FORMATION MECHANISMS OF TRIBO-COATING FOR LOW FRICTION IN UHV

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ABSTRACT
Solid lubrication film formed by tribo-coating, which deposits a solid lubricant by evaporation to the contact interface during friction in vacuum, gives low friction coefficient below 0.03 that can not be observed by any other solid lubricants of soft metals. The tribo-coating film formed on the pin has nano-order composite structure which the crystalline indium of nano size are distributed in an amorphous matrix of silicon oxide and chromium oxide. Because of the nano composite structure, a very thin indium film is formed without break down like conventional pre-coated thin film. The thinner indium film can give smaller value of friction coefficient than that of conventional solid lubricant.

INTRODUCTION
Lubrication of tribo-elements in devices under ultra-high vacuum such as space mechanisms is important and being developed to guarantee its durability and reliability. Many solid lubricants and coating deposition techniques have been applied for these tasks, however, all of them have some limited lifetime because of their wear.

A new lubrication method namely “Tribo-coating” has been proposed by authors to solve such tribological problems [1]-[3]. It is a kind of vapor deposition assisted by friction. With pin-on-disk experiment, it was discovered that tribo-coating of indium gave very small friction coefficient that could not be observed by conventional solid lubricants of soft metal (Fig. 1) [4].

The purpose of this paper is to clarify the low friction mechanism of tribo-coating from view point of structure of tribo-coating film.

EXPERIMENTAL PROCEDURE
Figure 2 shows the schematic diagram of pin-on-disk type friction apparatus with in-situ tribo-coating system, where a solid lubricant (Indium) is evaporated from an Al₂O₃ crucible by heating of Mo heater in vacuum and forms a thin film on the friction surface during sliding. Since solid lubricant can be supplied at any time by heating

Fig. 1 Comparison of friction properties of tribo-coated In film and conventional soft metal films [4].

Fig. 2 Schematic image of friction apparatus with tribo-coating system.

of Mo heater, in-situ and on-demand restoration of solid lubricant film becomes possible. Silicon nitride was used as ball material based on previous data [1]. In order to clarify the effect of structure of the tribo-coating film on friction property, two different disk materials (stainless steel: SUS440C and bearing steel: SUJ2) were used.
EXPERIMENTAL RESULTS AND DISCUSSION

Figure 3 shows effect of disk material on friction property of tribo-coated indium film. In case of Si$_3$N$_4$ pin/SUS440C disk, very low friction coefficient less than 0.03 is observed after 2,000 sliding cycles. On the other hand, in case of Si$_3$N$_4$ pin/SUJ2 disk, value of friction coefficient is around 0.07 which is the similar as that of conventional soft metals. Figure 4 (a1)-(b2) show SEM images and mapping of indium with EDX analysis of both pin surfaces. It is considered that difference in tribo-coating film formed on the pin surface generates different friction property. The tribo-coating film formed in case of Si$_3$N$_4$ pin/SUS440C show much lower friction coefficient even indium as solid lubricant is not detected strongly as compared with that in Si$_3$N$_4$ pin/SUJ2 disk.

Figure 5 shows two different magnified TEM images of the tribo-coating film which gives lower friction coefficient less than 0.03. (It was formed on the pin surface in case of Si$_3$N$_4$ pin/SUS440C.) Black point in the order of nano-meter distributes in the tribo-coating film. Figure 6 (a) and (b) show results of EDX analysis of the black part and white part shown in Fig. 5, respectively. It can be summarized from Figs. 3, 4, 5 and 6 that tribo-coating film has nano-structural composite in which indium of nano-order size distributes in the matrix of silicon oxide and chromium oxide.

It is well known that friction property of soft metal is considered as almost same as that of high viscosity liquid. Further, if liquid film does not break down, friction coefficient decreases with decreasing of liquid film thickness. Indium in the order of nano-size is easily formed and restored thin layer on the tribo-coating film formed on the pin surface. A very thin indium film, which can not be formed by conventional pre-coated thin film, is therefore formed by the distributed nano-size indium without break. Such thinner indium film can give smaller value of friction coefficient than that of conventional soft metals.

CONCLUSIONS

(1) The tribo-coating film formed on the pin has nano-order composite structure in which the indium of nano size are distributed in matrix of silicon oxide and chromium oxide.

(2) A very thin indium film is formed by the distributed nano-size indium without break down like conventional pre-coated thin film. The thinner indium film can give smaller value of friction coefficient than that of conventional solid lubricant.

REFERENCES