ULTRASONIC MOTOR USING SURFACE ACOUSTIC WAVE DEVICE

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ABSTRACT

We have proposed HF band (3-30 MHz) and higher frequency surface acoustic wave motors and demonstrated its possibility. With a stator transducer of 15x60x1 mm^3 operating at 9.6 MHz, no-load speed of 1 m/s and maximum output force of 10 N were obtained. With burst drive of 200 μs intervals and 4 μs driving period, each stepping motion of the slider about 8 nm was observed. The surface acoustic wave motor has potential to be high performance small linear motion actuator that is fabricated with surface micro machining process.

INTRODUCTION

A stator transducer of surface acoustic wave motor is a surface acoustic wave device that is widely utilized in communication instrument signal processing circuit for filtering [1]. The driving force of the motor is elastic wave motion of the surface acoustic wave device. Through the frictional force between stator surface and slider surface, mechanical output force in uni-direction is converted from vibration [2]. A slider has a lot of contacting circular projections on its surface to control contact condition between the slider and the stator [3]-[6].

For saving the driving electric power, energy circulation driving method has been investigated [7]. Newly designed stator transducer was fabricated. In order to save the space of the interdigital transducers (IDTs), the driving frequency was slightly changed up to about 14 MHz. With this driving method, the highest vibration velocity of 3 m/s has been accomplished with the driving power about 30 W. The driving power was reduced a sixth of single IDT driving method. The no-load speed and output force was measured at lower driving power than without circulation. Performance of the motor was tested higher driving power we have already reported [7].

Nano meter order stepping motion of this motor was also examined. With burst drive [8],[9] of 200 μs intervals and 4 μs driving period, each stepping motion of the slider about 8 nm was observed. Possibility of sub nano step motion is discussed.

The surface acoustic wave motor is small and miniaturizable linear motor. The working distance is more than 1 cm, however the fine stepping motion is nano meter order and will be sub nano meter range. Furthermore, quick response is available because the thrust is very large in spite of its stator transducer is small and thin.

PRINCIPLE

A schematic view of a surface acoustic wave (SAW) motor is illustrated in Fig. 1. A surface acoustic wave device is a stator transducer to drive a slider in linear motion. RF electrical power is transduced to elastic wave motion by piezo electric effect of the substrate in the stator transducer. The Rayleigh wave is excited at an interdigital transducer (IDT). The Rayleigh wave propagating beneath the slider transmits driving force through the frictional force. The slider is pressed to the slider to obtain large thrust.

For motor operation, traveling wave is required. By traveling wave propagation, the surface particles of the SAW device move in elliptical motion as illustrated in Fig. 2. Between the crests of the wave and the pre-loaded slider friction force is at work. The particles at the crest have peak vibration velocity component in horizontal direction. Therefore, linearly driving force act to the slider in opposite direction of the wave propagation.

Since the amplitude of the elliptical motion is tens nm order, the contact condition of the slider is very critical [8]. To control the contact condition, actually, the elastic deformation of the slider and the stator surface in nano meter order, for example, a lot of projections are fabricated on the slider surface. The contact point diameter is from several microns to tens of micron.

EXPERIMENTAL SETUP

A stator transducer and an experimental setup are shown in Figs. 3 and 4. The stator transducer made of lithium niobate ($LiNbO_3$; 128 deg. rotated-Y, X-propagation) was attached to a linear guide. The stator transducer, hence, moves in linear motion. Electrodes of IDT were deposited both end part of the stator. The IDTs line width and space were 100 μm, so that the resonance frequency was 9.61 MHz in this experiment.

A slider made of silicon was pushed with a bar. The other end of the bar, a spring was connected in order to give a certain pressing force. This pressing force is pre-load for the friction drive of the motor. The pre-load was adjusted with a micrometer head. The pre-load was calculated from the spring constant and shorten length of the spring

The silicon slider was 5x5 mm square that had 4x4 square contact region as shown in photograph of Fig. 5. The contact region had a lot of projections as shown in SEM photo of Fig. 5. Several kinds of sliders whose projection diameter d and interval l were changed were prepared. The diameters of the projection were from 5 micron to 50 micron. The contact area, namely the projection surface area, was changed from about 2 % to 44 % of 4x4 mm square by changing the interval.

The enhanced side SEM view of the projection is Fig. 6. The height of the projection is 2 micron. Dry etching process was used to fabricate this surface.

TRANSIENT RESPONSE AND EVALUATED LOAD CHARACTERISTICS

Performance of the surface acoustic wave motor was estimated from measurement of the transient responses. An example of the response is shown in Fig. 7. The slider projection diameter and the interval were 20 micron and 26 micron was used. The motor speed rose up to the stationary speed within several ms.

