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# Fabrication of Electrostatic Actuated Rotary for Micro Interferometer

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## 1. Introduction

The chemical information of materials can be obtained by Fourier Transform Infrared (FTIR) spectroscopy with a Michelson interferometer. The FTIR spectrometers have been used for the qualitative and quantitative analyses of liquid, solid and gaseous substances. Recently, some miniaturized near infrared spectrometers are already commercially available, and Fourier Transform (FT) spectrometers have been studied for the near infrared wavelength range [1, 2]. However, the wavelength range of near infrared is not broad enough for measurements of environment gases due to the vibration wavelength of the most molecules have absorption line in mid-infrared wavelength range. Also, the ppt (parts per trillion) sensitivity can be obtained using FT spectroscopy with mid-infrared because it has a strong resonance lines unlike absorption lines at the near infrared range. Therefore, if the FT spectroscopy for mid-infrared wavelength range be miniaturized, the environment gases can be easily monitored for safety applications, for example, at factories and chemical plants. We designed and fabricated a miniaturized "wishbone" interferometer with electrostatic rotary comb drive actuators for FT Spectroscopy with mid-infrared wavelength range.

## 2. Device design and Fabrication

A schematic of the electrostatic actuated rotary device and the basic concept of FTIR spectroscopy with a "wishbone" interferometer are shown in Fig.1. In the FTIR spectroscopy, the intensity variation of interfered wave of the introduced infrared light is measured as a function of the optical path difference. The optical path difference is generated during actuation of the corner cube mirror when rotary comb drives are working by electrostatic force. Comb drives provide a rotational torque with electrostatic forces at the overlapped area of comb fingers when a voltage is applied to the comb fingers.

The device consists of four sets of rotary comb drives and four springs that are connected to the ring located at the center. The four springs from the anchors support the center ring. The ring is designed to be stiff enough to escape form deformation when the comb drive is working. The corner cube mirror is mounted at the end of the rotary comb drives. The "wishbone" interferometer is deigned to be the maximum optical path difference of 1.2 mm at 5˚ rotation angle.

The Si interferometer is formed on a glass support. The rotary comb drive part and its support part are fabricated separately. Finally, both parts are bonded together. The rotary comb drive and support part are fabricated from a (100) n-type Si and Pyrex glass, respectively. At first, 300-nm-thick $SiO_2$ was formed on 200-μm-thick Si wafer by thermal oxidation. Then, $SiO_2$ is etched by a buffered HF solution. After photolithography processes, the back and top sides were etched in 150 μm depth by ICP-RIE (Inductively Coupled Plasma Reactive Ion Etching). To form the comb fingers and the springs, the remained 50-μm-thick Si is etched with ICP-RIE etching. The device structure is formed by ICP-RIE using $SiO_2$ as a mask. In order to define fine comb drive structure, Si was partly thinned from back side using ICP-RIE. The Pyrex glass is patterned by sandblast using dry film resist mask. After that, both Si and glass is bonded together using anodic bonding. Finally, Al was evaporated on the top to make electrodes.

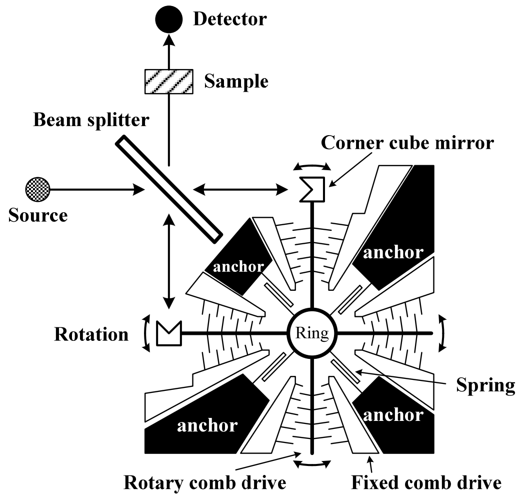



Fig.1 Schematic of miniature a "wishbone" interferometer with rotary comb drive

The size of fabricated device is 6.8 mm × 6.8 mm and geometric parameters of comb fingers and spring are showing the Table I.

Table I Design parameters of the electrostatic rotary comb drive

| | |
|---|---|
| Number of comb drive, *x* | 4 |
| Number of comb fingers, *n* | 47 |
| Gap between comb fingers, *g* | 10 μm |
| Comb fingers and spring thickness, *t* and *h* | 50 μm |
| Spring width, *w* | 5 μm |
| Total spring length, *L* | 2550 μm |
| Ring radius, *R* | 100 μm |

## 3. Electrostatic Rotary Comb Drive

The rotation angle of device depends on the spring constant of comb drive and electrostatic force.

