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FRICTION AND WEAR PROPERTIES OF CN_X COATINGS IN THE FLOW OF N_2 GAS

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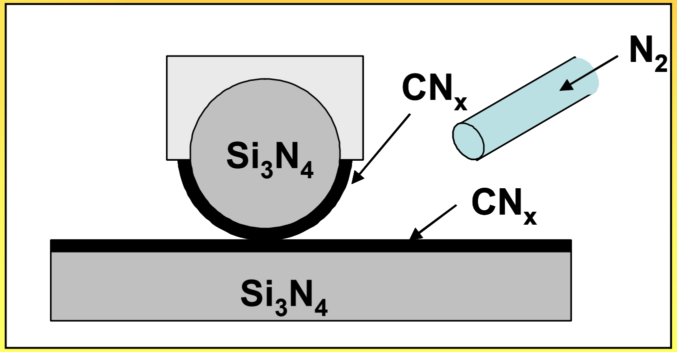
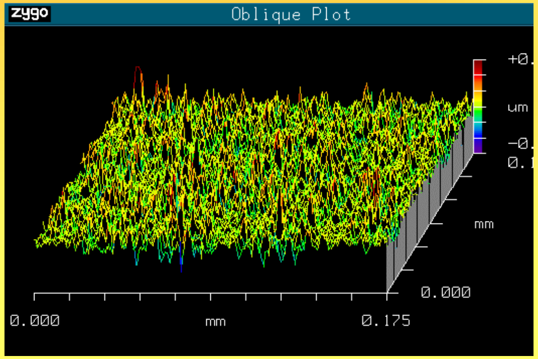
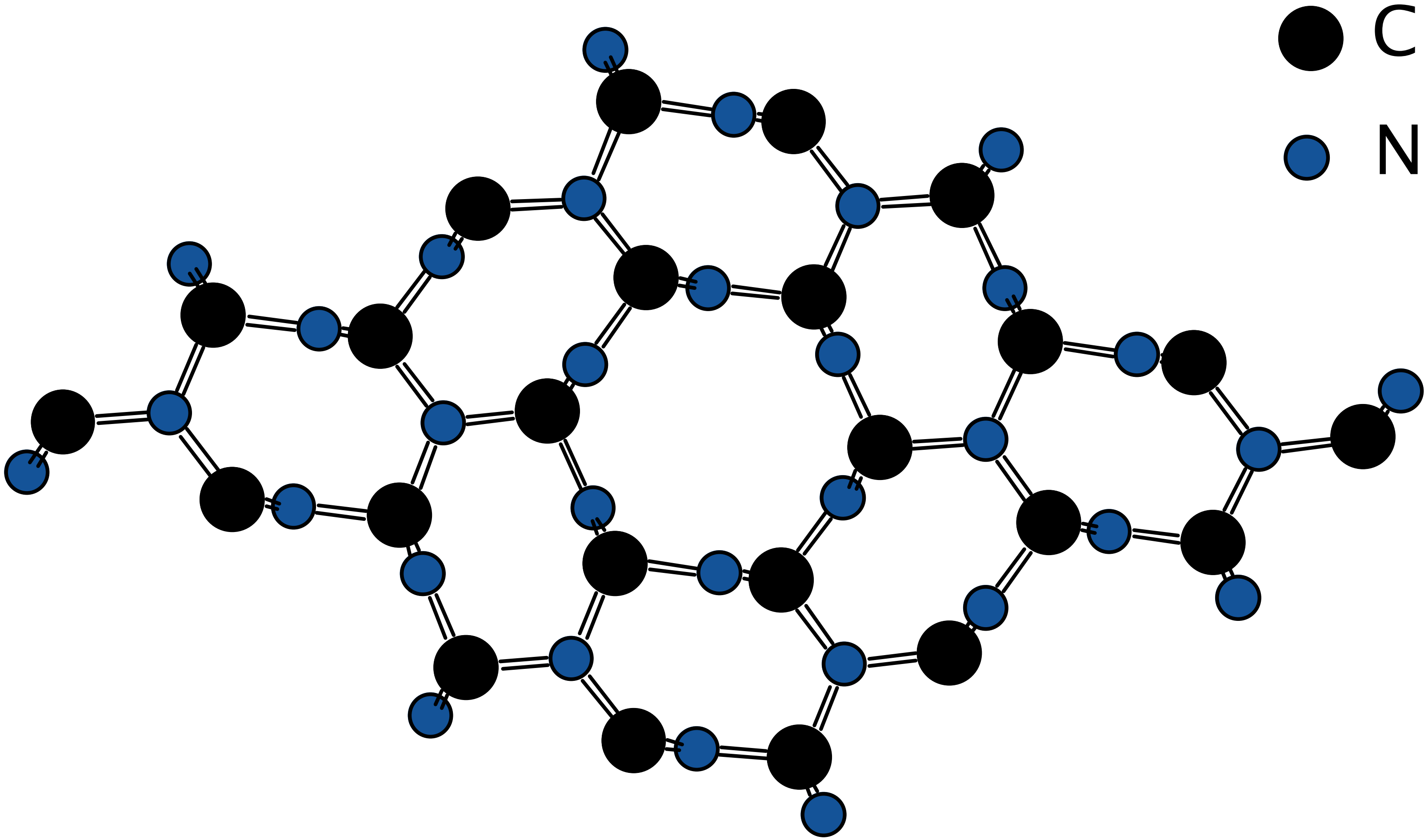




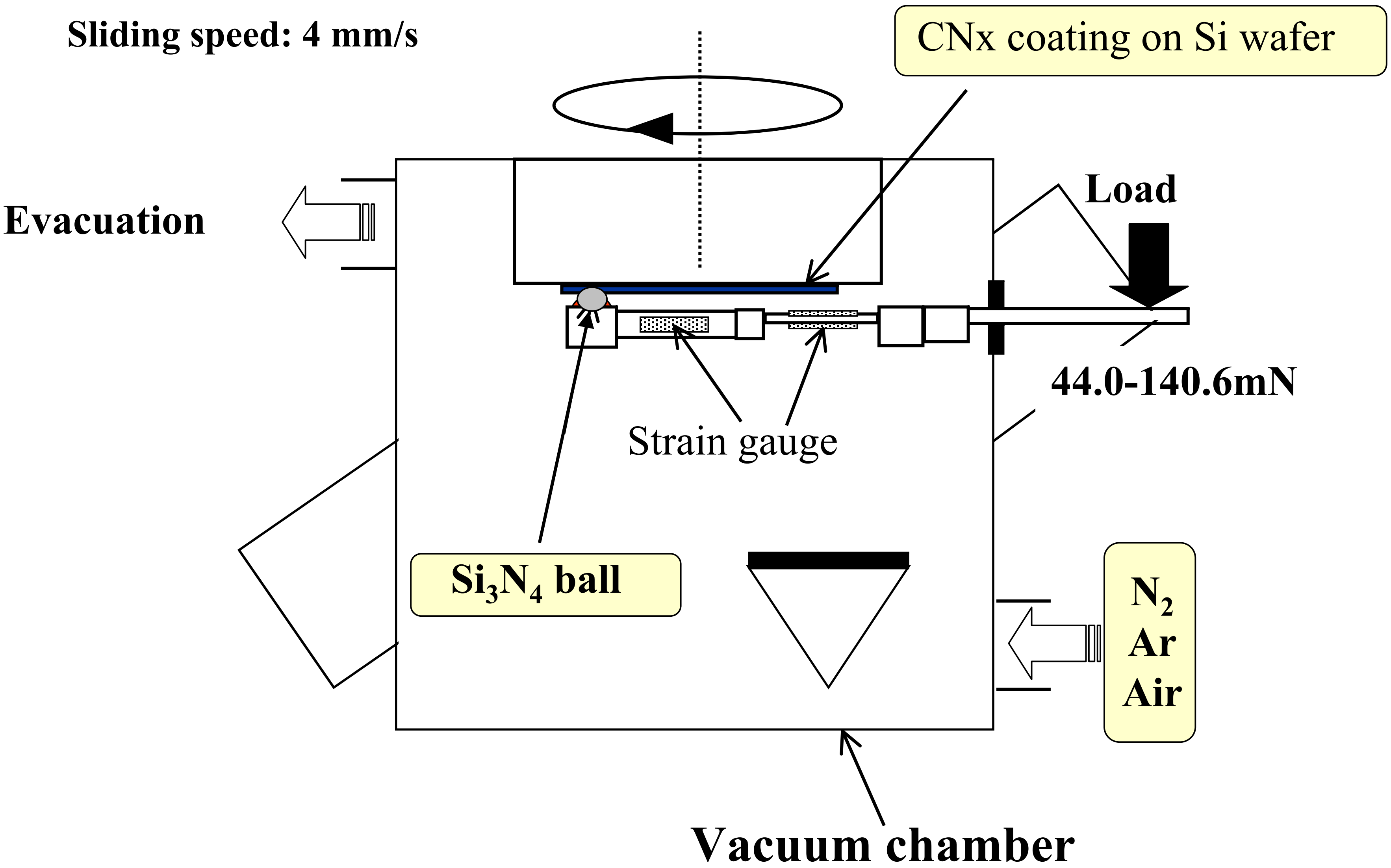


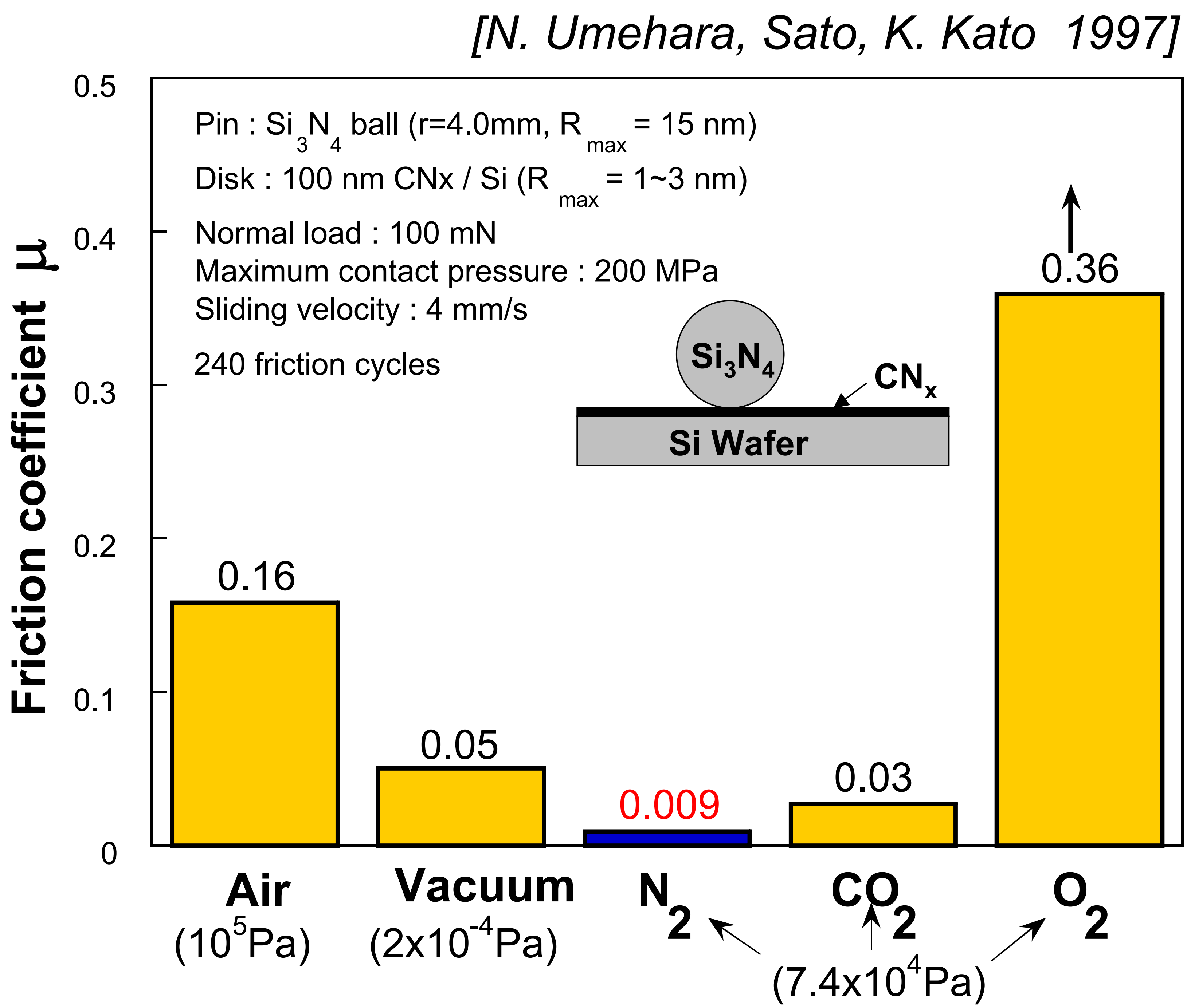
β-C_3N_4



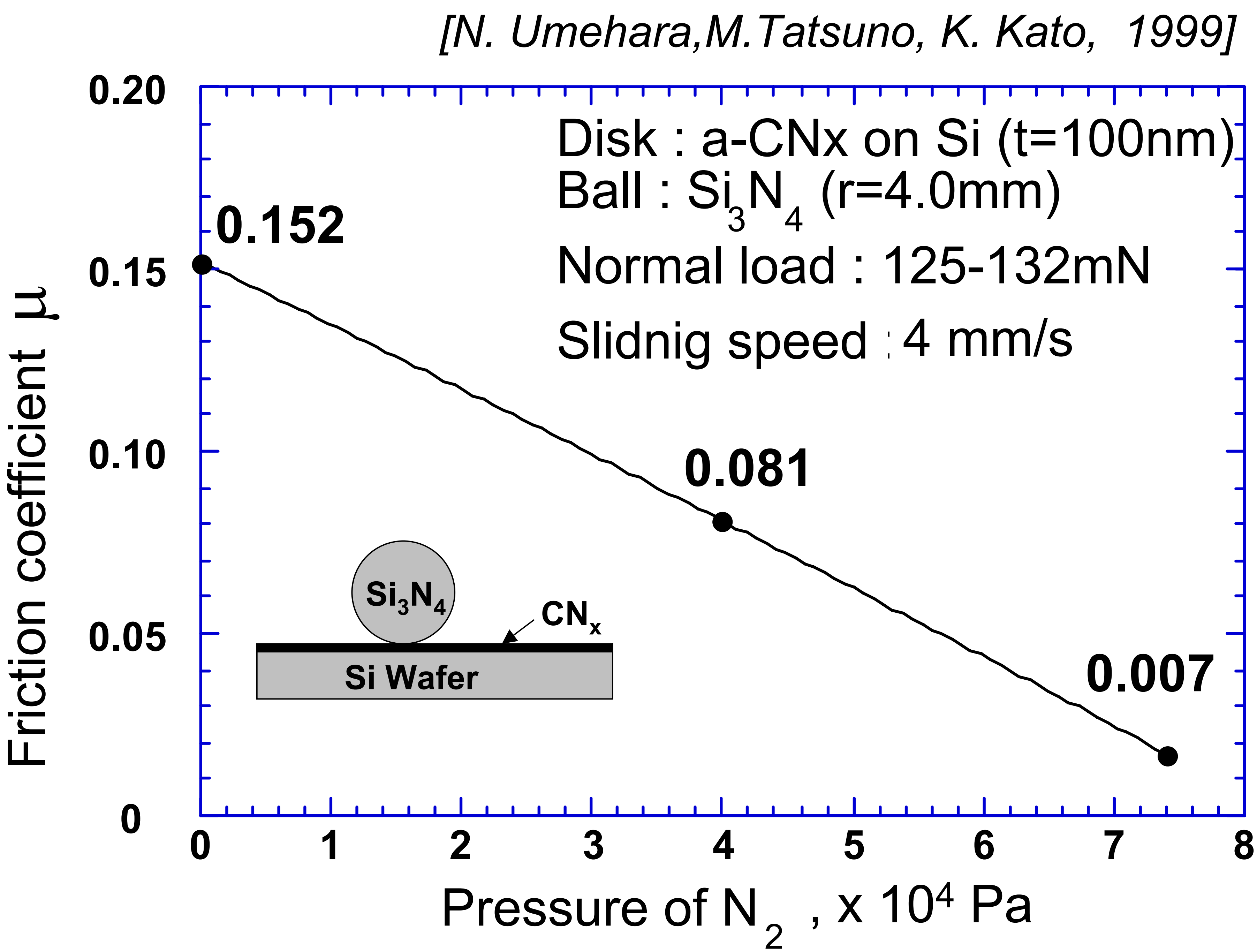
[A. I. Liu, M. L. Cohen, 1989]

