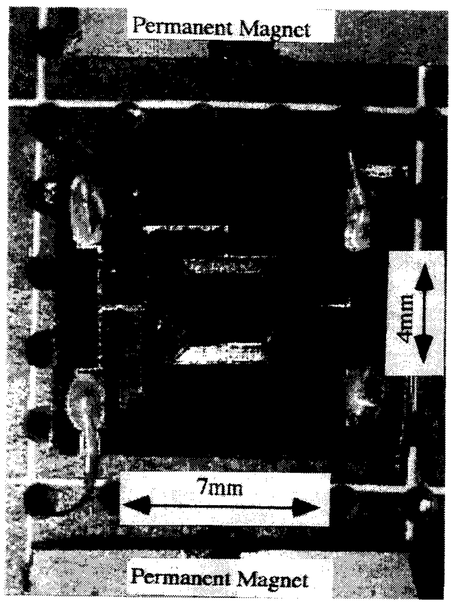

Fig.3 Photograph of fabricated scanner.

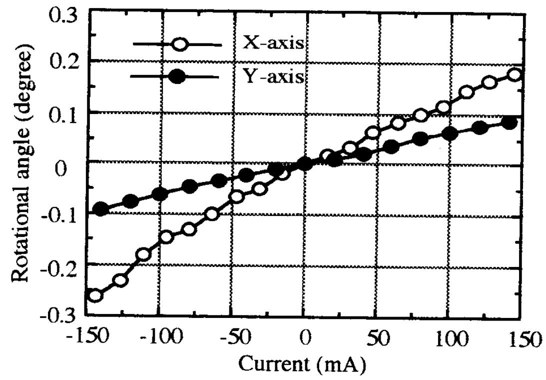

Fig.4 Dependence of the rotational angle on the applied DC current.

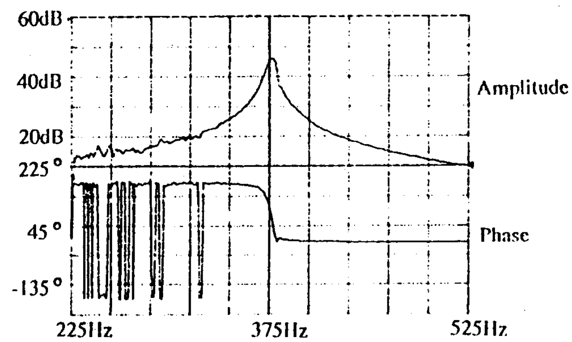

Fig.5 Frequency characteristic of deflection in X-axis.

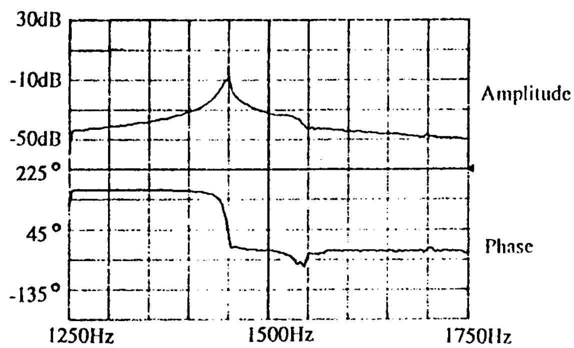

Fig.5 Frequency characteristic of deflection in Y-axis.

The outer dimension of the X-axis plate is 7 x 7mm^2. The dimension of the Y-axis plate is 4 x 4mm^2. The torsion bar has a length of 500μm. The cross section of the torsion bar is a triangle with the hight of 50μm and the base of 250μm.

IV. EXPERIMENTAL RESULTS AND DISCUSSION

The static deflection was measured using a focus calibrated microscope. Fig.4 shows the dependence of the rotational angle on the applied DC current. Spring constants evaluated from above results were 6.48 x 10^{-4} Nm for the X-axis and 12.8 x 10^{-4} Nm for the Y-axis.

The frequency characteristic was measured at 1 atm. using an optical position sensor and a network analyzer. Fig.5 and 6 show the results for the X-axis and the Y-axis deflection respectively. The measured resonant frequencies were 380Hz for the X-axis and 1450Hz for the Y-axis.

The dynamic deflection at resonant frequency was measured

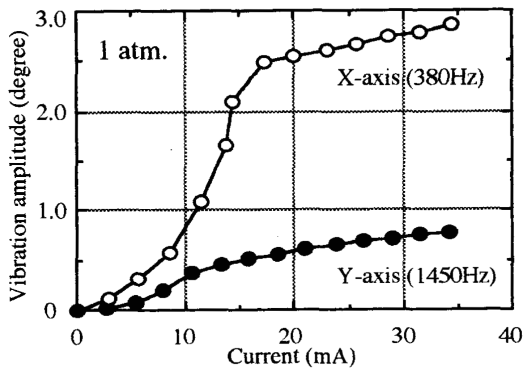

Fig.7 Dependence of vibration amplitude on applied AC current at resonant frequency.

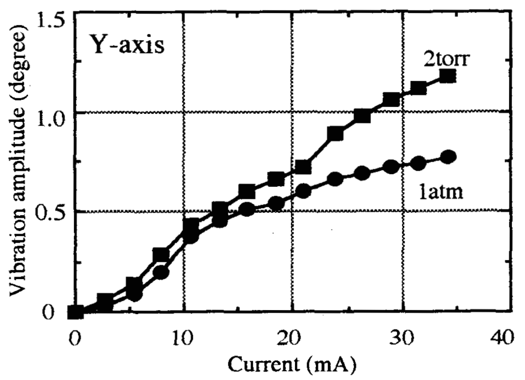

Fig.8 Dependence of vibration amplitude on applied AC current at resonant frequency in vaccum and atmosphic pressure.

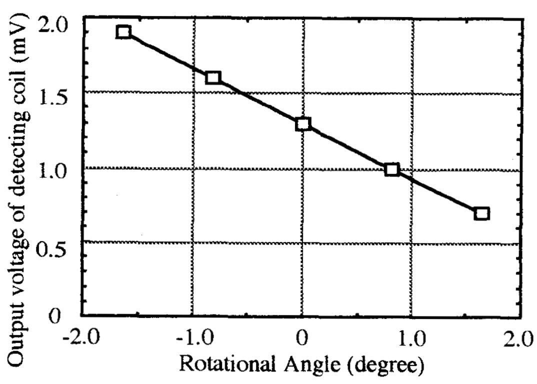

Fig.9 Relation between rotational angle and output voltage of detecting coil.

using a laser beam and a position sensitive device (S3932, Hamamatsu Photonics Ltd., Hamamatsu, Japan) at 1 atm. Fig.7 shows the dependence of vibration amplitude on the applied AC current. The X-axis plot is a somewhat parabolic up to 2 degrees. This phenomenon is not clearly explained at this stage. It may be caused by stress of torsinal bar. The vibration amplitude was saturated by air damping.

The dynamic deflection was also measured in vacuum (Fig.8). The vibration amplitude was not saturated. Therefore, by the vacuum packaging method presented in [7], a linear relation of amplitude-current can be obtained.

The relation between rotational angle and output voltage Vo of detecting coil is presented in Fig.9. The detection was realized by a high frequency current (1MHz, 100mA) applied to the driving coil. This frequency is much larger than the mechanical resonant frequency.

V. Conclusion

A two-dimensional galvano optical scanner realized as a silicon micromachined gimbal structure was fabricated and tested. For closed loop operation perposes the scanner has a built-in electromagnetic detector of the rotational angle. To increase scanning amplitude, the spring constant of the torsion bar can be reduced, but this is with a trade-off of the frequency response.

Acknowledgment

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