Surface Acoustic Wave Motor with Flat Plane Slider

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Abstract:
A flat plane slider for a surface acoustic wave (SAW) motor has been enabled by using a chemically reduced lithium niobate stator. Since a slider with no projections or the flat plane slider can drive with higher preload than a slider with projections, it is expected to obtain a higher output force. In this paper, driving properties such as a no-load speed characteristic and output force characteristic of the flat plane slider was measured. The SAW motor with the flat plane slider achieved 18 N high output force and 0.9 m/s no-load speed.

1. INTRODUCTION
A surface acoustic wave (SAW) motor is a traveling wave type ultrasonic linear motor which uses the Rayleigh wave, a kind of SAW, for friction drive. Since a driving frequency of the SAW motor, approximately 10 MHz, is much higher than other ultrasonic motors, amplitude of Rayleigh wave is nanometer level. Therefore, the SAW motor was reported; high speed, high output force and high resonance specific were achieved. In the past papers, 10 N output force, 1.5 m/s no-load speed and 0.5 nm stepping motions were reported [1, 2].

To date, the SAW motor, especially a slider has been developed to realize a stable drive and higher output force. At the beginning of the SAW motor research, three ruby balls were used for a slider to obtain a high contact pressure at a contact area [3]. Then, many steel balls were used to obtain higher output force [4]. Furthermore, by introducing silicon micro machining process, silicon sliders that have many minute projections have been used for the SAW motor [5].

In the past research, parameters of the projections, such as a diameter of projections or distance between projections, were examined for the sake of higher speed or higher output force [6]. Then, it was developed that the smaller projections and the higher density of projections bring about better driving properties. When making the projection density to the limit, finally a flat plane is an ultimate geometry. Therefore, the flat plane slider will improve the driving properties of the SAW motor.

However, the projections have realized high contact pressure for the friction drive and a good contact condition between the stator and the slider. It was reported that the flat plane slider is difficult to achieve a stable drive [7]. To improve the driving stability, by utilizing a chemically reduced lithium niobate stator, driving experiment of the flat plane slider was carried out.

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Figure 1: Schematic view of surface acoustic wave motor.

Figure 2: Schematic view of frictional force at contact area.

2. PRINCIPLE
The SAW motor is composed of a stator and a slider, as illustrated in Figure 1. The stator, which is made of a lithium niobate, has interdigital transducers (IDTs) at both ends. When a RF electrical power is inputted to the IDT, the propagating Rayleigh wave is generated on the stator by the piezoelectric effect. The propagating Rayleigh wave energy is transferred to a slider motion through frictional force [8].

Details of the friction drive are shown in Figure 2. A particle movement of the stator is elliptic vibration. When the slider is putted on the stator with pre-load, the slider is driven to the opposite direction of the traveling wave by the frictional force as Figure 2. The output force of the SAW motor is obtained through the frictional force.

The slider is made of silicon. Up to now, many micro projections have been fabricated on the contact surface by
dry etching process, as shown in Figure 3. Through these projections, a high contact pressure for the friction drive has been obtained and a good contact condition between the stator and the slider has been realized. However, the flat plane slider could not drive stably. From an analysis of a friction drive mechanism [9]-[13], it was found that the root cause of the unstable drive was a charge occurred at the contact area between the slider and the stator during the actuation. Therefore, by utilizing the chemically reduced lithium niobate, which has increased electric conductivity on the order of $10^4$ as compared with that of normal lithium niobate, the flat plane slider can drive stably.

3. EXPERIMENTAL SETUP

The stator was a 60x15x1 mm³ rectangular plate of chemically reduced 128 degrees y-rotated x-propagation lithium niobate, shown in Figure 4. IDTs are fabricated at the both end of the stator by means of the vacuum vapor deposition. The materials of the electrode for the IDT were chromium and aluminum. The IDT was composed of 20 strip electrode pairs, and the dimensions of the IDT were...
400 µm in pitch, 100 µm in electrode strip width, 100 µm in electrode strip space and 9 mm in aperture. From the dimensions of the electrode, the resonance frequency of the IDT was 9.61 MHz.

The flat plane slider was a square plate of silicon substrate. The dimensions of the slider were 5x5x0.5 mm³. In this paper, not only the flat plane slider but the silicon slider with projections, shown in Figure 3, was used on account of a comparison with the flat plane slider. The slider with projections used for driving experiments was the same dimensions as that of the flat plane slider. The projections were fabricated in a 4x4 mm² central square region of the surface by means of the dry-etching process. The dimensions of the cylindrical projections were 10 µm in diameter and 2 µm in height, and arranged at a 20 µm pitch.

A photograph of an experimental setup of the SAW motor is shown in Figure 5. The motor consists of a fixed part and a movable part. The fixed part is composed of the stator and a linear guide rail. The stator is fixed in a steel jig, and the linear guide rail is fixed to a steel block. The movable part is composed of the slider, a slider block and a linear guide rail. The total weight of the movable part was 2.0 g.
A photograph of the slider block is shown in Figure 6. The slider block was glued with epoxy resin onto the slider. To prevent a stress concentration at the edge of the flat plane slider, the slider block was designed; the dimensions of the contact area between the slider and the slider block were 4x4 mm$^2$. Hence, the effective contact area between the slider and the stator was 4x4 mm$^2$, which was the same as that of the slider with projections. The upper side of the slider block was shaped into a sphere, as shown in Figure 6. The sphere part of the slider block was put into a washer, which was glued with epoxy resin onto the linear guide block. A connection between the sphere part of the slider block and the washer achieves a parallel contact between the slider surface and the stator surface.