Past works on CNx coating and N_2 lubrication

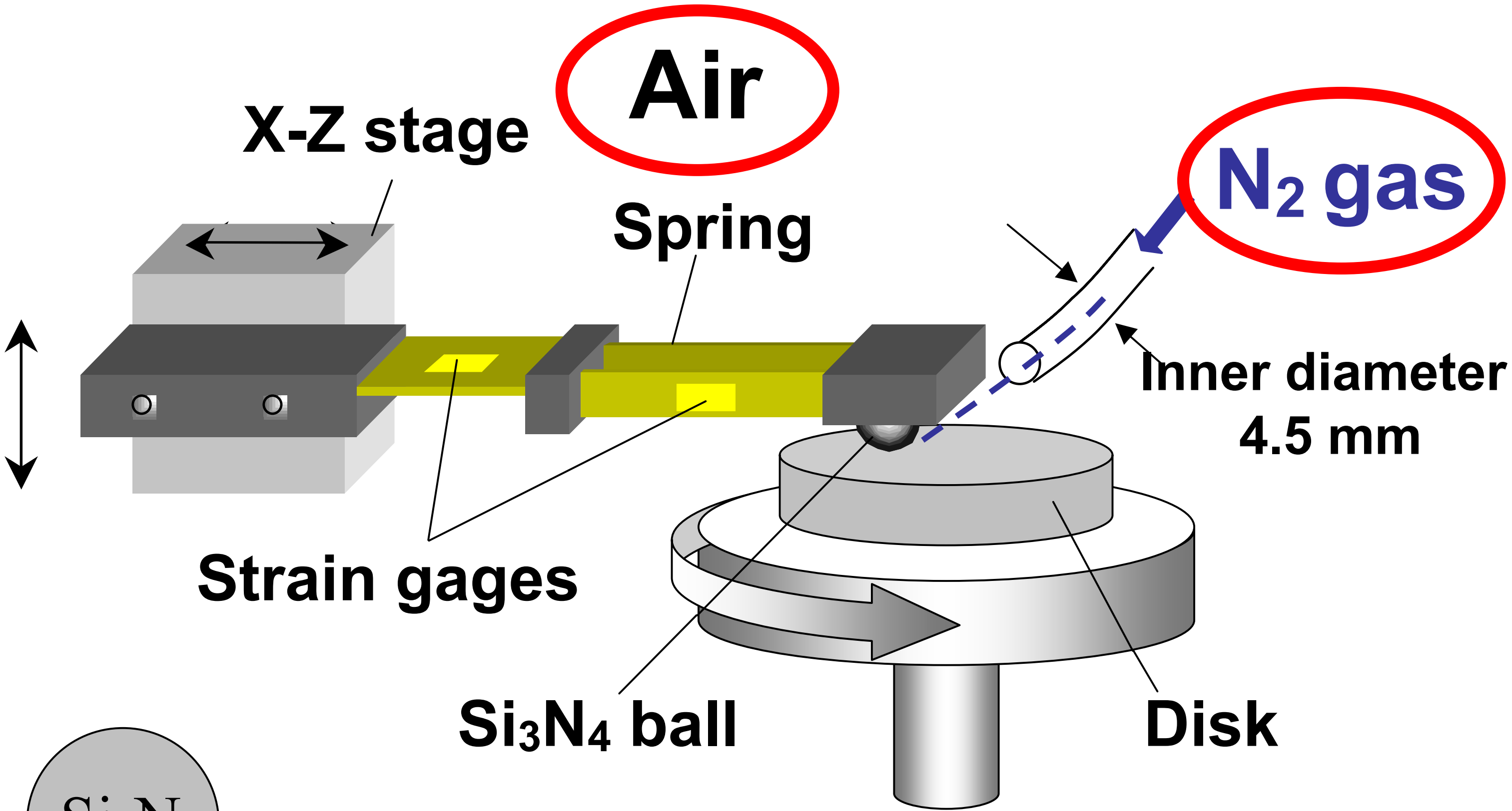


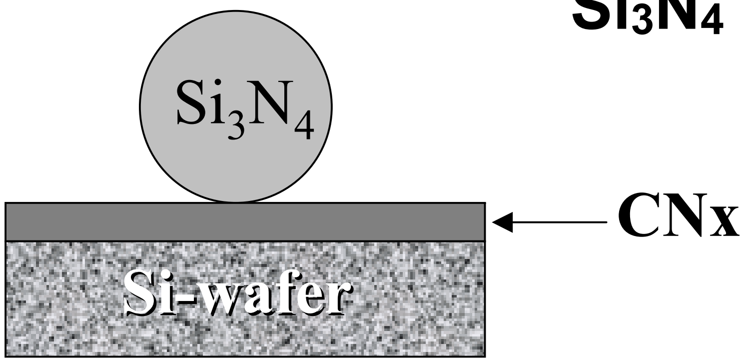


[N. Umehara, Sato, K. Kato 1997]
Pin : Si3N4 ball (r=4.0mm, Rmax = 15 nm)
Disk : 100 nm CNx / Si (Rmax = 1~3 nm)
Normal load : 100 mN
Maximum contact pressure : 200 MPa
Sliding velocity : 4 mm/s
240 friction cycles
Si3N4
CNx
Si Wafer
Friction coefficient μ
0.5
0.4
0.3
0.2
0.1
0
0.16
0.05
0.009
0.03
0.36
Air
(10^5 Pa)
Vacuum
(2x10^-4 Pa)
N2
CO2
O2
(7.4x10^4 Pa)



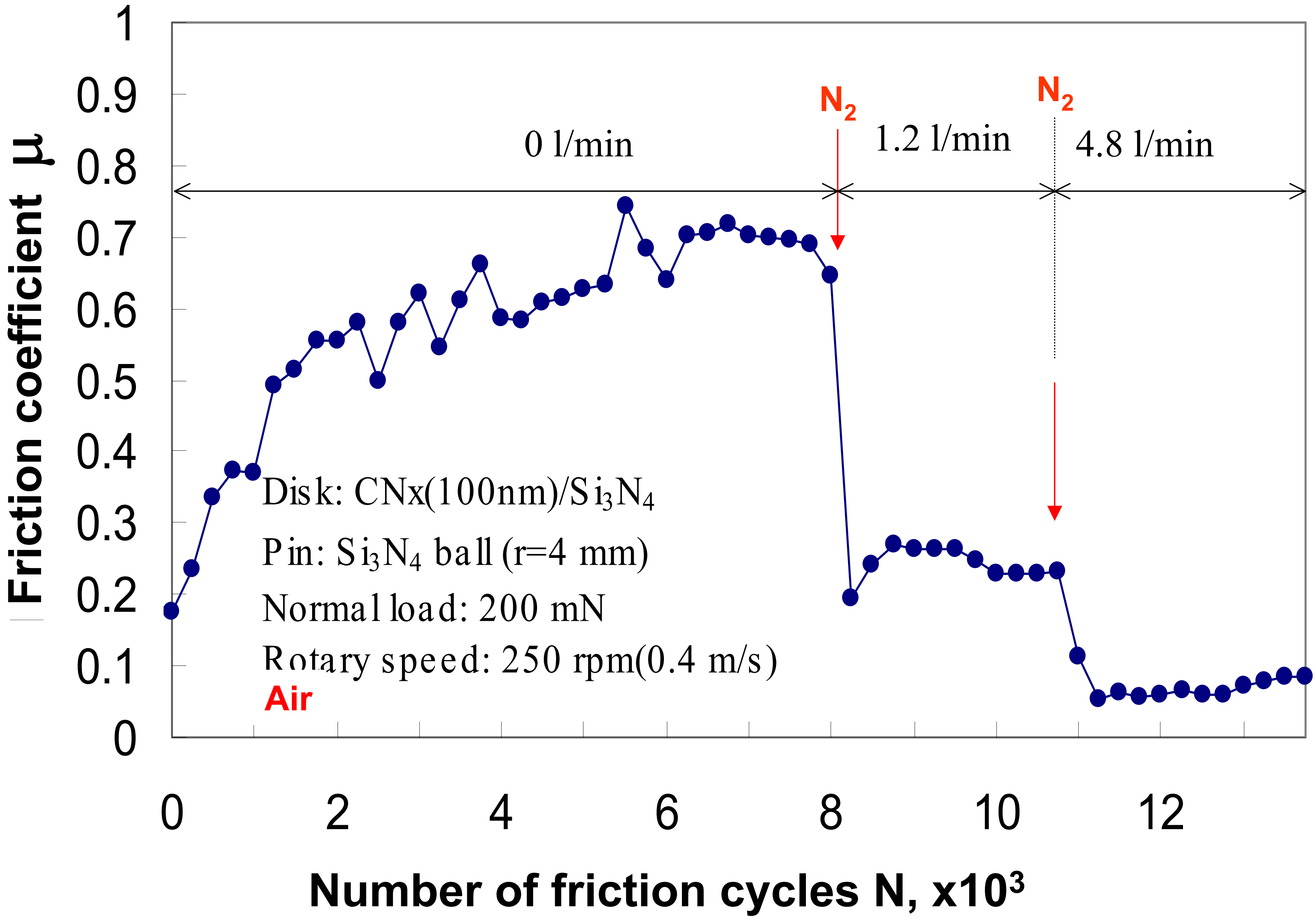
[N. Umehara,M.Tatsuno, K. Kato, 1999]
Disk : a-CNx on Si (t=100nm)
Ball : Si3N4 (r=4.0mm)
Normal load : 125-132mN
Slidnig speed : 4 mm/s
0.152
0.081
0.007
Si3N4
CNx
Si Wafer
Friction coefficient μ
0.20
0.15
0.10
0.05
0
0
1
2
3
4
5
6
7
8
Pressure of N2 , x 10⁴ Pa

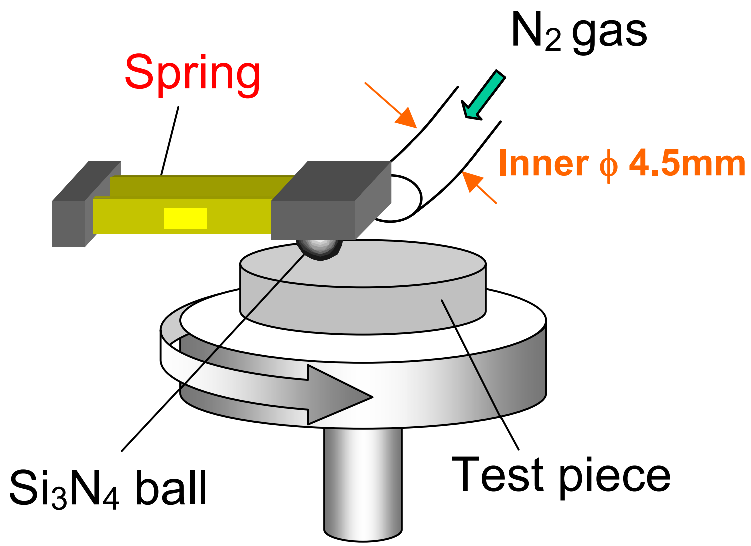


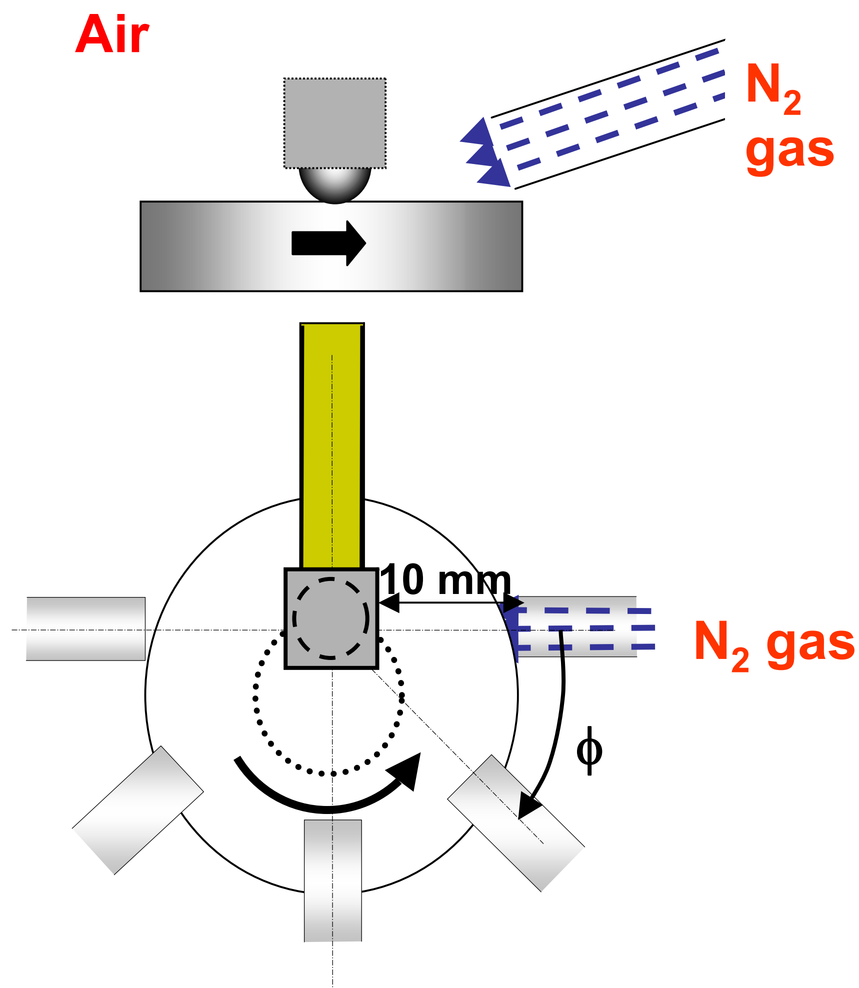


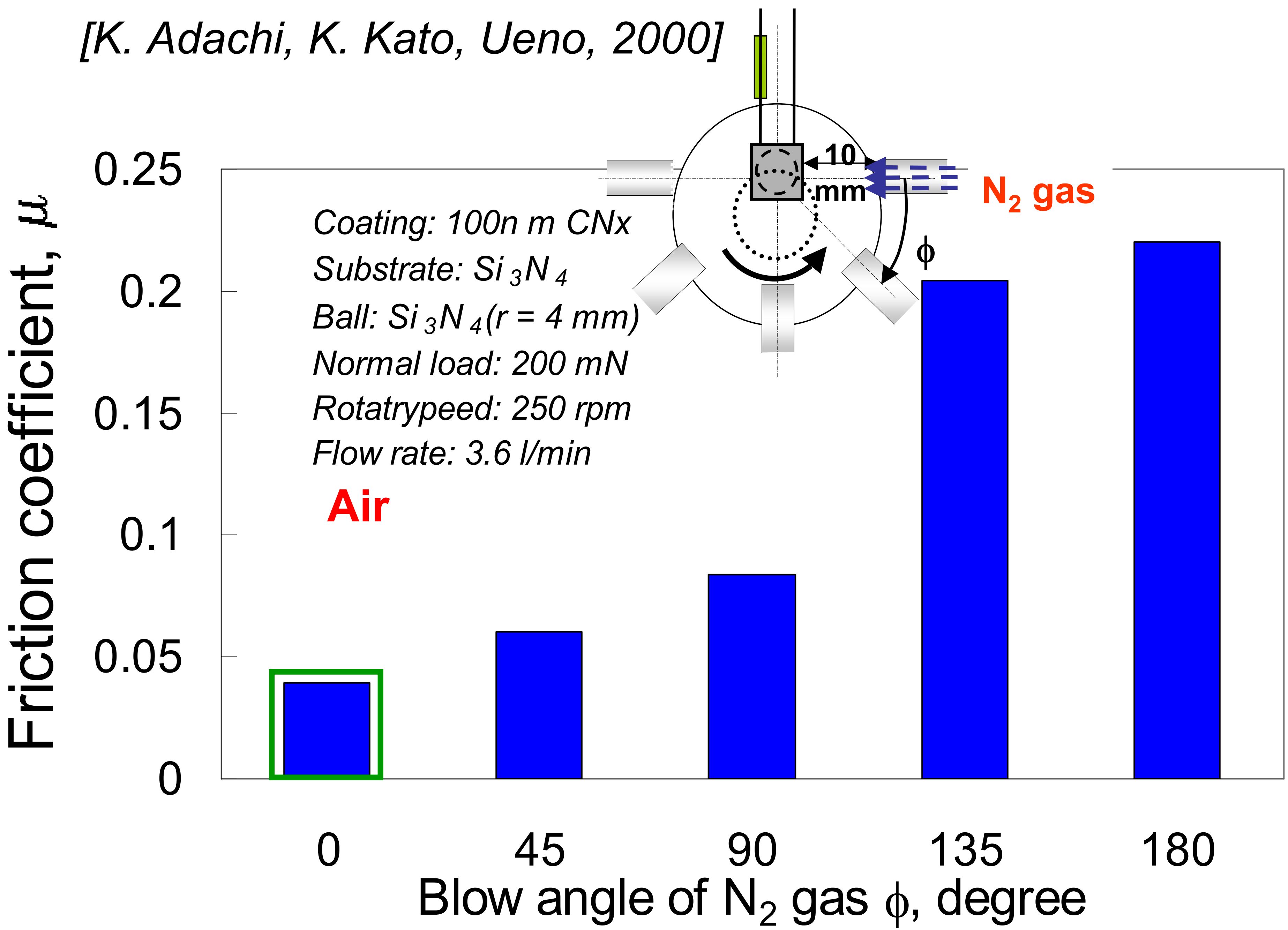
Ball-on disk tester

[K. Adachi, K. Kato, Ueno, 2000]