Mechanical output force of the motor was calculated from the acceleration of the rise up. From the moving part mass and the acceleration at each temporal speed, relationship between the mechanical load and the speed was estimated as shown in Fig. 8. The no-load speed was about 0.5 m/s and the maximum mechanical output force was about 10 N. The mechanical output force, namely the thrust of the motor, was huge value comparing with the transducer mass of about 4 g or the total mass of the moving part 10.5 g. The maximum acceleration of Fig. 6 was 1000 m/s^2.

The no-load speed and the output force depended on the driving force and the pre-load. Using a slider whose projection diameter and interval were 29 micron and 90 micron, the no-load speed and the output force were measured as shown in Figs. 9 and 10. In case of this experiment, the no-load speed depended on the driving voltage mainly. Hence, the vibration velocity of the stator transducer is proportional to the driving voltage, the speed changed with the driving voltage. The output force also depended on the driving voltage and also the pre-load as can be seen from Fig. 10. Basically, the thrust increased with the pre-load. However, in case of not enough vibration amplitude, the thrust decreased.

Using the sliders whose projection diameter was 20 micron and numbers were from 10000 to 23409, the no-load speed dependence on the pre-load at driving voltage of 125 V_{peak} was measured as plotted in Fig. 11. At this condition, the tangential vibration velocity was 1.1 m/s, hence, the maximum speed of 0.97 m/s was 88 % of the vibration velocity.

The output force dependence on the pre-load is also plotted on Fig. 12. At around pre-load of 100 N, the maximum force of 10 N was obtained.

BURST STEPPING DRIVE

With cyclic burst drive, the stepping motion of the slider was measured. The slider moved about 8 nm by 40 waves and 2 nm by 25 waves as shown in Figs 13 and 14. The driving voltage was 125 V_{peak} and the driving period was 0.2 ms. Each stepping traveling distance is controllable by changing wave numbers and the driving voltage. In experiment, much fine stepping drive was available. However, vibration of the slider part masked the stepping motion. Due to the drift of the measurement equipment, a laser heterodyne interferometer, stable data was not obtained. Sub nano stepping motion will be confirmed with improvement of the measuring environments and the structure of the motor.

ENERGY CIRCULATION DRIVE

In order to reduce driving power of stator transducer, an energy circulation drive as illustrated in Fig. 15 has been developed [5]. A stator transducer was newly designed and fabricated as shown in Fig. 16. The designed operation frequency was 14.34 MHz. The dimensions of the device were about 50x15x1 mm. The material was same as the previous one.

Frequency responses of inner and outer driving IDTs and designed curves agreed excellently. The operation frequency was 14.337 MHz from the experiments in both of the inner and outer IDTs. The vibration amplitude and velocity was measured, then, compared with non-circulation driving method. The maximum vibration velocity of 3 m/s was obtained when the driving power was 32 W. It was about a seventh of single power source drive.

Transient responses of the motor were measured using silicon slider. Examples of the responses at pre-load of 9.8 N are shown in Fig. 17. From similar transient curves, output force and no-load speed were measured. Even in low driving power of 9 W with pre-load of 5 N, no-load speed and the output force were 0.56 m/s and 0.9 N.

In case of the energy circulation drive, the input power becomes small, so that the continuous drive as shown in Fig. 13 is possible. The direction of the wave propagation was alternated in every 5 ms in sequence.

CONCLUSION

Micro linear motor using surface acoustic wave device is being developed. The maximum speed, the output force and stepping motion were 1 m/s, 10 N and 2 nm. These performances are temporal values. The energy circulation driving method was also examined. This actuator has extremely high performance than conventional small linear actuator that has cm order traveling distance.

The energy circulation drive method was demonstrated to reduce the driving power. Less than 10 W driving power, no-load speed of 0.56 m/s and maximum output force of 0.9 N was obtained. Stepping motion of nano meter order resolution was also demonstrated.

ACKNOWLEDGMENT

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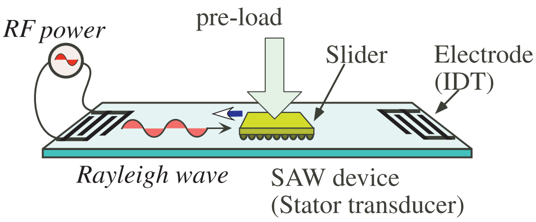

Fig. 1. Schema of surface acoustic wave motor.

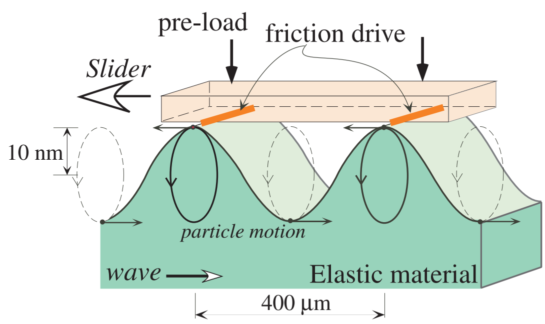

Fig. 2. Principle of surface acoustic wave motor using Rayleigh wave.

