Effects of Ceramic Thin Film Coating on Friction Surfaces for Surface Acoustic Wave Linear Motor

Yuta Nakamura, Minoru Kuribayashi Kurosawa, Takashi Shigematsu
Tokyo Institute of Technology, Department of Advanced Applied Electronics,
G2-606, 4259 Nagatsuta, Midori-ku, Yokohama, 226-8502, Japan
and Katsuhiko Asai

Matsushita Electric Industrial Co., Ltd., Advanced Technology Research Laboratories,
3-4 Hikaridai, Seika, Souraku, Kyoto 619-0237, Japan

Abstract — The effects of ceramic thin film coating on friction surfaces for surface acoustic wave (SAW) linear motor were estimated. By using a slider coated with SiC, the maximum no-load speed of the slider was approximately 1.1 m/s, which was equivalent to the horizontal vibration velocity of the Rayleigh wave at the driving voltage of 125 V_{0-p}. The transient responses about four kinds of driving voltage by using the slider coated with SiC was examined, then the no-load speed of the slider was 1.5 m/s at 170 V_{0-p}. Furthermore, by using a slider coated with HA-DLC and a stator coated with Al₂O₃, the no-load speed and the output force of the slider were approximately 1.5 m/s and 3 N at 190 V_{0-p}. It was shown that the driving characteristics were improved by ceramic thin film coating with the proper materials such as SiC, HA-DLC and Al₂O₃ on friction surfaces.

I. INTRODUCTION

Surface acoustic wave (SAW) devices for ultrasonic motor utilizing HF frequency band (3-30 MHz) has been proposed and demonstrated its possibility [1]. A multi contact type slider using a lot of steel balls [2] and silicon slider [3] have also been proposed. They were succeeded in gaining large output force. The driv-

ing frequency of the SAW device was enhanced up to 70 MHz for miniaturization [4]. Diameter and density of projections fabricated on silicon sliders were examined experimentally [5]. For saving the driving electric power, the energy circulation driving methods were investigated [6]. Nanometer step motion of the SAW motor was also investigated [7].

In this paper, the effects of ceramic thin film coating on friction surfaces for SAW linear motor were estimated. The driving characteristics by using coated sliders with eight kinds of material were examined, and the driving of the motor by using a coated slider and a coated stator was also investigated.

II. PRINCIPLE

A schematic view of surface acoustic wave motor is illustrated in figure 1. RF electric power is transduced to elastic wave, and then the Rayleigh wave is excited at the interdigital transducer (IDT) with piezoelectric effect. A stator was a substrate of 128 degrees rotated Y-cut X-propagation LiNbO₃. A slider was made of silicon and many projections were fabricated on the surface by dry etching as shown in figure 2. Because of these projections, the sufficient contact pressure is generated and the better contact condition is obtained.

Figure 1: Schematic view of surface acoustic wave motor.

Figure 2: The photograph of silicon slider and the enlargement of the surface

III. EXPERIMENTAL SETUP

The photograph of the experimental setup is shown in figure 3. Two IDTs cannot be seen in this figure because they were hidden by a stator holder, which was fabricated to fix the stator and change the stator easily. A movable part, a linear guide block, a hemisphere, a block for pressure and the slider, moves along a linear guide rail. The slider was glued with double-stick tape onto the block for pressure as shown in figure 4. The steel hemisphere was glued with epoxy resin onto the linear guide stage, and it was put into the block for pressure. A hemisphere and block connection was used to maintain the parallel contact between the slider surface and the stator surface.

The stator was sized $62 \times 13.6 \times 1 \text{ mm}^3$. The driving frequency was 9.61 MHz, which was the resonance frequency to propagate the Rayleigh wave. The slider was sized $5 \times 5 \text{ mm}^2$, which had projections in $4 \times 4 \text{ mm}^2$ square area. Diameter, pitch and height of the projection on the slider were $1 \text{ }\mu\text{m}$, $5 \text{ }\mu\text{m}$ and $0.5 \text{ }\mu\text{m}$. The mass of the movable part was 1.89 g.