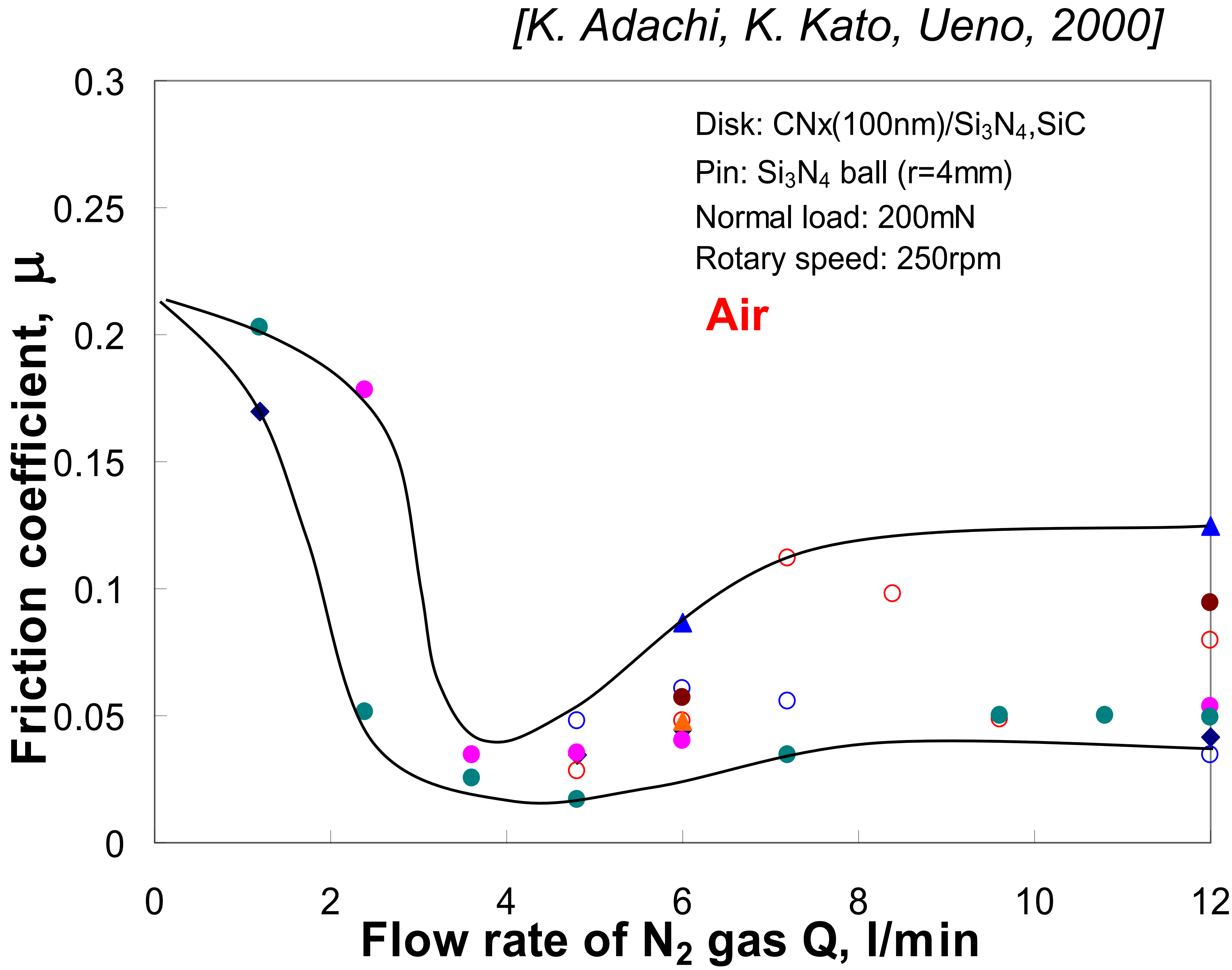



N2 gas
Spring
Inner ϕ 4.5mm
Si3N4 ball
Test piece

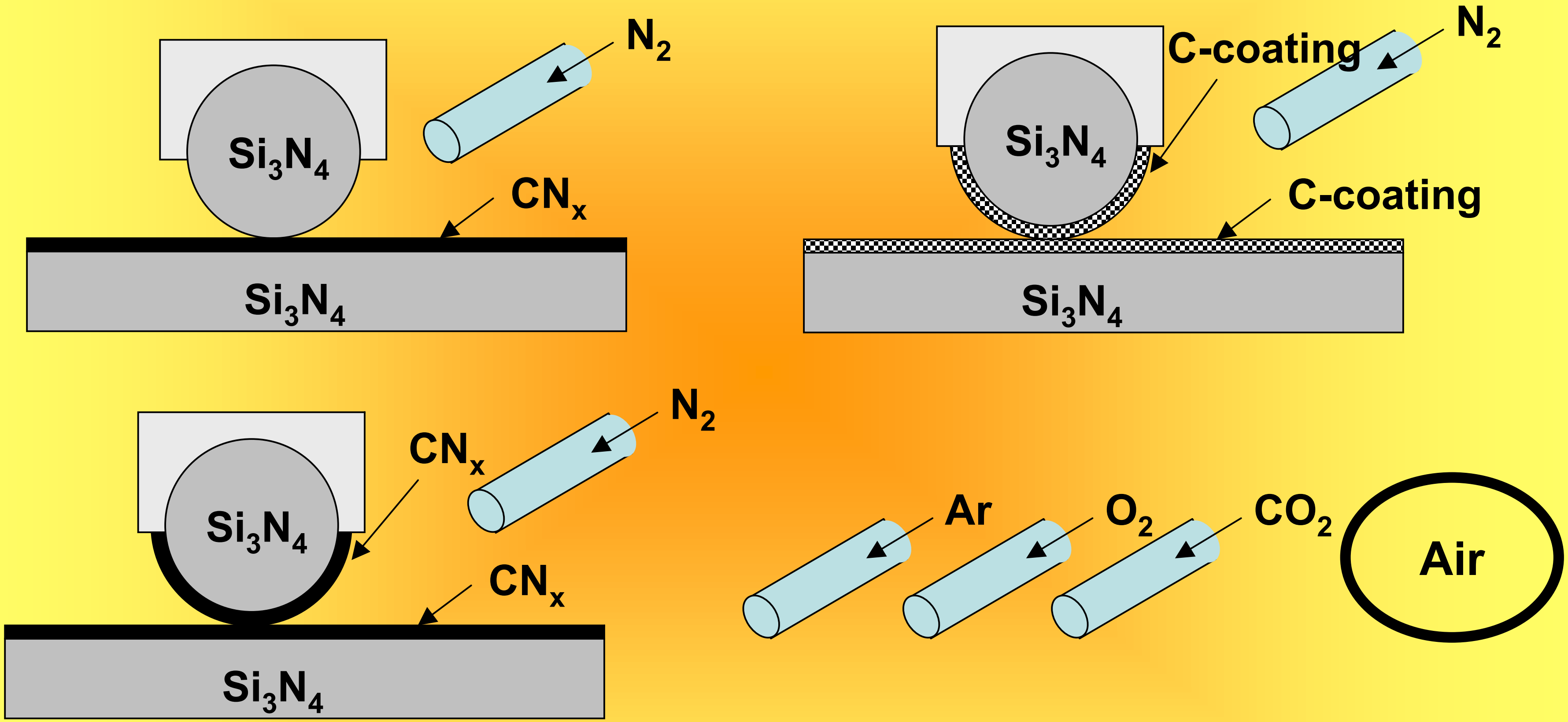

Air
N2 gas
10 mm
N2 gas
ϕ



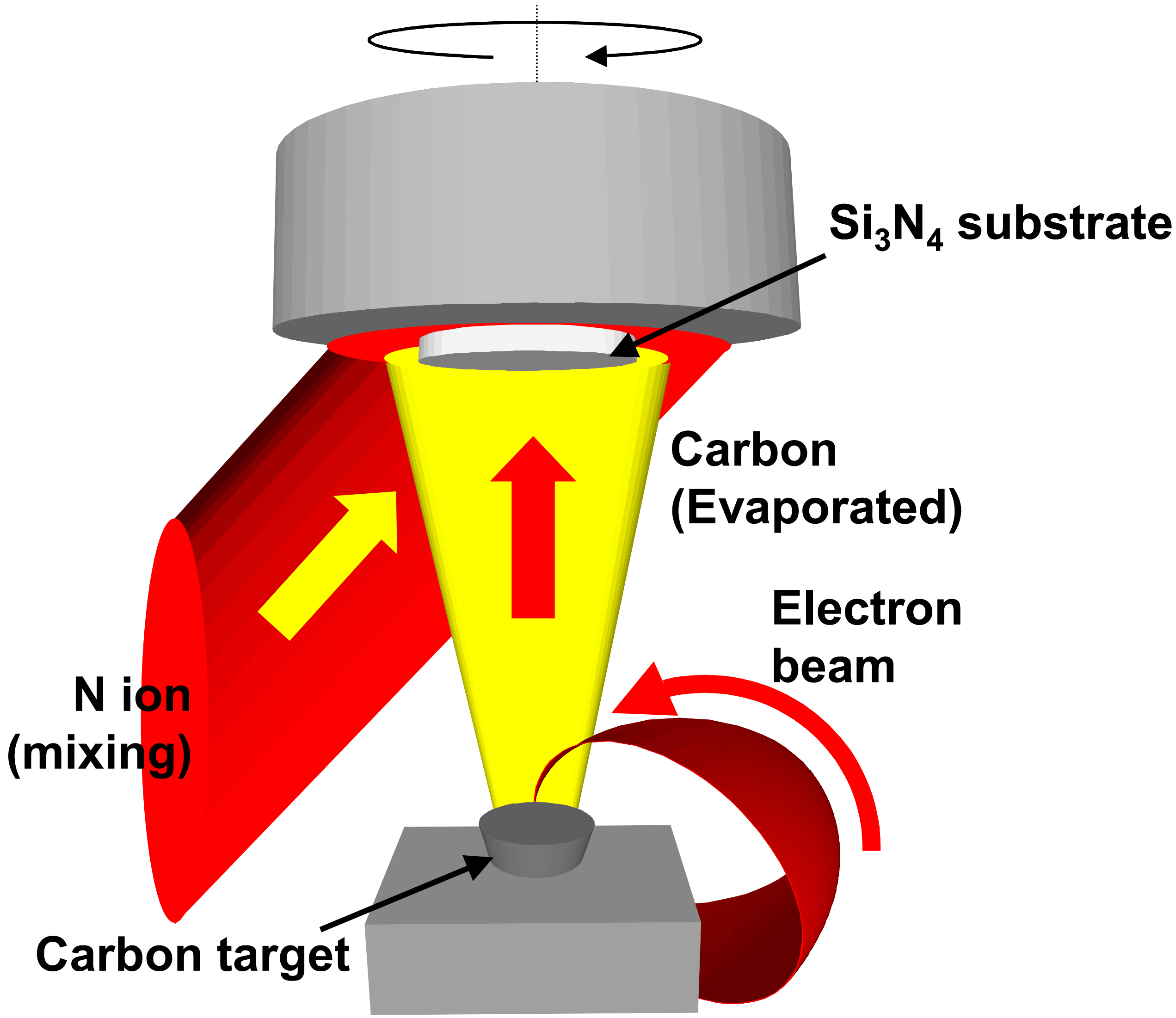
[K. Adachi, K. Kato, Ueno, 2000]
Coating: 100n m CNx
Substrate: Si 3N 4
Ball: Si 3N 4(r = 4 mm)
Normal load: 200 mN
Rotatrypeed: 250 rpm
Flow rate: 3.6 l/min
Air
10 mm
N2 gas
ϕ
Friction coefficient, μ
0.25
0.2
0.15
0.1
0.05
0
0
45
90
135
180
Blow angle of N2 gas ϕ, degree


[K. Adachi, K. Kato, Ueno, 2000]
Disk: CNx(100nm)/Si_3N_4,SiC
Pin: Si_3N_4 ball (r=4mm)
Normal load: 200mN
Rotary speed: 250rpm
Air
Friction coefficient, μ
Flow rate of N_2 gas Q, l/min
0.3
0.25
0.2
0.15
0.1
0.05
0
0
2
4
6
8
10
12

What is the best combination among Si_3N_4/CN_x , CN_x/CN_x and C/C?



Is N_2 gas blow better than Ar, O_2, CO_2 or open air for lubricating CN_x/CN_x contact?