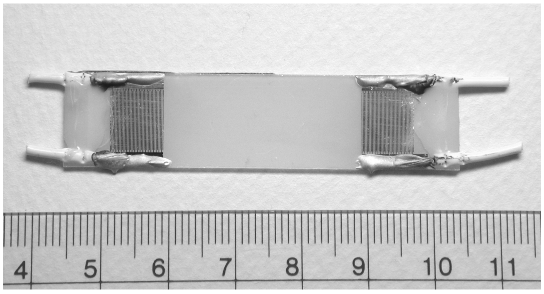

Fig. 3. Surface acoustic wave device for stator transducer; 128 y-rot. x-prop. $LiNbO_3$ and 9.6 MHz driving frequency.

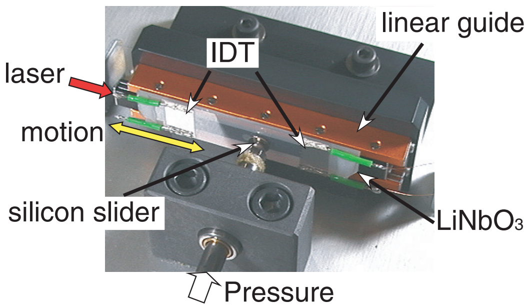

Fig. 4. Experimental setup.

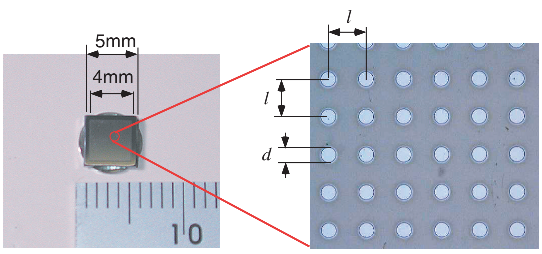

Fig. 5. Silicon slider and its surface view with SEM.

Fig. 6. Silicon slider surface cross view with SEM.

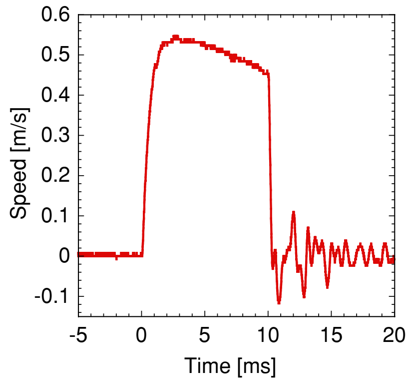

Fig. 7. Transient response; driving voltage and pre-load were 125 V and 113 N

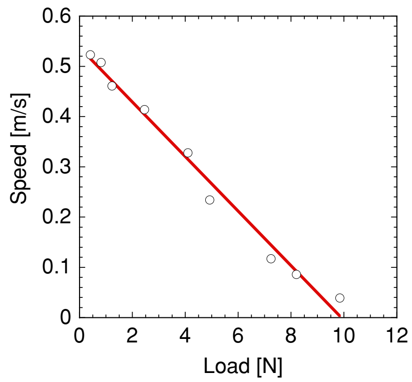

Fig. 8. Sped versus mechanical load characteristics estimated from Fig. 7.

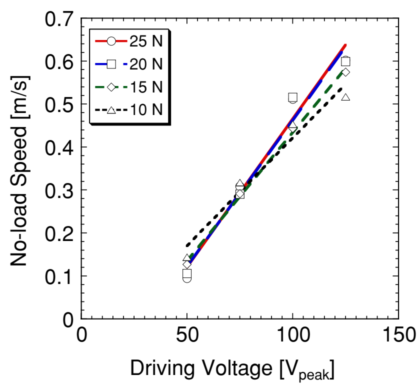

Fig. 9. No-load speed vs. driving voltage with a function of pre--+load.

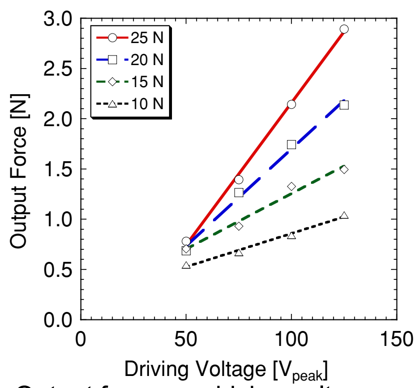

Fig. 10. Output force vs. driving voltage.