The preload of the slider was provided by a coil spring. Figure 7 shows a photograph of the experimental setup. The coil spring was connected to a micrometer. Therefore, the preload of the slider could be adjusted easily by a rotation of the micrometer head. In this experiment, the preload was adjusted from 10 N to 120 N.

4. EXPERIMENTAL RESULT

4.1 Particle Velocity of Stator

The performance of the SAW motor, especially the no-load speed, depends on the particle movement on the stator surface. A particle velocity of the chemically reduced lithium niobate stator was measured.

The horizontal vibration velocity $v_H$ is given by,

$$v_H = 2\pi f A_H$$

where $f$ and $A_H$ denote the driving frequency and the horizontal vibration amplitude. Then, the horizontal vibration amplitude of the particle on the stator surface is decided by the vertical vibration amplitude from the shape of the particle motion. Hence, the horizontal vibration velocity can be estimated from the vertical vibration amplitude.

The vertical vibration amplitude of the Rayleigh wave against the driving voltage at the center of the stator was measured by a laser Doppler vibrometer as illustrated in Figure 8. The experimental result is shown in Figure 9. The vibration amplitude was 25 nm at 125 Vpeak driving voltage, and the horizontal vibration velocity was estimated to be about 1.3 m/s at 125 Vpeak driving voltage.

4.2 Transient Responses

To examine the speed responses of the motor using the flat plane slider, the transient responses of the motor were measured by the laser Doppler vibrometer. The transient responses of the flat plane slider are shown in Figure 10. The preload was 20 N and the driving voltage was changed from 35 Vpeak to 125 Vpeak. The speed depends on the driving voltage, since the horizontal vibration velocity on the stator surface is proportion to the driving voltage as shown in Figure 9.

The maximum speed of the flat plane slider was 0.81 m/s at 125 Vpeak driving voltage. The minimum driving voltage
required for the actuation was 35 V peak with 20 N preload. For a comparison, the transient responses of the slider with projections, explained in the experimental setup, were also measured, shown in Figure 11. The maximum speed of the slider with projections was 0.95 m/s and the minimum driving voltage was 30 V peak. The speed differences between the flat plane slider and the slider with projections were under 20%. From Figures 10 and 11, it is found that the flat plane slider could obtain similar speed responses to that of the slider with projections.

4.3 Driving Characteristics

From the transient responses of the motor as shown in Figures 10 and 11, mechanical outputs such as a no-load speed and an output force were examined. The no-load speed can be estimated from the saturated speed of the transient response. The output force can be calculated from the rise acceleration of the transient response and the movable part weight of 2.0 g.

The no-load speed of the flat plane slider and the slider with projections is shown in Figure 12. The preload was changed from 10 N to 120 N. The driving voltage was 125 V peak so that the horizontal vibration velocity on the stator surface was about 1.3 m/s from Figure 9. The no-load speed of the flat plane slider and the slider with projections decreased with increasing the preload. Although the no-load speed of the flat plane slider was lower than that of the slider with projections with less than 70 N preload, the flat plane slider was faster than the slider with projections with more than 70 N preload. The maximum no-load speed of the flat plane slider was 0.90 m/s with 10 N preload, namely, about 69 % of the vibration velocity of 1.3 m/s, while the maximum no-load speed of the slider with projections was 0.93 m/s with 10 N preload, namely, about 72 % of the vibration velocity of 1.3 m/s. It was found that the no-load speed characteristics of the flat plane slider and the slider with projections were almost same.

The output force of the flat plane slider and the slider with projections is shown in Figure 13. The output force was calculated from the same transient responses of those of the no-load speed experiment. Less than 60 N preload, the output force of the flat plane slider and the slider with projections were almost same, and increased with increasing the preload. More than 60 N preload, the output force of the flat plane slider was higher than that of the slider with projections. The maximum output force of the flat plane slider was 18 N with 120 N, which was twice or more as high as that of the slider with projections. From the output force characteristic in Figure 13, the optimum preload for the maximum output force of the slider with projections was about 100 N. However, the optimum preload for the maximum output force of the flat plane slider was higher than 120 N. Hence, the flat plane slider is expected to obtain still higher output force with over 120 N.

5. CONCLUSION

The performances of the SAW motor with the flat plane slider were examined. The flat plane slider could drive stably by using the chemically reduced lithium niobate for the stator. The flat plane slider achieved 18 N output force.
at 125 V_{peak} driving voltage with 120 N preload, which was about twice as high as that of the slider with projections. The no-load speed of the flat plane slider was 0.9 m/s at 125 V_{peak} driving voltage, which was about 69% of the vibration velocity of 1.3 m/s.

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REFERENCES