Si_3N_4 substrate
Carbon
(Evaporated)
Electron
beam
N ion
(mixing)
Carbon target

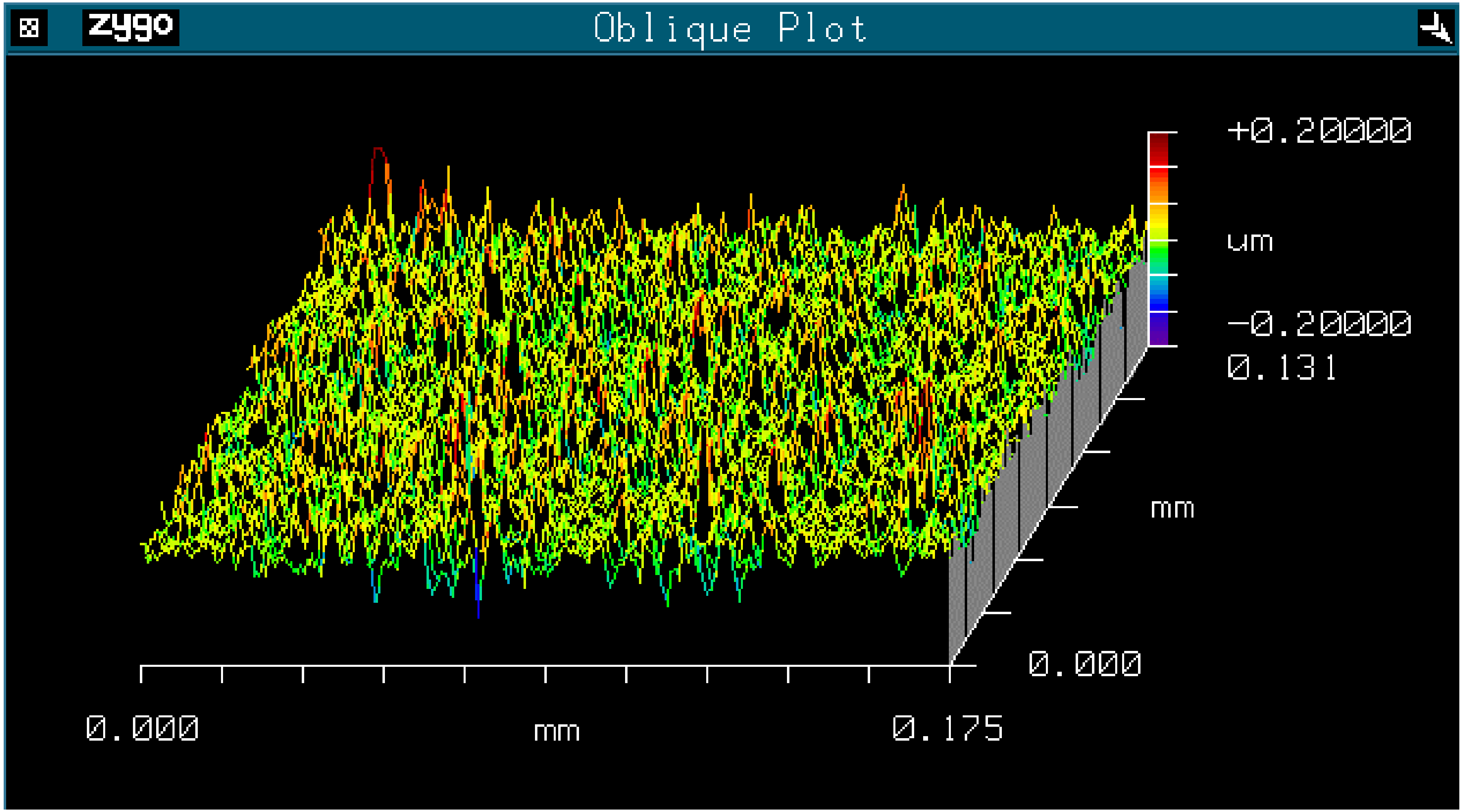
Deposition conditions

Evaporation	Target	Carbon : 99.999 %	
	Coating speed	5, 10, 20, 30, 50 Å/s	
Mixing	N ion beam	Acc. voltage	1.5 kV
		Current density	90 μA/cm^2
	Gas flow	N_2: 3.0 SCCM *	
Pressure	Background	< 2.0×10^{-4} Pa	
	Operating	7.1×10^{-3} Pa	
Substrate		Si_3N_4	
Coating thickness		about 400nm	
Rotation speed		4 rpm	

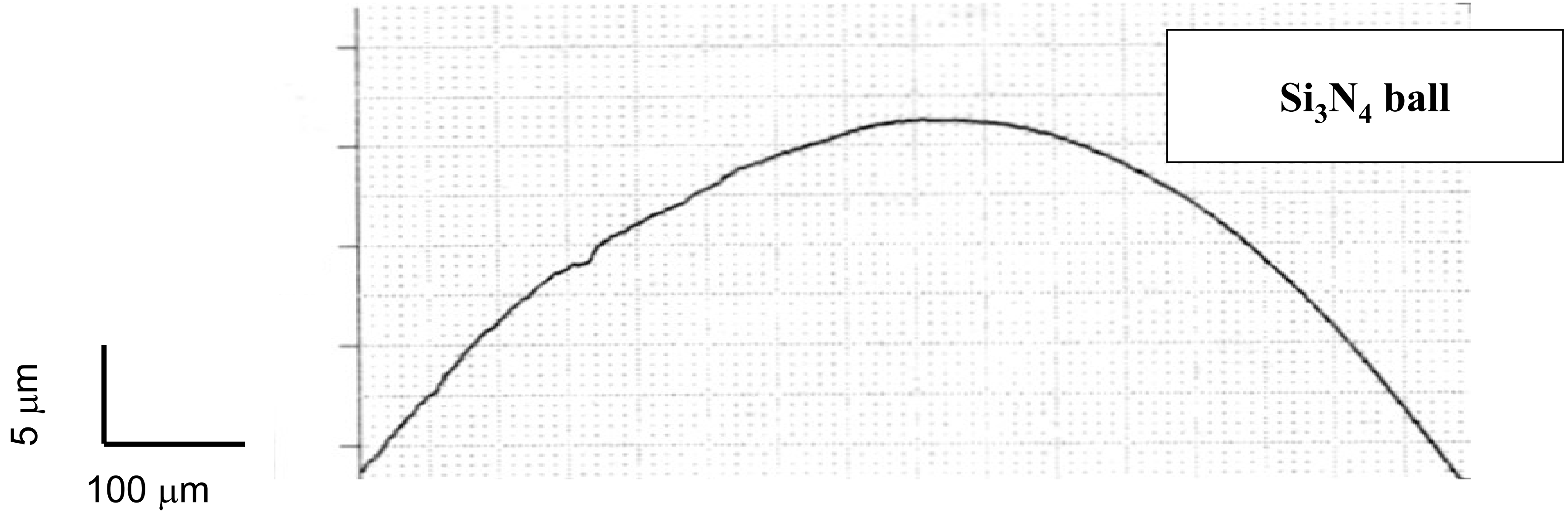
Sputter cleaning	N ion beam	Acc. Voltage	1.5 kV
		Current density	100 μA/cm^2
	Gas flow	N_2: 3.0 SCCM *	
	Duration	5 minutes	

*SCCM: Standard Cubic Centimeter per Minute

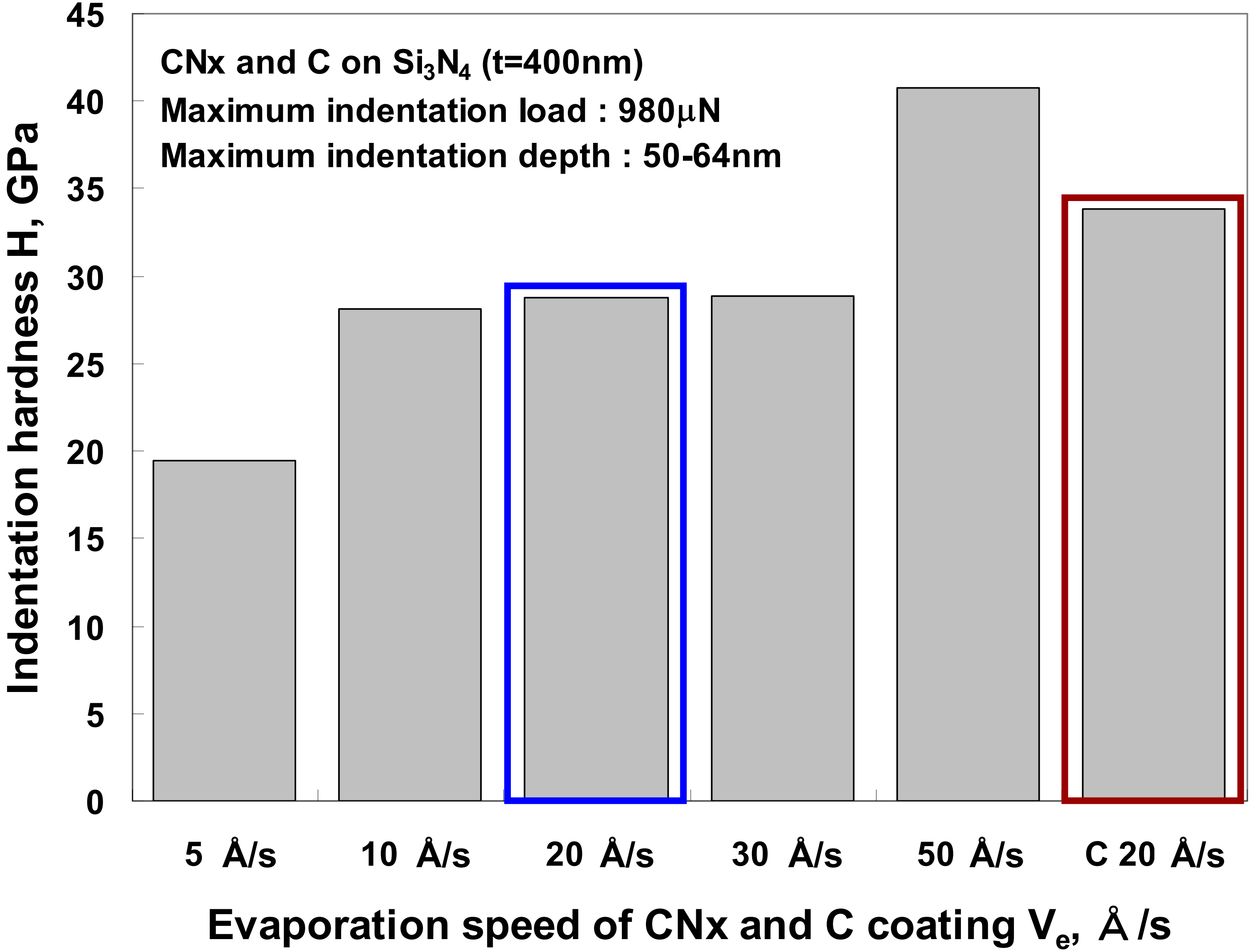
The surface of CN_x coating on Si_3N_4 substrate disk



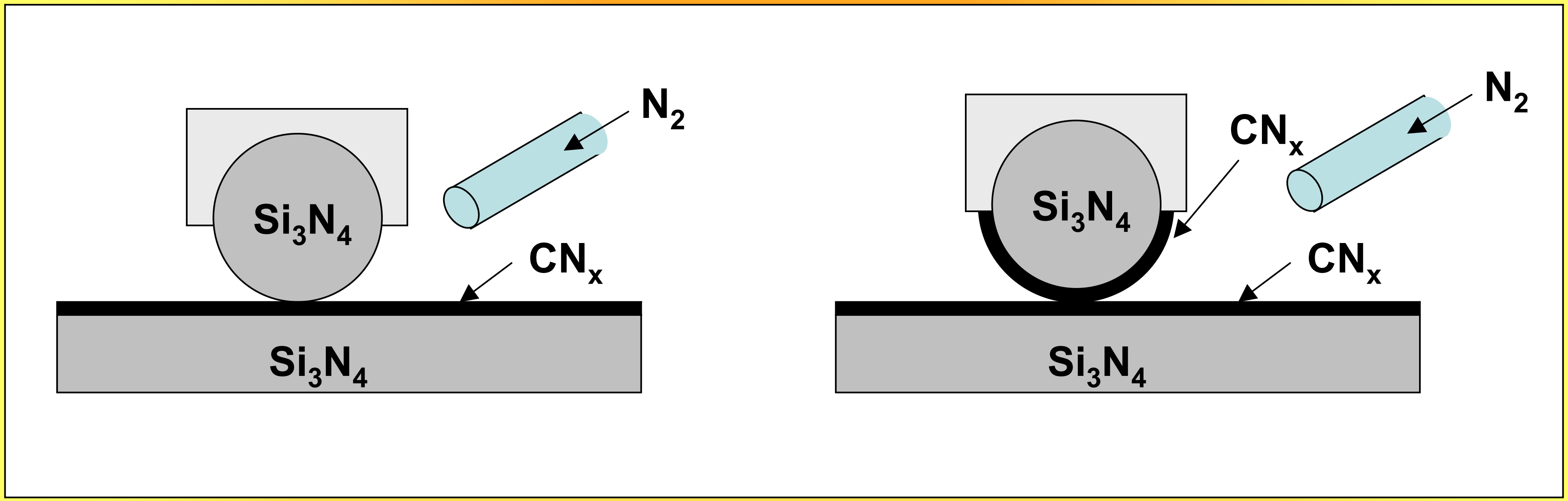
The surface of CN_x coating on Si_3N_4 substrate ball



Hardness of CN_x and C coatings

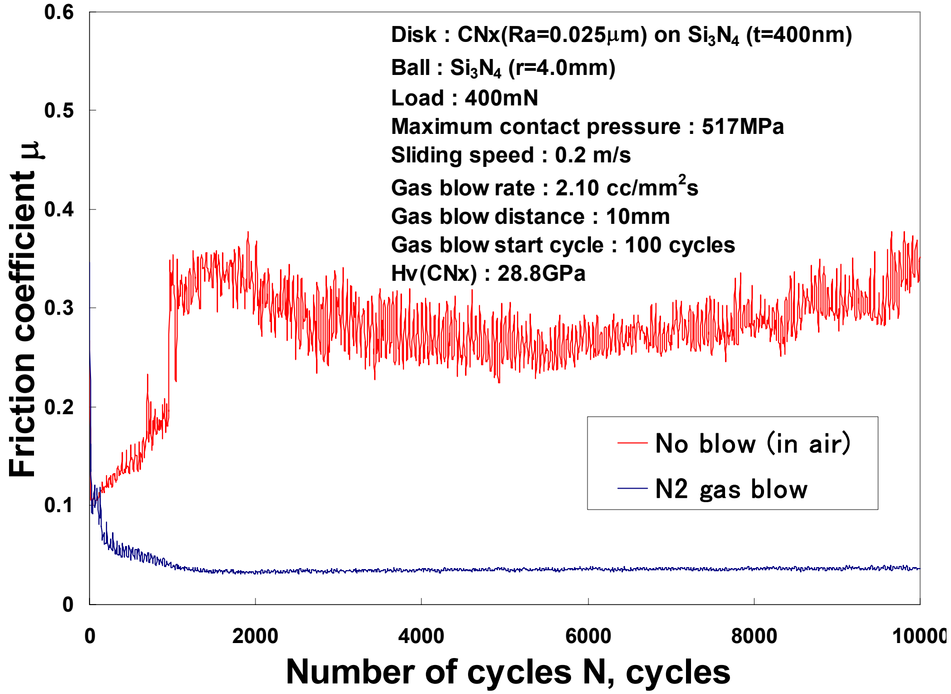


Si_3N_4/CN_x vs. CN_x/CN_x

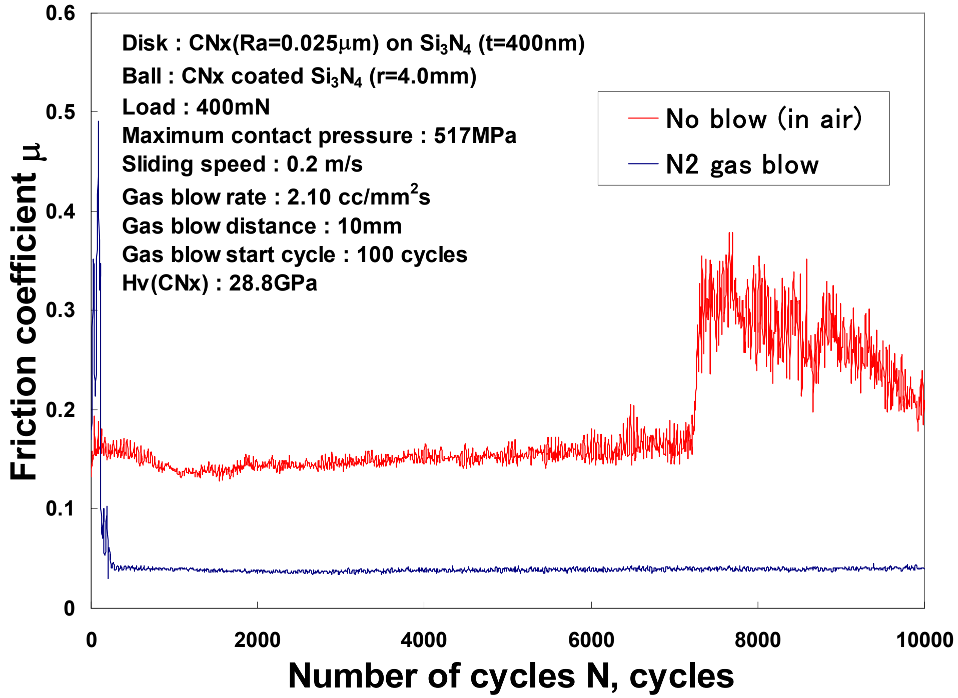


Friction in N_2 gas blow

Si_3N_4 / CN_x sliding



CN_x / CN_x sliding



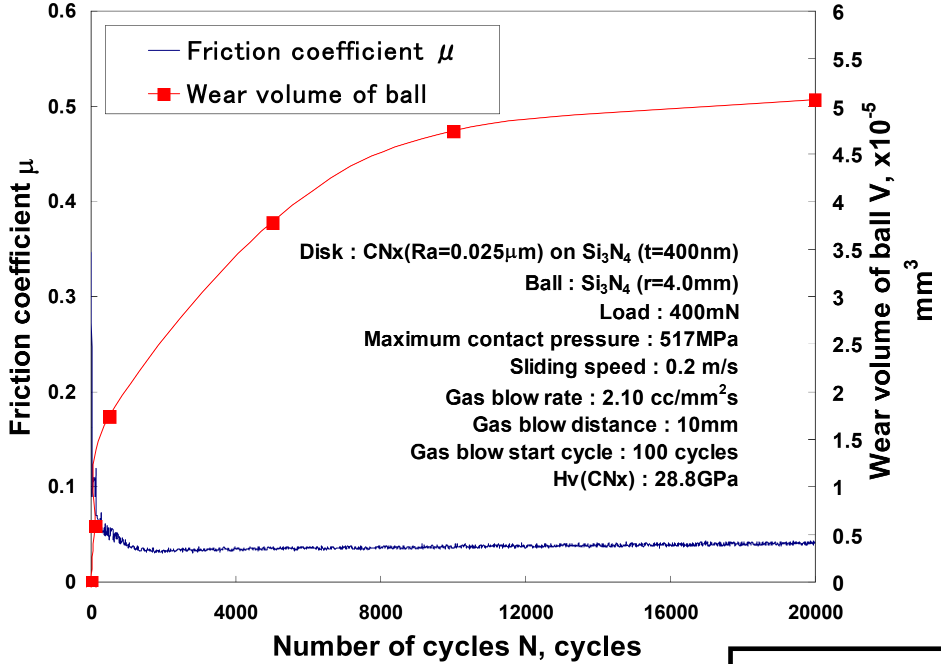
CNx / CNx sliding :

