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ADVANCED CLEAN LUBRICATION OF MEMS

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Abstract: CNx-coatings exhibit friction coefficients below 0.01 when tested in a N_2 gas atmosphere during sliding against itself, Si_3N_4 or steel although these material combinations give friction coefficients higher than 0.1 in air. Wear rates are below 10^{-7} mm^3/Nm. H-DLC coatings ask behave in a similar manner in N_2 gas atmosphere. Observed behaviors of these carbon based coatings in N_2 promise high potential of clean lubrication methods of MEMS.

Key words: CNx, H-DLC, N_2, low friction, low wear

1. INTRODUCTION

The contact load of elements of MEMS generally ranges in nN～μN. When such contacts are lubricated with liquid, stiction of contact surfaces is caused by the meniscus force which generates problems in operating MEMS. Dispersion and/or evaporation of the liquid lubricants generate another problem of contamination of the system.

Traditional solid lubricants such as graphite and MoS_2 are not suitable for MEMS as they are not supplied continuously and their solid particles in nm～μm are too large and too contaminant for the system to be accepted.

By considering those difficulties in applying traditional lubricants of liquids and solids to MEMS, N_2 gas lubrication[1] of carbon based coatings is introduced in this paper as the advanced clean method of lubrication of MEMS.

2. CARBON NITRIDE COATINGS (CN_X)

Hard coatings are supposed to be used for the elements of MEMS. CNx-coatings introduced in this paper are produced on disks of Si-wafers or Si_3N_4 by having the deposition of carbon from a solid carbon target of 99.999% purity together with the mixing of nitrogen ions irradiated simultaneously from the ion beam gun. The carbon for the coating on Si-disk is sputtered from a carbon target by argon ion, and on Si_3N_4 disk it is evaporated by heating with electron beam.

The thickness of coatings ranges in 100～400nm and the surface average roughness Ra ranges 0.1～0.3nm on Si-disk and 20～80nm on Si_3N_4 disk. The hardness of coatings is about 30GPa in indentation depth from 10 to 50nm. The atomic concentration of nitrogen in the CNx-coatings is observed as 12～13% and the microstructure of coatings in amorphous.

3. FRICTION OF SI_3N_4 PIN/CN_X-SI DISK IN VARIOUS GASES

Fig.1 shows the effect of surrounding gas or vacuum on friction coefficient of Si_3N_4 pin/CNx-Si disk in air, O_2, CO_2 and N_2 of 7.4×10^4 Pa, and vacuum of 2×10^{-4} Pa. CNx-coatings are exposed to air for 1hr after deposition before the test in each gas or vacuum.

Among the gases, N_2 generates the lowest friction coefficient below 0.01[2].

Similar friction tests are carried in the gases of He and Ar with 1.0×10^5 Pa and high friction coefficient values above 0.2 are observed. It means that the inertness of nitrogen does not give explanation for the low friction.

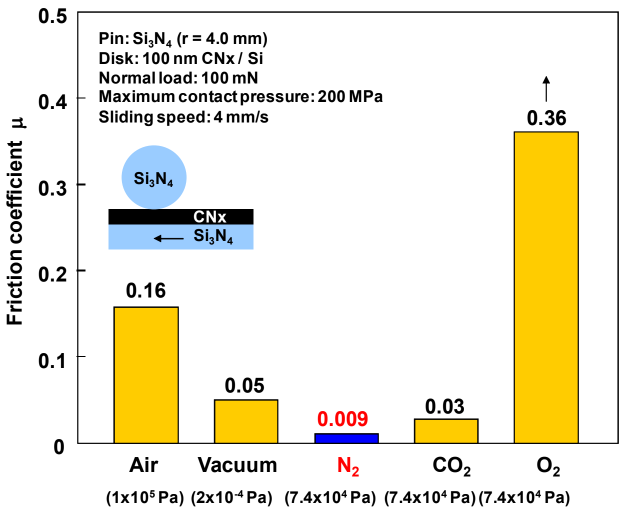

Fig.1: The effect of gas on friction coefficient after 240 friction cycles at Si_3N_4pin/CN_x-Si disk[2].

4. FRICTION OF SI_3N_4 PIN/CN_X-SI DISK AND CN_X PIN/CN_X-DISK WITH N_2 GAS STREAM IN AIR ATMOSPHERE

When N_2 gas is supplied through a tube of 4.5mm diameter to the sliding interface between Si_3N_4 pin and CNx coating on Si_3N_4 disk in air, high friction coefficient of 0.7 in air is effectively reduced as shown in Fig.2.

The amount of reduction in friction depends on the amount of N_2 gas supply, and the friction coefficient around 0.05 is generated by the supply of 4.8 *l*/min[3].