A laser beam of a laser Doppler vibrometer was incident on the linear guide stage to measure the speed of the slider. Pre-load was given by a coil spring so that the pre-load adjusted easily.

Ceramic thin film coating

To examine the effects of ceramic thin film coating on a friction surface, sliders coated with eight kinds of material by way of PVD or CVD process were prepared. The materials were SiC, SiN, TiC, TiN, Al_2O_3 , CrN, and Diamond Like Carbon (DLC). In regard to DLC, we prepared two kinds of DLC, H-DLC and HA-DLC [8]. H-DLC is conventional DLC. HA-DLC has high hardness next to diamond and high adhesive strength (a few times higher than that of conventional DLC). The hardness of eight kinds of material is shown in Table.1. In this experiment, the thickness of each coating film was $0.1 \text{ }\mu\text{m}$. For the improvement in wear protection, thin film coating will be effective because

Figure 3: The photograph of the experimental setup

Figure 4: The photograph of the block for pressure

Figure 5: The cross section of the coated projection on the slider

Table 1: The hardness of materials for ceramic thin film coating [8]

Material	Hardness[kg/mm ²]	Material	Hardness[kg/mm ²]
TiN	1700-2000	Al_2O_3	2000-2400
TiC	3000-3200	SiN	1800-2000
CrN	1500-1800	H-DLC	1000-2000
SiC	3000-3500	HA-DLC	1500-4500

the sharp edge corners of the projections become round by thin film coating as shown in figure 5.

IV. EXPERIMENTAL RESULT

From a transient response of the motor, mechanical output such as maximum force and stationary speed were examined. The mechanical output force was calculated from the rise acceleration, and the no-load speed was estimated from the saturated speed of the transient response.

First, we examined the effects of ceramic thin film coating about the no-load speed against pre-load and the output force against pre-load. Figures 6 and 7 show the no-load speed against pre-load about the sliders coated with each ceramic thin film. In these figures, the three sliders coated with SiC, HA-DLC and SiN were superior. Especially, by using the slider coated

Figure 6: No-load speed against pre-load: The driving voltage was $125 V_{0-p}$. The slider was coated with SiC (●), Al_2O_3 (Δ), TiC (X), and CrN (□), respectively.

with SiC, the maximum no-load speed of the slider was approximately 1.1 m/s, which was equivalent to the horizontal vibration velocity of the Rayleigh wave at $125 V_{0-p}$. On the other hand, the two sliders coated with CrN and H-DLC were inferior. As shown in figure 6, by using the slider coated with Al_2O_3 , the no-load speeds of the slider at 10-40 N pre-load were lower than those of the slider at 50-60 N. The Al_2O_3 slider was examined several times, but the same results were obtained.

Figures 8 and 9 show the output force against pre-load about the sliders coated with each ceramic thin film. Regarding the maximum output force, the three sliders coated with SiC, Al_2O_3 and HA-DLC were superior. To the contrary, the two sliders coated with CrN and H-DLC were inferior. When the pre-load was in the range of 10-30 N, the more output force could be obtained by using the two sliders coated with SiC and HA-DLC than that of the slider without coating. For example, when the pre-load was 30 N, the output force of the slider without coating was approximately 6 N. To the contrary, the output forces of the two sliders coated with SiC and HA-DLC were approximately 8 N at the same pre-load. It is considered that the coefficient of friction between the coating material and LiNbO₃ increased.

Considering these results about no-load speed and output force, high speed and large output force can be produced at lower pre-load by using the two sliders coated with SiC and HA-DLC. In view of the hardness as shown in table 1, the hardness of SiC and HA-DLC are higher than those of other six materials. While, the hardness of CrN and H-DLC are lower than those of other six materials; the driving characteristics of CrN slider and H-DLC slider were inferior.