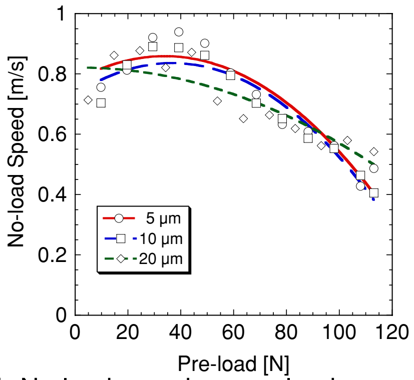

Fig. 11. No-load speed vs. pre-load.

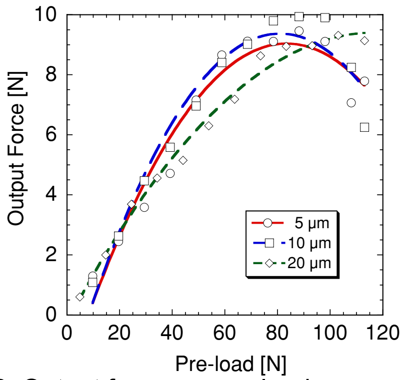

Fig. 12. Output force vs. pre-load.

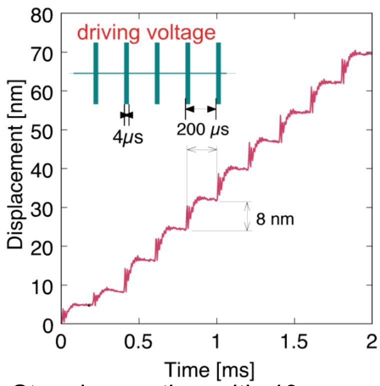

Fig. 13. Stepping motion with 40 waves burst drive.

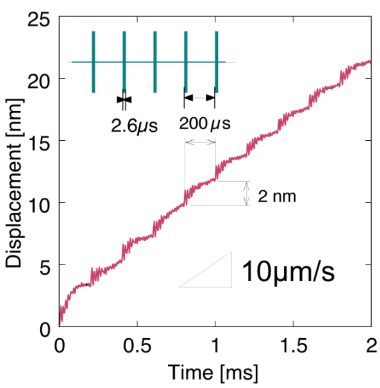

Fig. 14. Stepping motion with 25 waves burst drive.

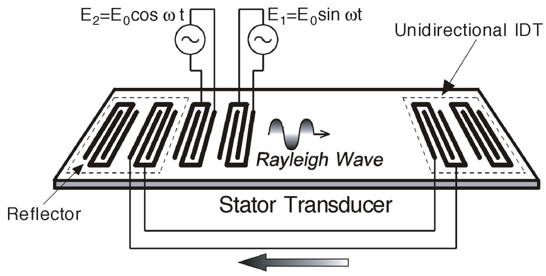

Fig. 15. Driving method of energy circulation for efficiency improvement.

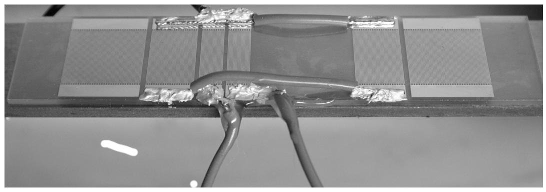

Fig. 16. Stator transducer for energy circulation drive.

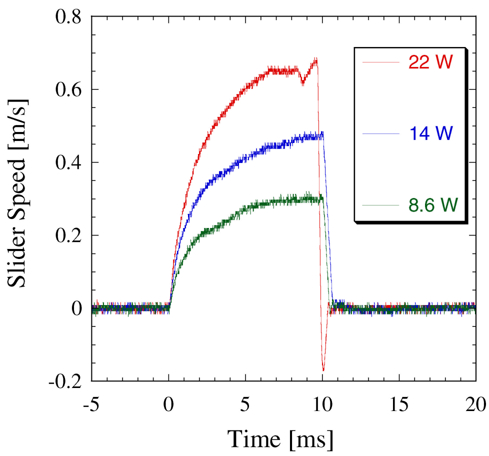

Fig. 17. Transient response of the energy circulated driving motor.

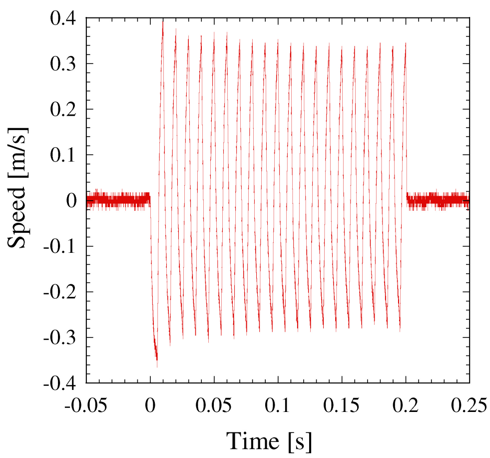

Fig. 18. Continuous reciprocation motion at 100Hz with energy circulation drive.