low and stable friction faster than CNx / Si_3N_4 sliding

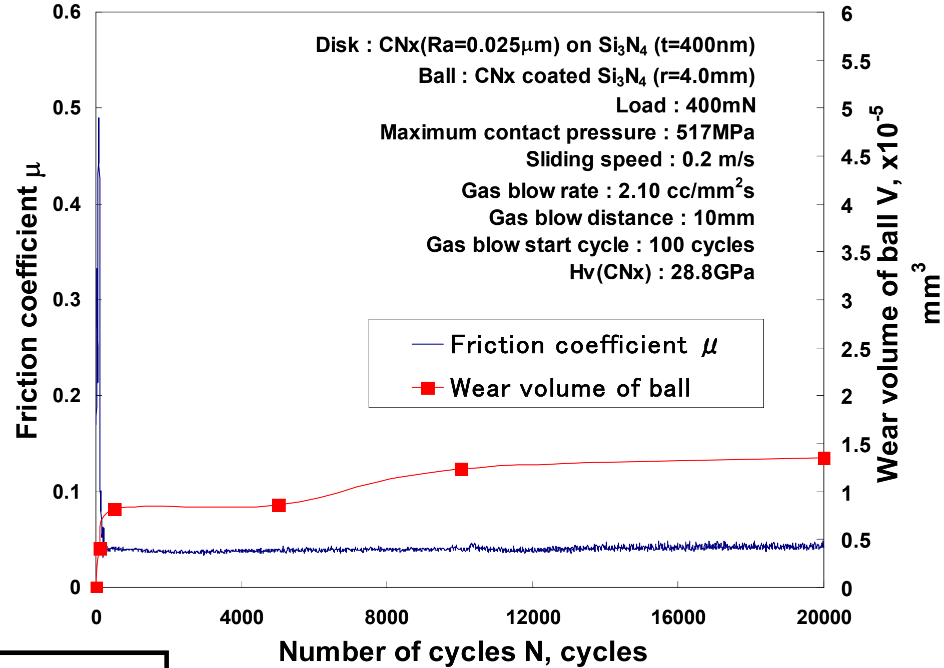
μ=0.03 (blow)
μ=0.15 (in air)

Wear of ball in N_2 gas blow

Si_3N_4 / CN_x sliding



CN_x / CN_x sliding



μ=0.03 (blow)

μ=0.15 (in air)

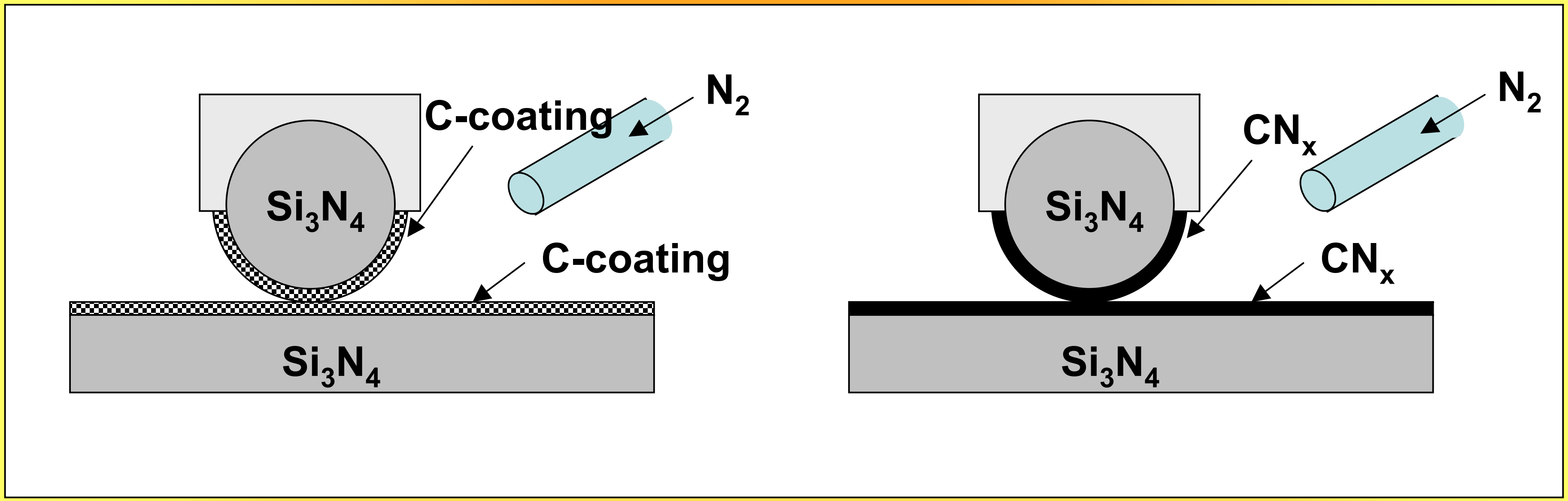
at 500~20000cycles

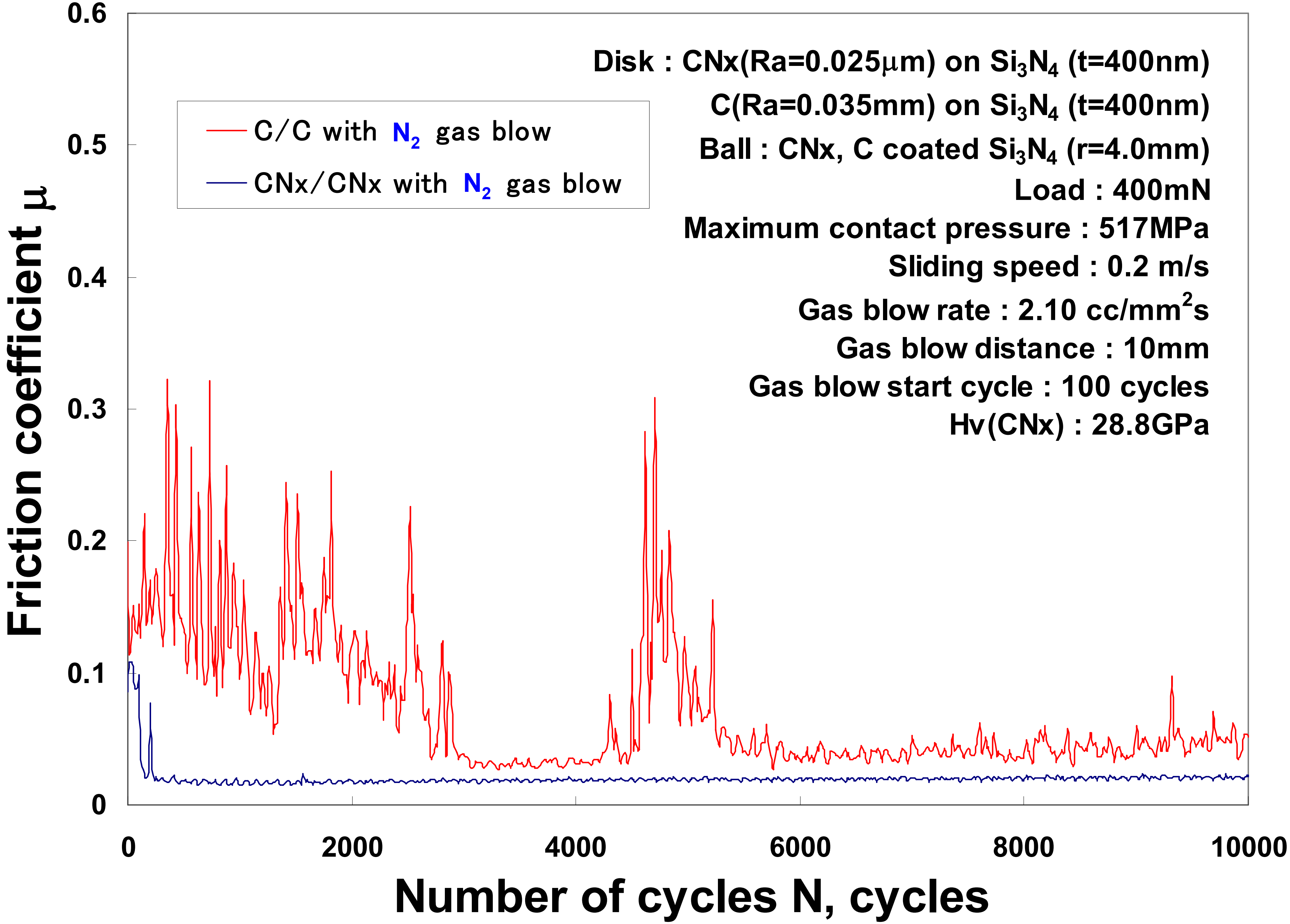
$W_{s,s}$ = 5.89x10^{-8} mm^3/Nm

at 500~20000cycles

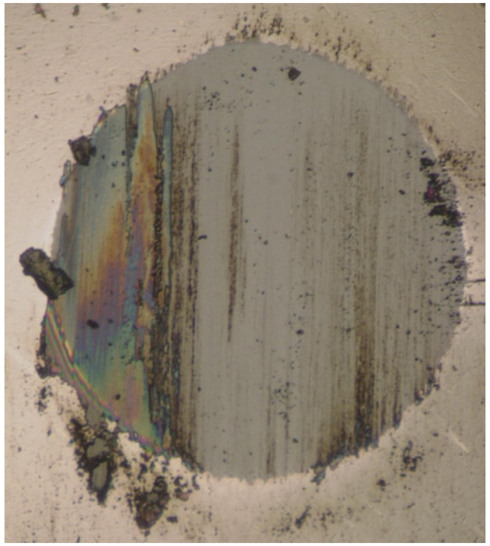
$W_{s,s}$ = 1.13x10^{-8} mm^3/Nm

C/C vs. CN_x/CN_x




Disk : CNx(Ra=0.025μm) on Si3N4 (t=400nm)
C(Ra=0.035mm) on Si3N4 (t=400nm)
Ball : CNx, C coated Si3N4 (r=4.0mm)
Load : 400mN
Maximum contact pressure : 517MPa
Sliding speed : 0.2 m/s
Gas blow rate : 2.10 cc/mm2s
Gas blow distance : 10mm
Gas blow start cycle : 100 cycles
Hv(CNx) : 28.8GPa
C/C with N2 gas blow
CNx/CNx with N2 gas blow
Friction coefficient μ
0.6
0.5
0.4
0.3
0.2
0.1
0
2000
4000
6000
8000
10000
Number of cycles N, cycles

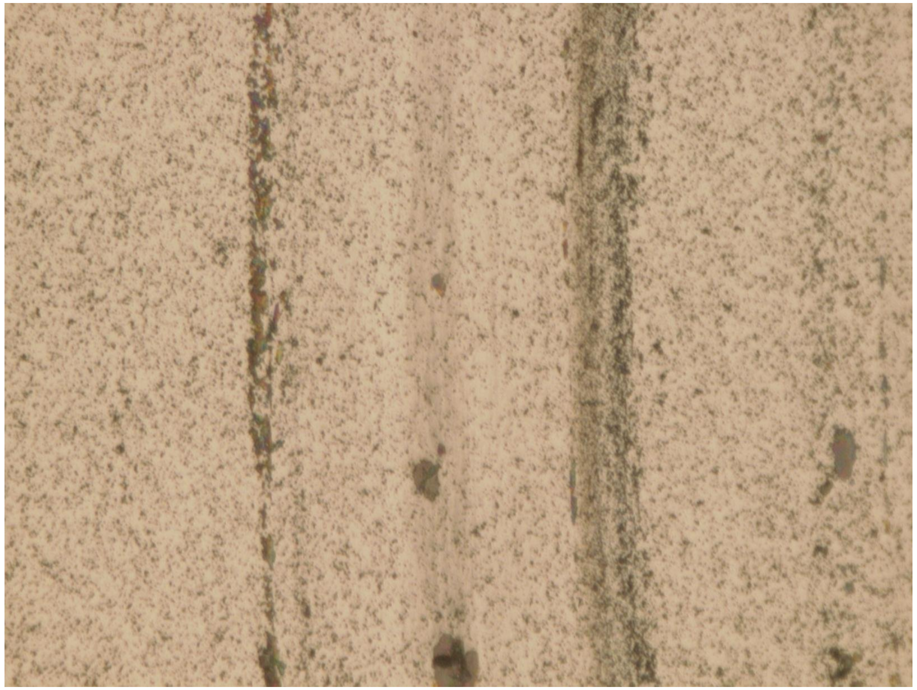
C-coated
Si_3N_4 ball



Sliding direction of counterface

100 μm

C-coated
Si_3N_4 disk



Sliding direction of disk

100 μm

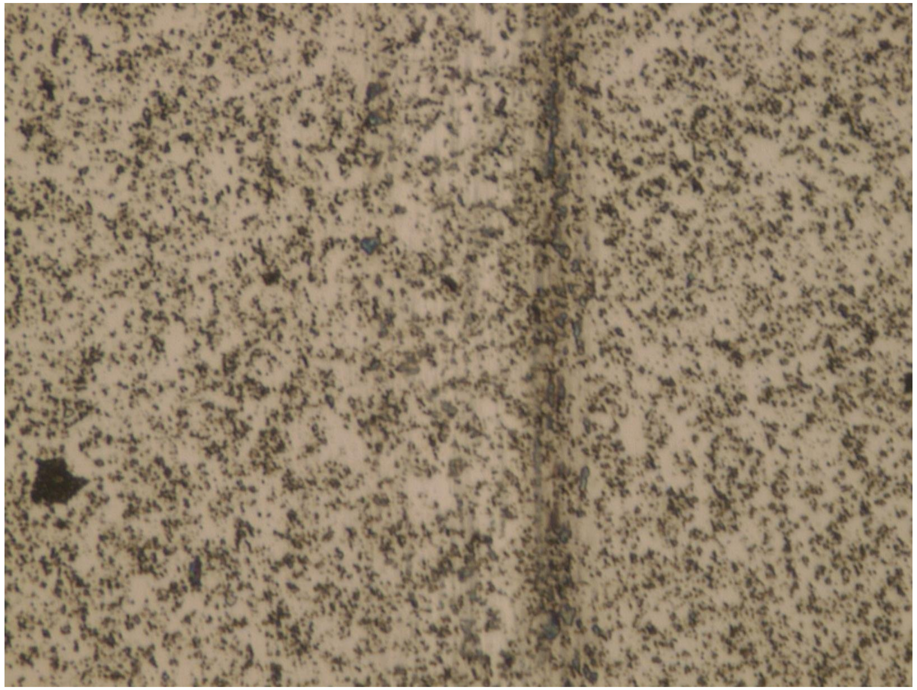
After sliding of 10000 cycles with N_2 gas blow in air