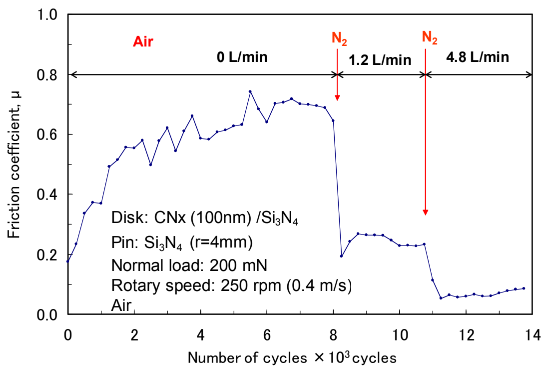

Fig.2: The effect of N_2 gas supply to the contact in air through a tube of 4.5mm diameter in sliding of Si_3N_4 pin against CN_x coating on Si_3N_4 disk [3].

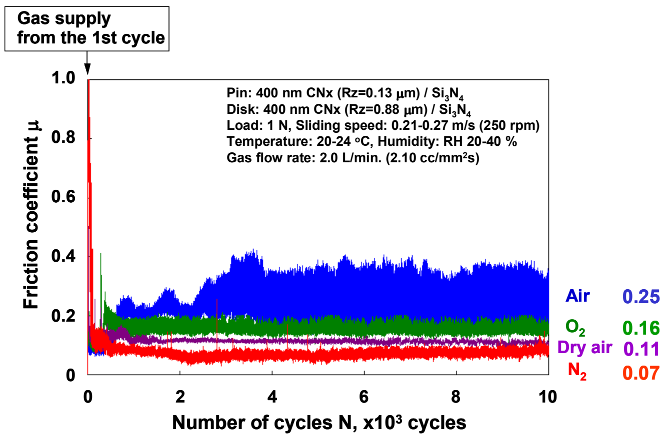

Fig.3: The effect of gas supply to the sliding interface between CN_x coatings on pin and disk of Si_3N_4.

5. THE SLIDING HISTORY EFFECT ON FRICTION OF CN_X-PIN/CN_X-DISK IN N_2 GAS STREAM

Fig.3 shows the change of friction between CNx coatings on pin and disk of Si_3N_4 in the stream of gases of N_2, dry air and O_2 supplied through a tube of 4.5mm diameter in air. The friction coefficient μ in air is steady at around μ=0.25, and it is reduced to about μ=0.07 by having the stream of N_2 gas. The gas stream of O_2 and dry air give the friction coefficients of 0.16 and 0.11 respectively[4].

Fig.4(a) shows the same data for N_2 gas in Fig.3 on the semi-log scale. N_2 gas is supplied after the initial running-in of 100 friction cycles in air in Fig.4(b), and after 50 friction cycles in O_2 in Fig.4(c).

The steady state values of friction coefficient μ_s in Figs.3 and 4 are shown in Fig.5 together with the values of wear rate w_s[4].

The values of μ=0.05 and $w_s=2.5\times10^{-8}$ mm^3/Nm in the atmosphere of Air →N_2 and those of μ=0.03 and $w_s=5.0\times10^{-8}$ mm^3/Nm in the atmosphere of O_2 →N_2 are low enough for the practical usage in sliding elements of MEMS.

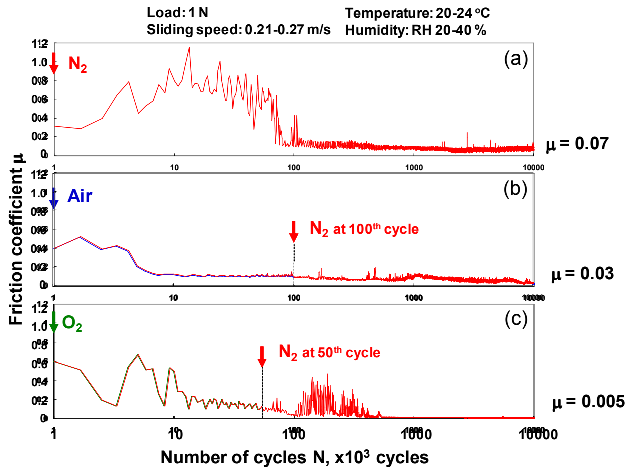

Fig.4: The effect of N_2 gas supplied to the contact after the running-in in air and in O_2 gas stream on reduction of friction coefficient between CN_x coatings on pin and disk of Si_3N_4 [4].

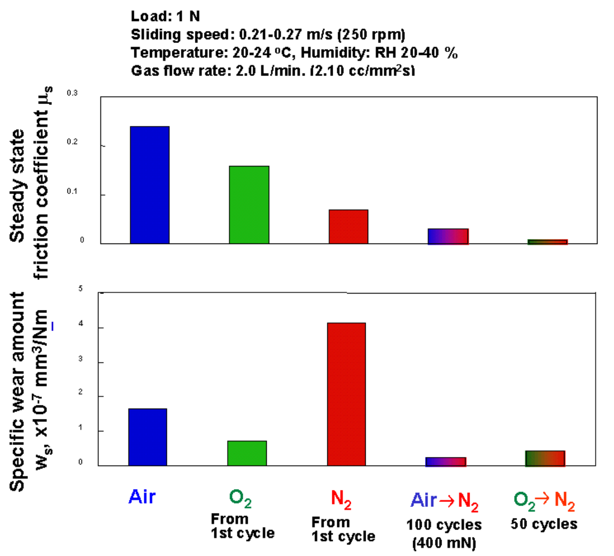

Fig.5: The values of friction coefficient μ of CN_x/CN_x and wear rate $w_s(mm^3/Nm)$ of CN_x coating on Si_3N_4 pin in the stream of N_2 or O_2 and in air [4].