The electrostatic torque $T_E$ for rotation is generated when a voltage is applied to comb drives. With a small rotation angle $\theta$, $T_E$ can be given as a function of the applied voltage $V$,

$$T_E = \frac{\partial C}{2\partial\theta}V^2 \;\; ; \;\; \frac{\partial C}{\partial\theta} = \frac{2nx\varepsilon_0 t r_{ave}}{g}, \quad (1)$$

Where $C$, $r_{ave}$, $n$, $x$, $\varepsilon_0$, $g$ and $t$ are the total capacitance, the average of the radial distance between the movable comb fingers and the center ring, the number of the movable comb fingers, the number of the rotary comb drivers, the permittivity of the vacuum ($8.85 \times 10^{-12}$ F), separated distance and thickness of comb fingers, respectively.

When the center ring rotates by an electrostatic torque $T_E$, a mechanical torque $T_M$ is generated by the springs. The mechanical torque $T_M$ is given by

$$T_M = k_m\theta. \quad (2)$$

This is a Hooke's law with a rotational mechanical spring constant $k_m$. The spring constant in a small rotation angle is calculated as follows.

$$k_m = \frac{2EI(2L+3R)}{L^2}, \quad (3)$$

where $L$, $E$, $R$ and $I$ are total spring length, Young's modulus, ring radius and moment of inertia, respectively [3]. Here, the moment of inertia $I$ is given by $w^3h/12$ where $w$, $h$ is spring width and spring thickness.

When the electrostatic torque $T_E$ and mechanical torque $T_M$ are equal, the device is in static equilibrium. Therefore, from Eq. 1 and Eq. 2, the relationship of the applied voltage and the rotation angle of the comb drive can be obtained.

## 4. Experimental results

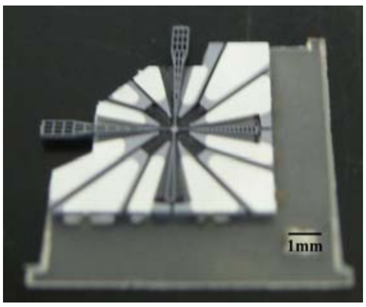
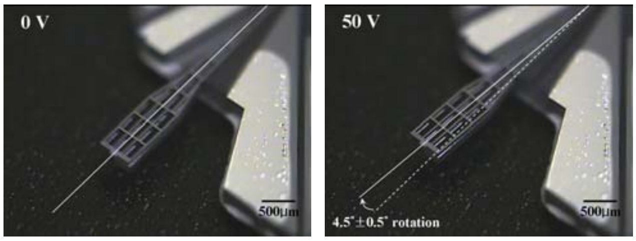



Fig. 2 Optical photo of the electrostatic actuated rotary drive

Figure 2 is the optical photo of the fabricated electrostatic rotary comb drive. The comb drive was evaluated by applying a voltage between 0 V and 50 V. The rotation angle of the rotary comb drive is measured by using a microscope at different applied voltages as showing in Figure 3. At an applied voltage of 50 V, the rotation angle of rotary comb drive is 4.5˚ ± 0.5˚ but the moving comb fingers seemed to be attached to the fixed fingers.




(a) (b)

Fig. 3 Demonstrated activation at (a) 0V and (b) 50 V

Figure 4 shows the theoretical and experimental rotation angles as a function of applied voltage. The experimental results are consistent with the theoretical result. The movement distance of corner cube mirror is 300 µm when the rotation angle of rotary comb drive is 4.5˚ ± 0.5˚ and the maximum optical path difference of 1.2 mm can be achieved. The theoretical resolution of the FTIR spectroscopy with "wishbone" interferometer is estimated to be 8.3 $cm^{-1}$.

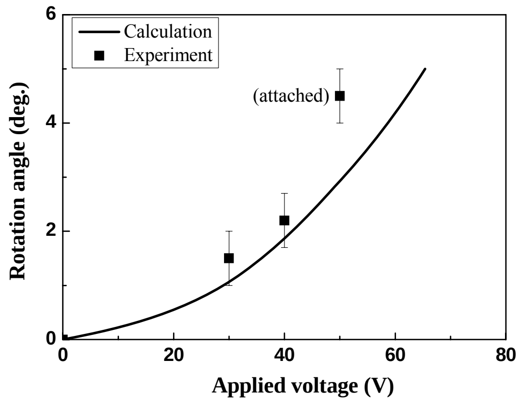



Fig. 4 Rotation angle versus the applied voltage

## 5. Conclusions

We designed and fabricated miniature interferometer with electrostatic comb drive actuators and successfully demonstrate the rotary motion. The fabricated device has a size of 6.8 mm × 6.8 mm. The maximum rotation angle 4.5˚ ± 0.5˚ was obtained with an applied voltage of 50 V. The maximum optical path difference of 1.2 mm for FTIR spectroscopy can be achieved.

## References

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