CN_x coated
Si_3N_4 ball

Sliding
direction of
counterface

100 μm

CN_x coated
Si_3N_4 disk

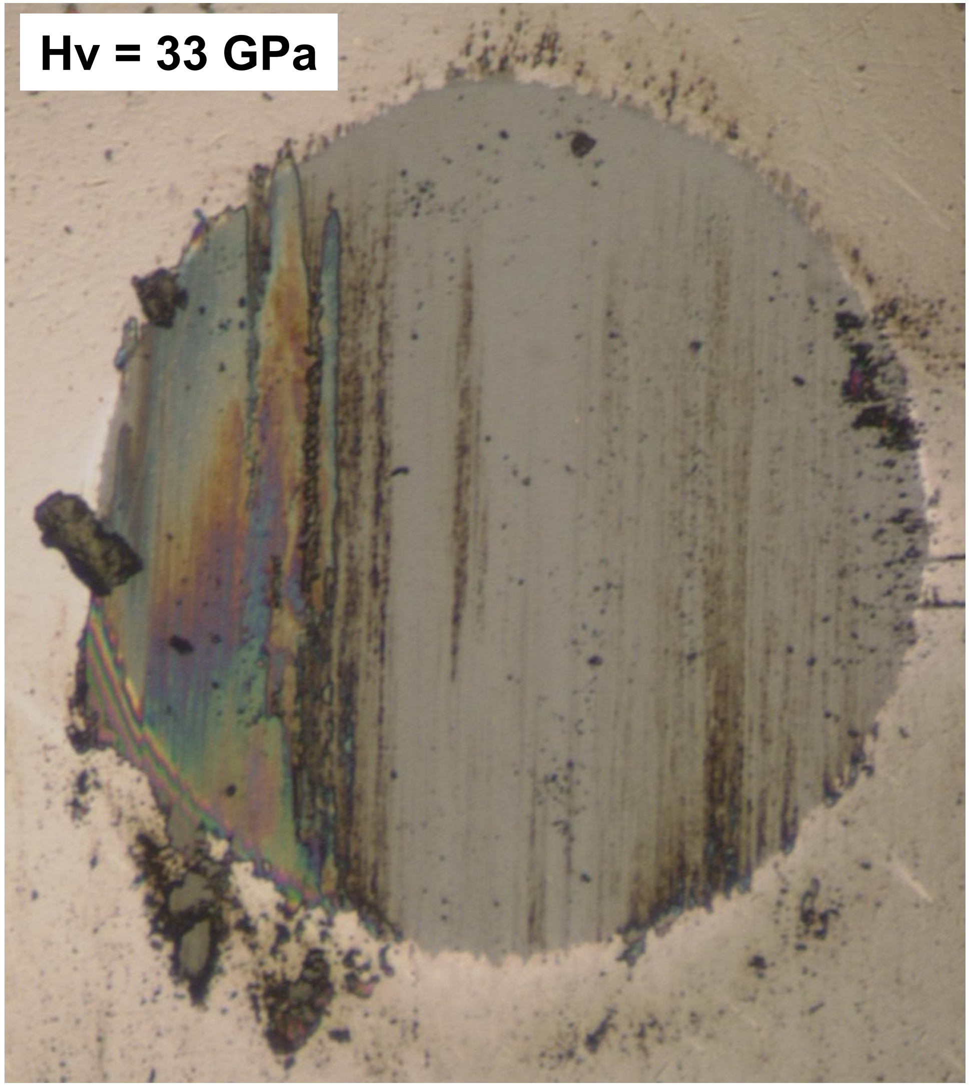


Sliding
direction of
disk

100 μm

After sliding of 10000 cycles with N_2 gas blow in air

C-coated Si_3N_4 ball



C / C

6.42×10^{-7} mm^3/Nm

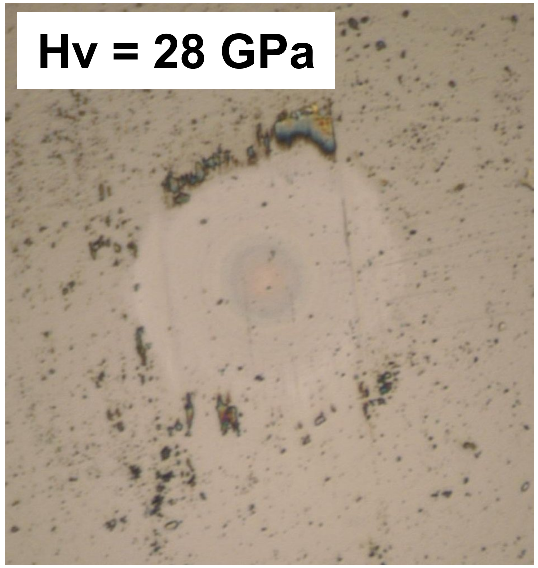
Sliding direction of counterface

100 μm

After

10000 cycles

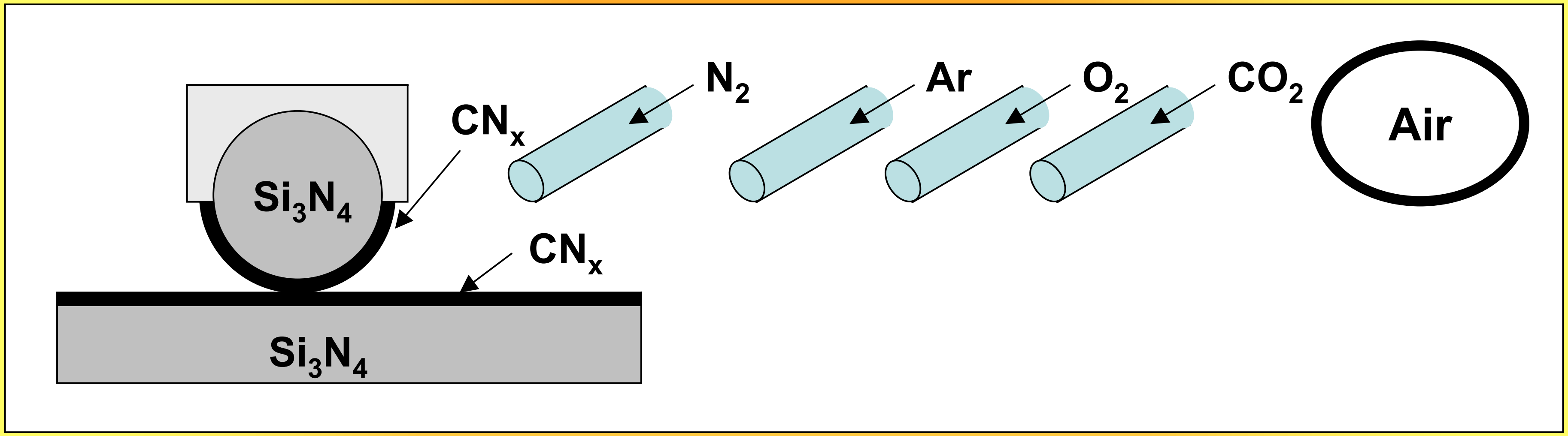
CN_x-coated Si_3N_4 ball

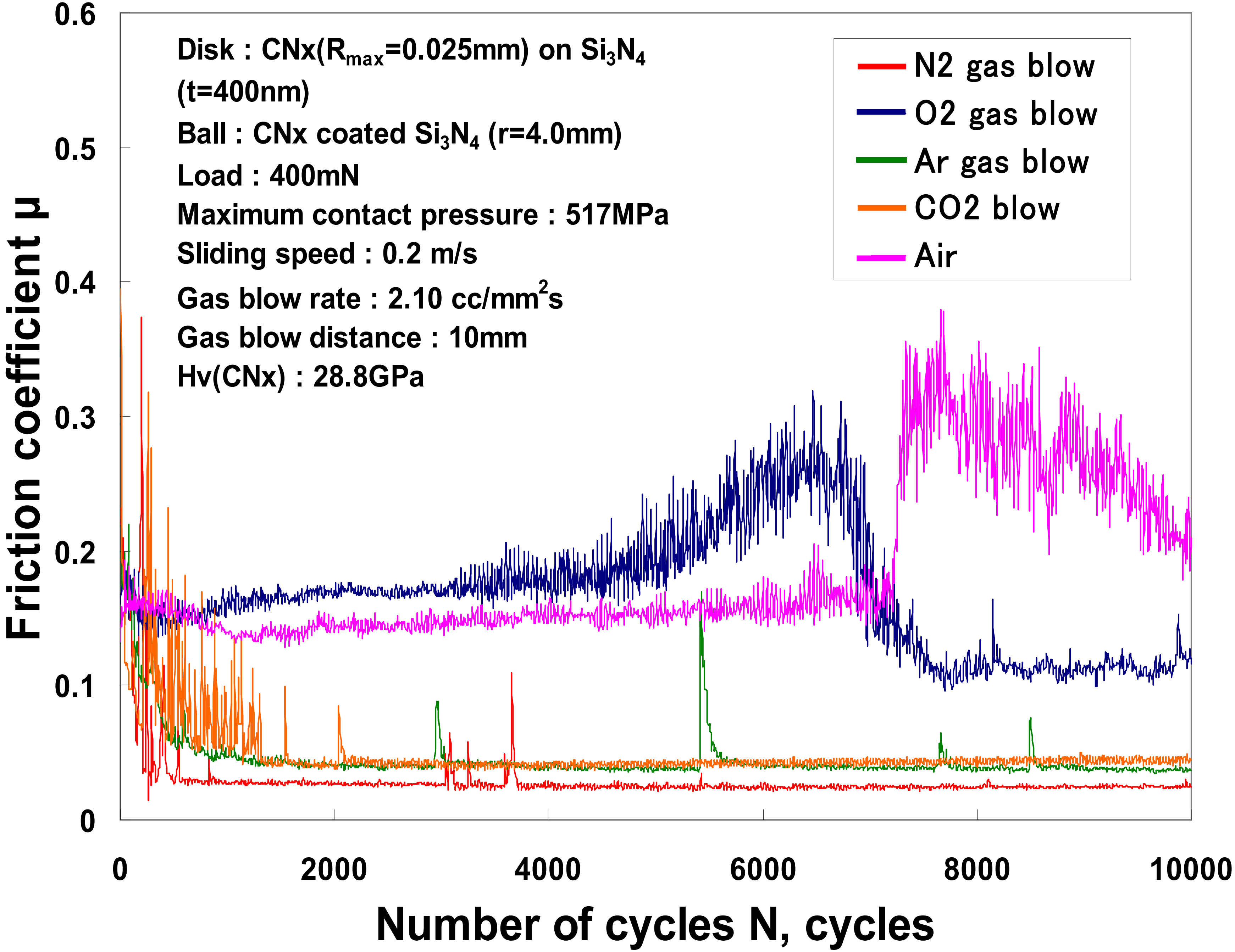


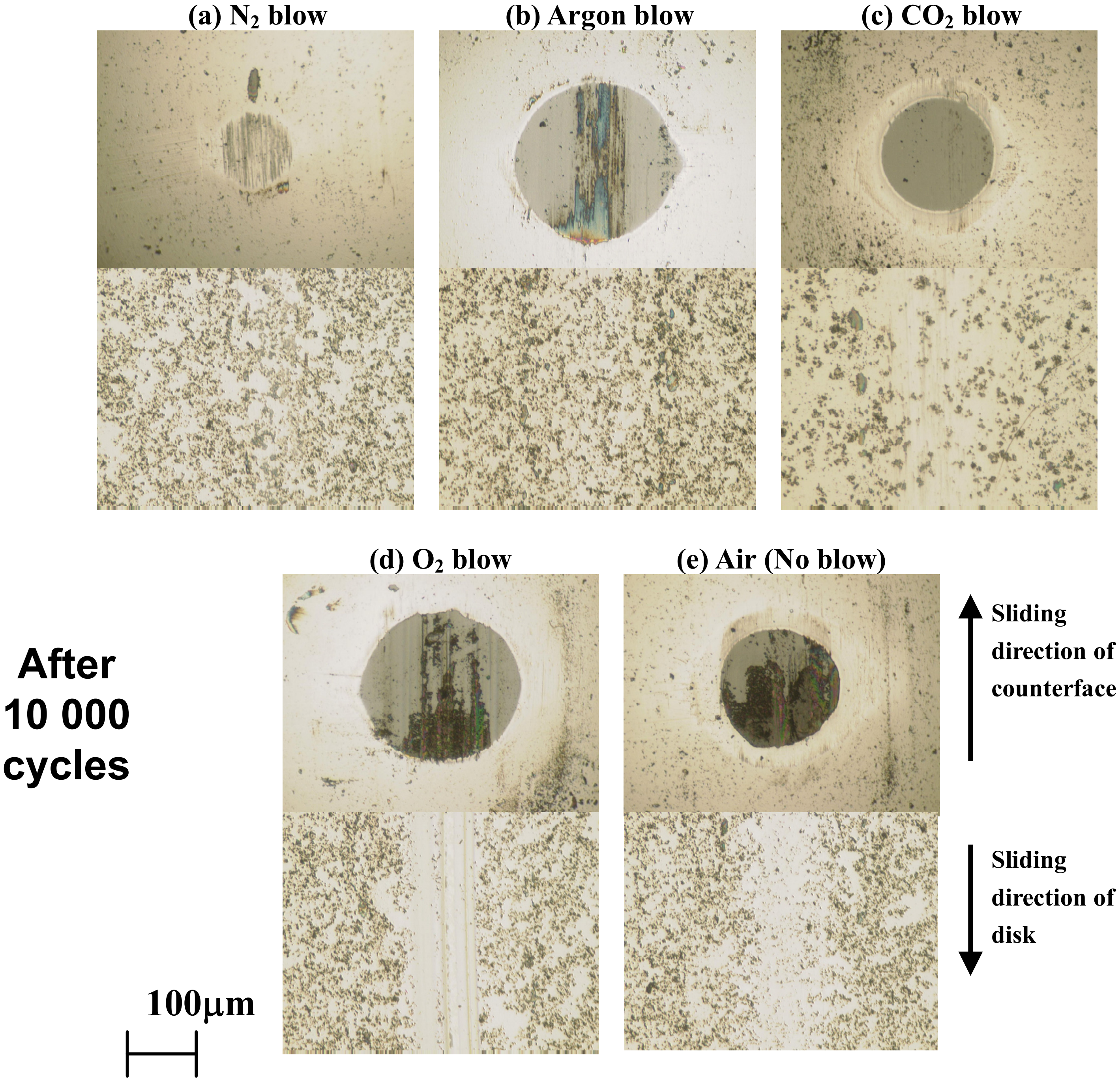
CN_x / CN_x

9.31×10^{-9} mm^3/Nm

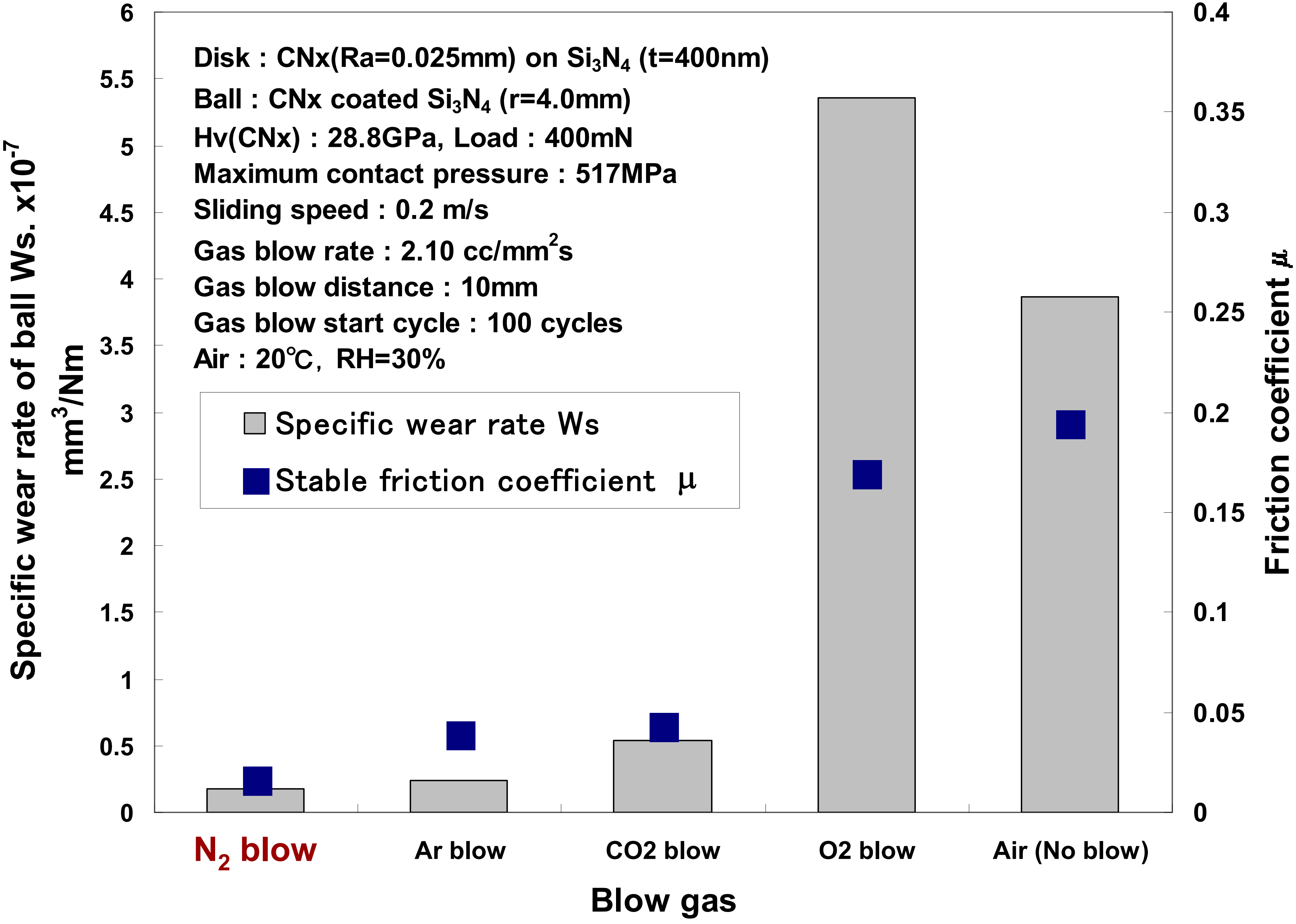
Effect of Gases of N_2, Ar, CO_2 and Air on friction and wear of CNx / CNx



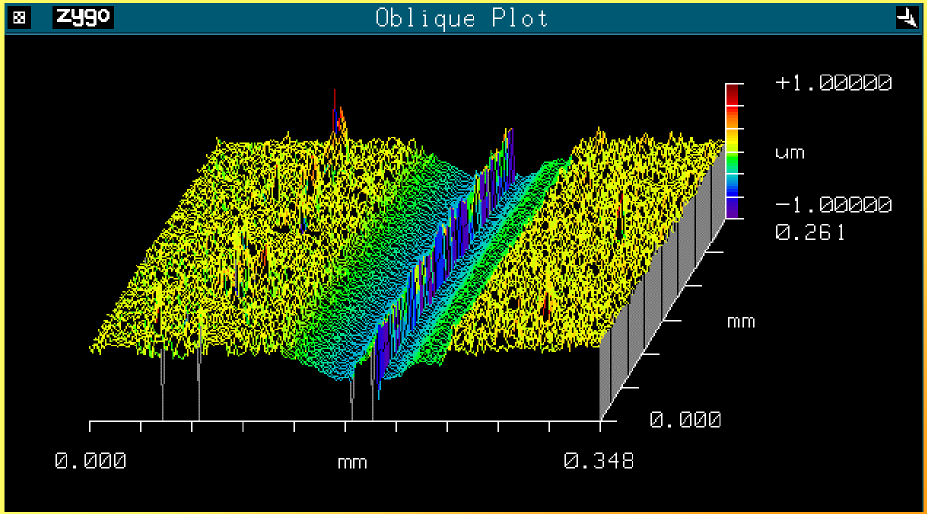

Disk : CNx(R_{max}=0.025mm) on Si_3N_4
(t=400nm)
Ball : CNx coated Si_3N_4 (r=4.0mm)
Load : 400mN
Maximum contact pressure : 517MPa
Sliding speed : 0.2 m/s
Gas blow rate : 2.10 cc/mm^2s
Gas blow distance : 10mm
Hv(CNx) : 28.8GPa
N2 gas blow
O2 gas blow
Ar gas blow
CO2 blow
Air
Friction coefficient μ
0.6
0.5
0.4
0.3
0.2