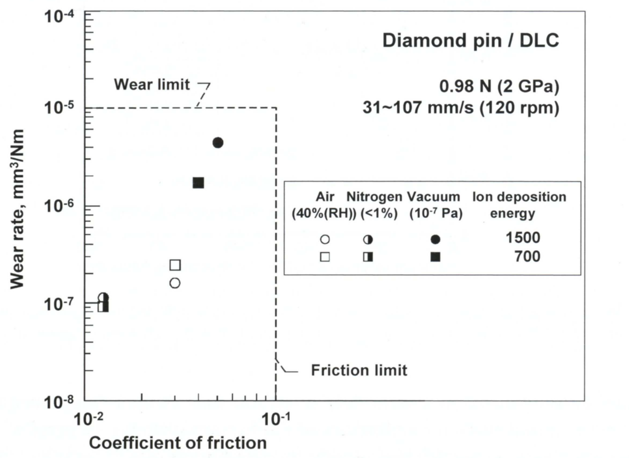

Fig.7:The effects of N_2, air and vacuum on friction coefficient and wear rate in sliding of a diamond pin against DLC on disk[6]

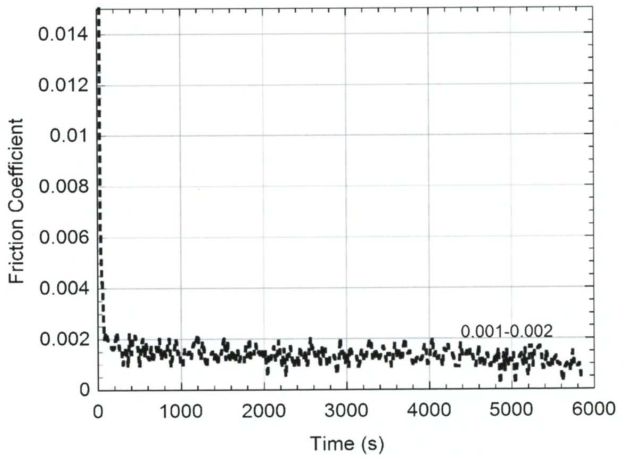

Fig.6: Low friction coefficient of a highly hydrogenated(~40 at % Hydrogen) DLC film coated on ball and disk of sapphire in dry nitrogen. Load:10N, sliding velocity:0.3m/s, temperature:23℃ [5]

6. THE EFFECT OF N_2 ON FRICTION OF CARBON FILMS AND DIAMOND

Friction coefficients as low as 0.001 are observed with highly hydrogenated (~40 at % hydrogen) DLC films in N_2 gas as shown in Fig.6[5]. Surface layers of hydrogen are supposed to form on the friction surfaces. The friction coefficients below 0.01 are observed between diamond and DLC in N_2 gas as shown in Fig.7[6]. It is very clear from the observations in Figs.1~7 that N_2 gas works to reduce friction between carbon based films and diamond, although mechanisms of generating low friction is not yet understood[7].

7. CONCLUDING REMARKS

MEMS may require lubrication method which does not generate problems of stiction and/or running out of prepaired lubricants by wear at contacts. N_2 gas lubrication of the carbon based coatings offers the possible technology for such requirement. The attainable values of friction coefficient ($\mu < 0.01$) and wear rate ($w_s < 10^{-7}$ mm^3/Nm) are quite sufficient for practical application is the development of getting N_2 gas around the contacts.

REFERENCES

[1] K.Kato and K.Adachi, "Superlubricity of CNx-coatings in Nitrogen Gas Atomosphere ," Chapter20 in Superlubricity edited by A.Erdemir and J.-M. Martin, Elsevier, 2007, 341-363.

[2] K. Kato, N. Umehara and K. Adachi, (2003), "Friction, Wear and N_2 -lubrication of Carbon Nitride Coatings: a Review," Wear, 254, 1062-1069.

[3] Y.Hori and K.Kato, "Studies on Tribology, "Proc. Japan Academy, Ser.B, Vol.84, No.8, 2008, 287-320.

[4] K. Adachi, T. Wakabayashi and K. Kato, (2005), "The Effect of Sliding History on the Steady State Friction Coefficient between CNx coating Under N_2 Lubrication," Proc. of the 31st Leeds-Lyon Symposium on Tribology, 2004, Leeds, UK, Tribology and Interface Engineering Series, 48, (eds. Dowson, D. et al.), Elsevier, 673-677.

[5] A.Erdemir, "The Role of Hydrogen in Tribological Propreties of Diamond-like Carbon Films," Surf. Coat. Technol. 146-147, 2001, 292-297.

[6] K.Miyoshi, M.Murakawa,S.Watanabe, S.Taguchi, S.Miyake, "CVD Diamond, DLC and C-BN Coatings for Solid Filmlubrication," Tribol.Lett.5, 1998, 123-129.

[7] Book "Superlubricity,"edited by A.Erdemir and J.-M. Martin, Eevier, 2007.