Figure 7: No-load speed against pre-load: The driving voltage was $125 V_{0-p}$. The slider was coated with HA-DLC (●), H-DLC (Δ), TiN (X), and SiN (□), respectively.

Figure 8: Output force against pre-load: The driving voltage was $125 V_{0-p}$. The slider was coated with SiC (●), Al_2O_3 (Δ), TiC (X), and CrN (□), respectively.

Figure 9: Output force against pre-load: The driving voltage was $125 V_{0-p}$. The slider was coated with HA-DLC (●), H-DLC (Δ), TiN (X), and SiN (□), respectively.

Figure 10: Transient responses about four kinds of driving voltage: The pre-load was 30 N. The slider was coated with SiC.

Second, the transient responses about four kinds of driving voltage were examined as shown in figure 10. The pre-load was 30N. The slider was coated with SiC, which showed one of the best driving characteristics. When the driving voltage was 170 V_{0-p}, the no-load speed was 1.5 m/s. When the driving voltage was 150 V_{0-p} or 170 V_{0-p}, the speed fell down before 10ms. This was because the starting point of the slider, that is, the stroke was different and the slider hit at the edge of the stator holder.

Lastly, we examined the effects of the stator which was coated with ceramic thin film. The stator was coated with Al₂O₃, and the slider was also coated with HA-DLC. The thickness of the stator coating film was 0.1 μm. The pre-load was 30N. When the driving voltage was 190 V_{0-p}, the no-load speed and the output force were 1.5 m/s and 3N as shown in figure 11.

V. CONCLUSION

The performances of SAW motor by way of ceramic thin film coating on friction surfaces were examined. The driving characteristics were improved by the coating with the proper material on the slider surface only, or on the both surfaces of the slider and the stator. Thin film coating will be effective for the improvement in wear protection because the sharp edge corners of the projections become round by thin film coating. In those points, this approach is considered to be beneficial.

VI. ACKNOWLEDGMENT

This work was supported by a Grant-in-Aid for the

Figure 11: Transient Response: The driving voltage was 190 V_{0-p}. The pre-load was 30 N. The slider was coated with HA-DLC, and stator was coated with Al₂O₃.

Development of Innovative Technology of the Ministry of Education, Culture, Sports, Science and Technology of Japan.

VII. REFERENCES

- [1] M. Kurosawa, M. Takahashi and T. Higuchi, "Ultrasonic linear motor using surface acoustic wave," IEEE UFFC 43(5), pp. 901-906, 1996.
- [2] M. Chiba, M. Takahashi, M. Kurosawa and T. Higuchi, "Evaluation of a surface acoustic wave motor output force," MEMS, pp. 250-255, 1997.
- [3] N. Osakabe, M. Kurosawa, T. Higuchi and O. Shinoura, "Surface acoustic wave linear motor using silicon slider," MEMS, pp. 390-395, 1998.
- [4] M. Takasaki, M. K. Kurosawa and T. Higuchi, "Optimum silicon slider design for 50 MHz SAW linear motor," Transducer '99, pp. 1756-1757, 1999.
- [5] M. K. Kurosawa, H. Itoh, K. Asai, M. Takasaki and T. Higuchi, "Optimization of slider contact face geometry for surface acoustic wave motor," Proc. of MEMS 2001 pp. 252-255, Jan. 21-25, 2001.
- [6] K. Asai, M. K. Kurosawa and T. Higuchi, "Novel power circulation methods for a surface acoustic wave motor," Proc. of IEEE Ultrason. Symp. '99, pp. 667-670, 1999.
- [7] T. Shigematsu, M. K. Kurosawa and K. Asai, "Nanometer Stepping Drives of Surface Acoustic Wave Motor," IEEE Trans. on Ultrasonics, Ferroelectrics and Frequency Control, Vol. 40, No. 4, pp. 376-385, 2003
- [8] Nippon ITF Inc., "Products Info.," Available: <http://www.nippon-itf.co.jp/products.html>