0.1
0
0
2000
4000
6000
8000
10000
Number of cycles N, cycles

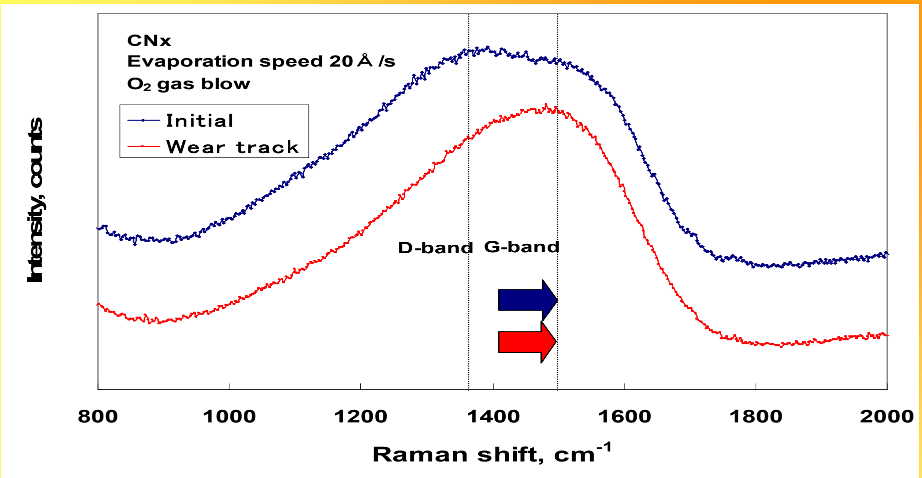


(a) N$_2$ blow
(b) Argon blow
(c) CO$_2$ blow
(d) O$_2$ blow
(e) Air (No blow)
After 10 000 cycles
Sliding direction of counterface
Sliding direction of disk
100μm



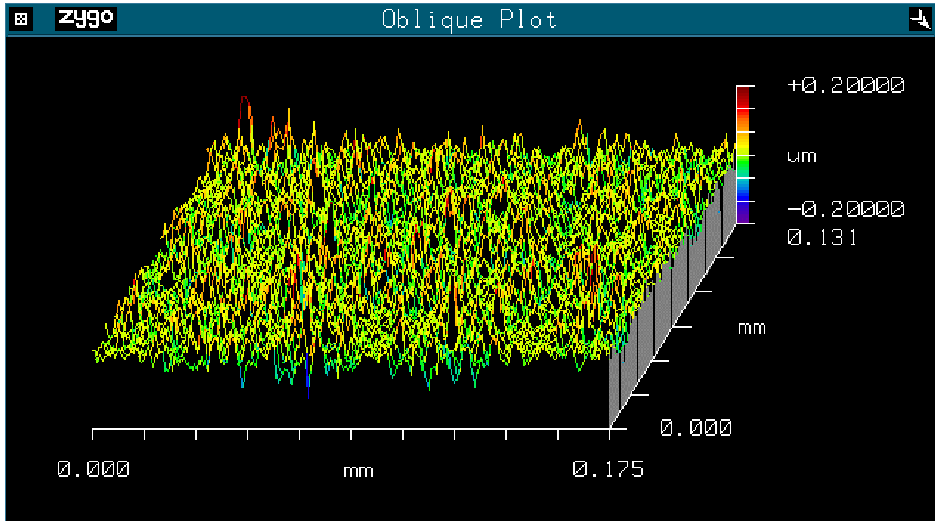
Disk : CNx(Ra=0.025mm) on Si_3N_4 (t=400nm)
Ball : CNx coated Si_3N_4 (r=4.0mm)
Hv(CNx) : 28.8GPa, Load : 400mN
Maximum contact pressure : 517MPa
Sliding speed : 0.2 m/s
Gas blow rate : 2.10 cc/mm^2s
Gas blow distance : 10mm
Gas blow start cycle : 100 cycles
Air : 20℃, RH=30%
Specific wear rate Ws
Stable friction coefficient μ
Specific wear rate of ball Ws. x10^{-7} mm^3/Nm
Friction coefficient μ
6
5.5
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
N_2 blow
Ar blow
CO2 blow
O2 blow
Air (No blow)
Blow gas



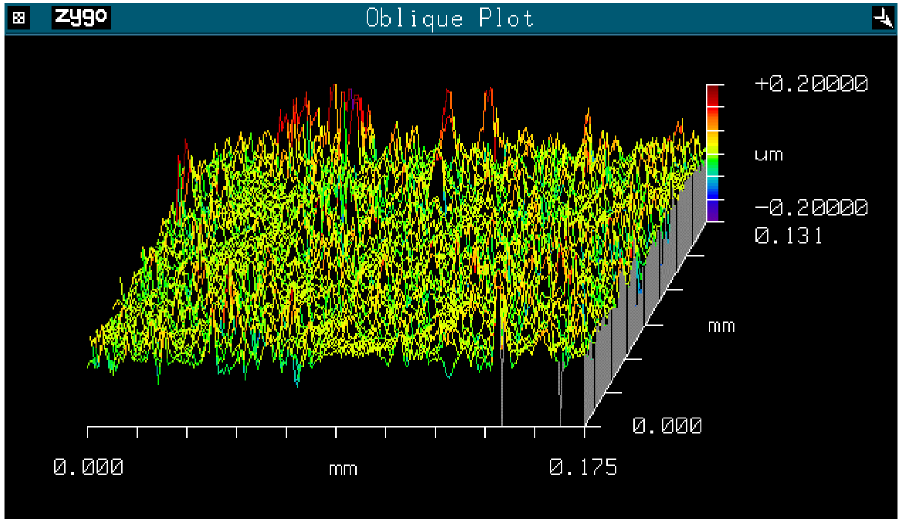


Surface analysis

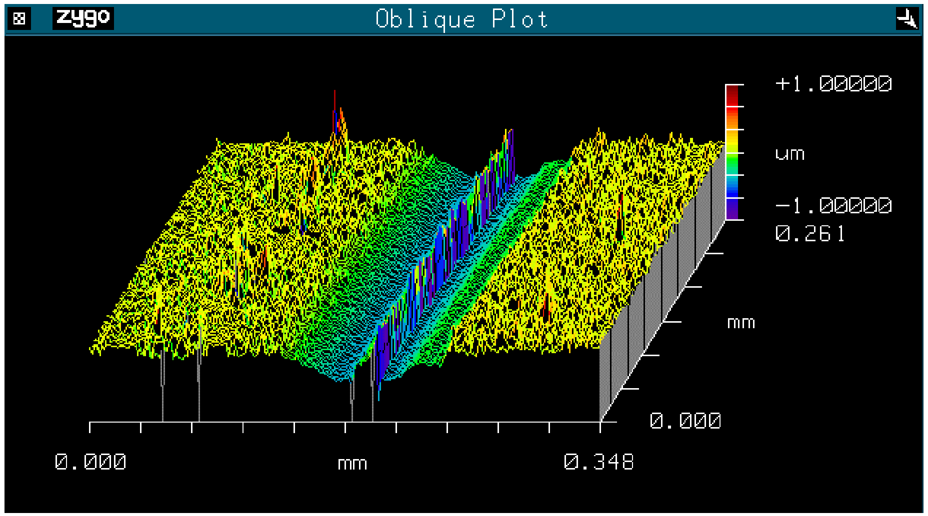
CNx on Si_3N_4 disk after 10000 sliding cycles in blows of Nitrogen , Oxygen, and in air. W = 400 mN, V = 0.2 m/s



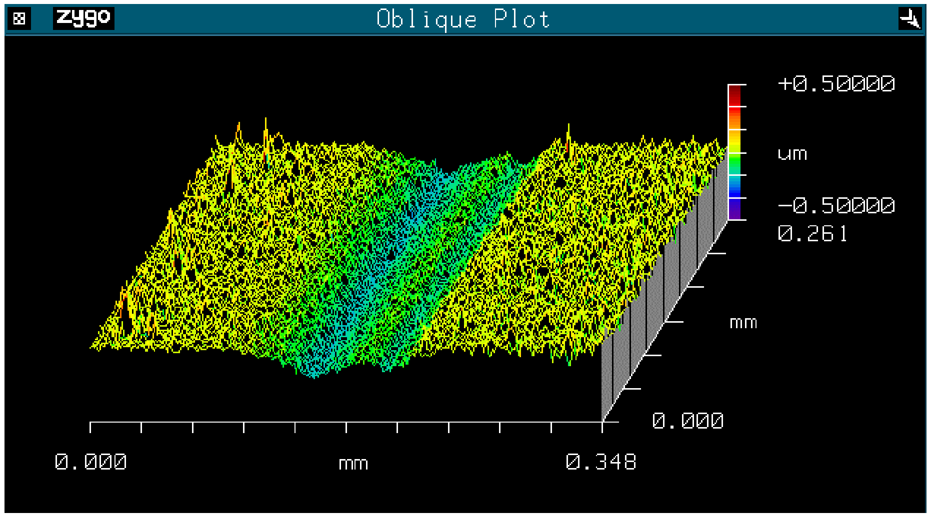
Initial surface



In Nitrogen blow

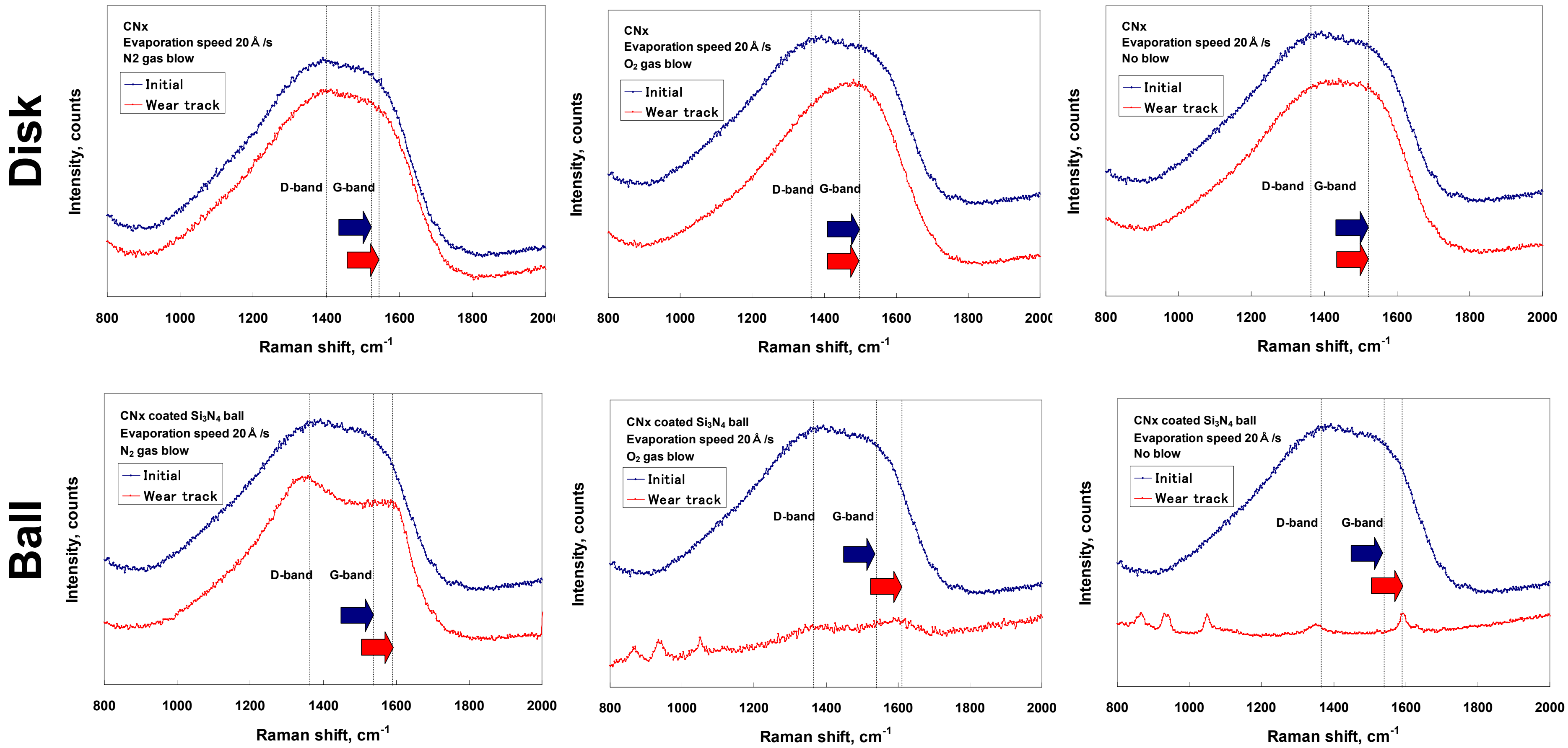


In Oxygen blow



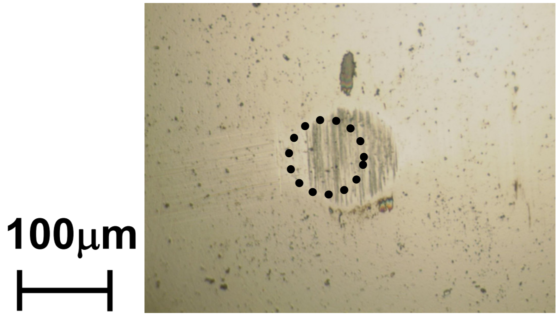
In Air

Raman spectra of initial surface and wear track of CN_x

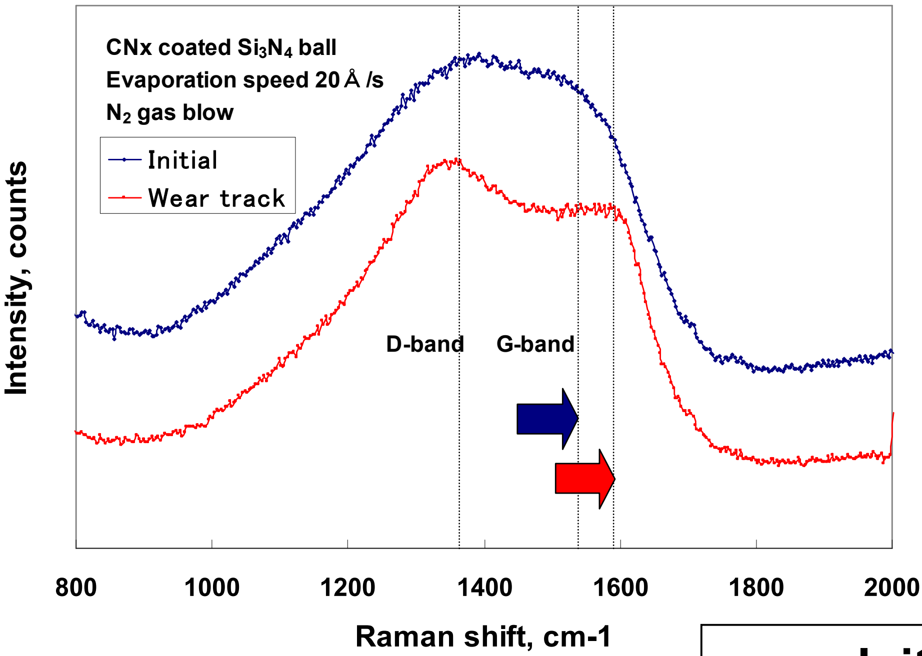


N$_2$ gas blow　　O$_2$ gas blow　　In Air

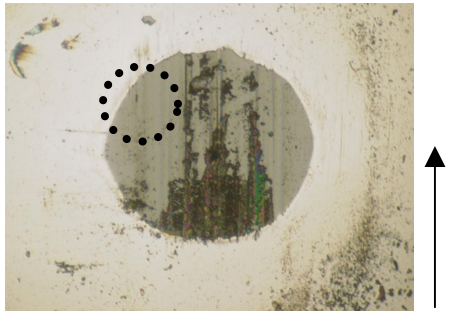
N_2 gas blow

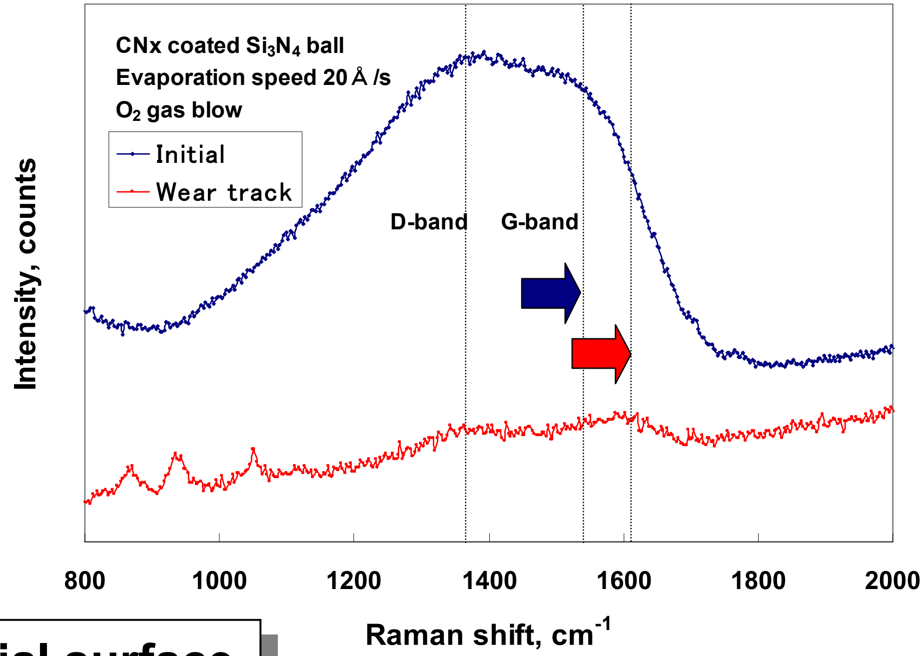


Sliding direction of counterface



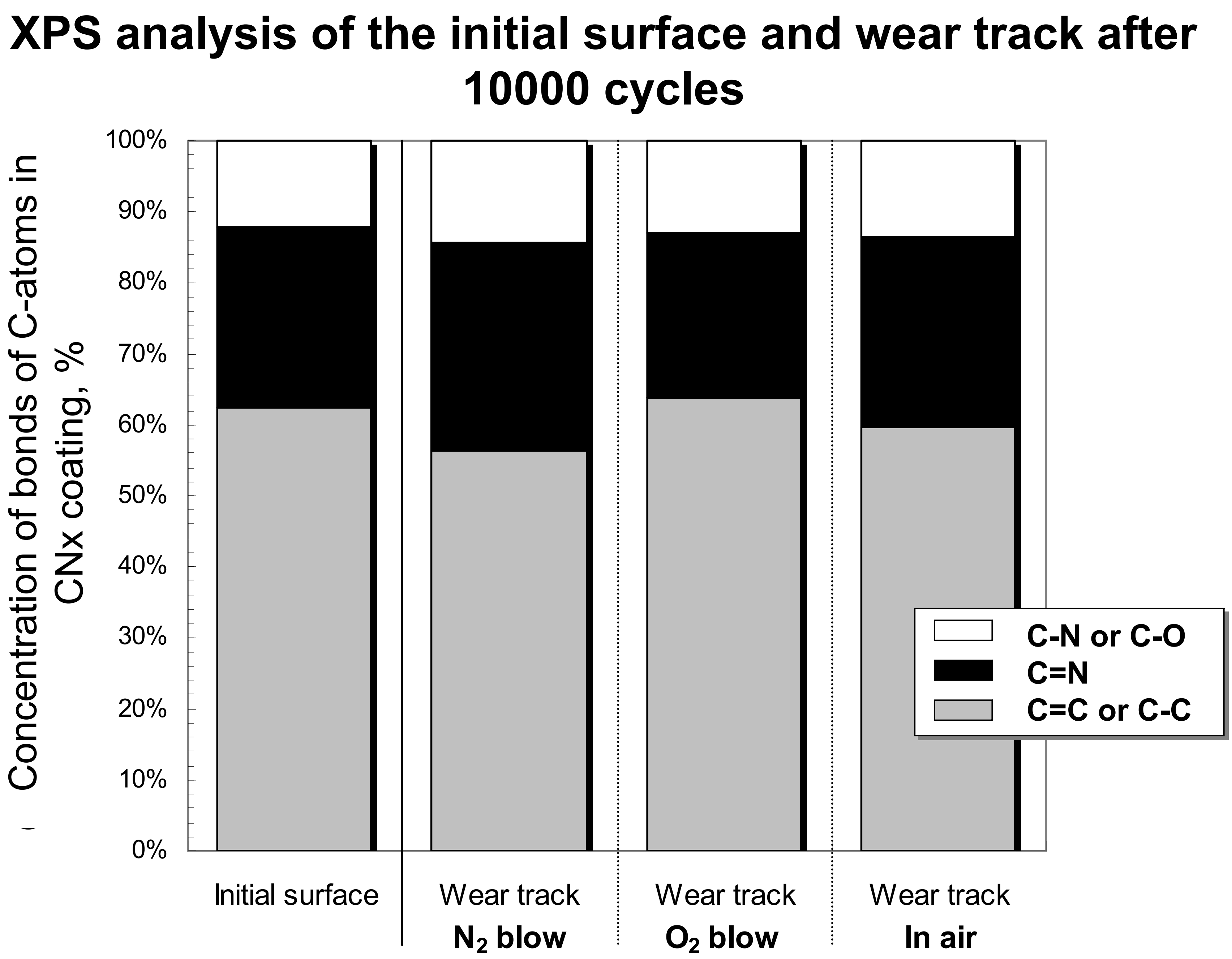
O_2 gas blow





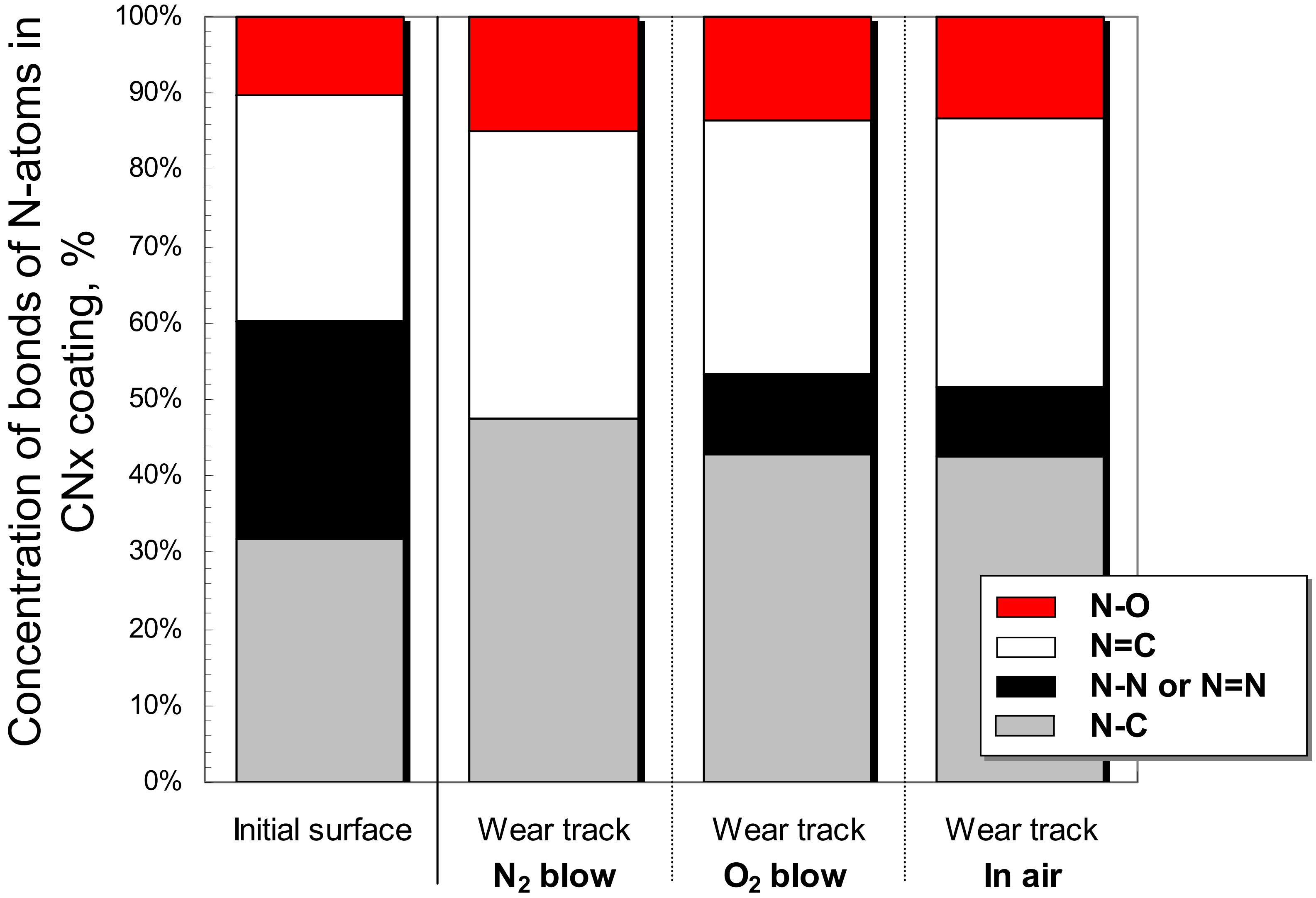
Initial surface

Wear track



XPS analysis of the initial surface and wear track after 10000 cycles
Concentration of bonds of C-atoms in CNx coating, %
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Initial surface
Wear track
N2 blow
Wear track
O2 blow
Wear track
In air
C-N or C-O
C=N
C=C or C-C

XPS analysis of the initial surface and wear track after 10000 cycles



Conclusions

1. The combination of CN_x/CN_x gives lower value of the friction coefficient and wear rate, than the combination of CN_x/Si_3N_4 and C/C in the blow of N_2 gas in open air.

2. For the contact of CNx coating against CNx coating N_2 gas blow in open air, gives lowest friction coefficient and wear rate among the gases N_2, Ar, CO_2, O_2 and lower than in open air.

In N_2 blow

	μ	W_s, $mm^3/N.m$
CN_x/CN_x	0.03	$1\sim3 \times 10^{-8}$
CN_x/Si_3N_4	0.03	5.9×10^{-8}
C/C	0.05 ~0.15	6.4×10^{-7}

CNx/CNx

Blown gas	μ	W_s, $mm^3/N.m$
N_2	0.03	3.0×10^{-8}
Ar	0.05	4.0×10^{-8}
CO_2	0.05	5.2×10^{-8}
O_2	0.17	5.4×10^{-7}
Air	0.19	3.5×10^{-7}