ELyT Annual Workshop Sendai Feb. 22-24, 2011

CarbonCoat

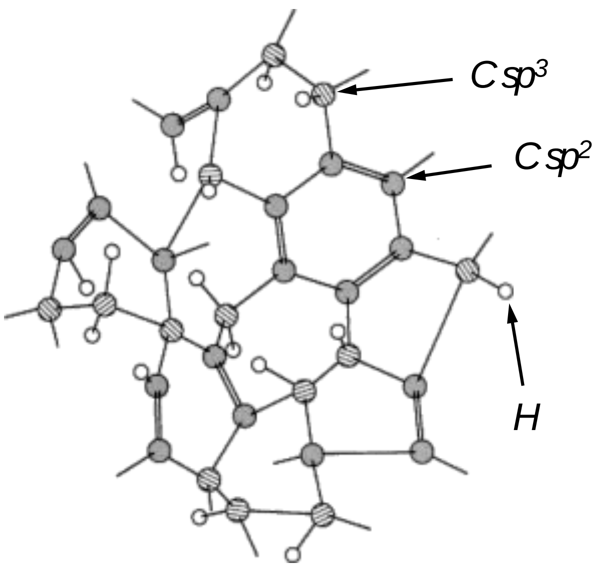
Tribologically-based designed strategies for advanced carbon coatings

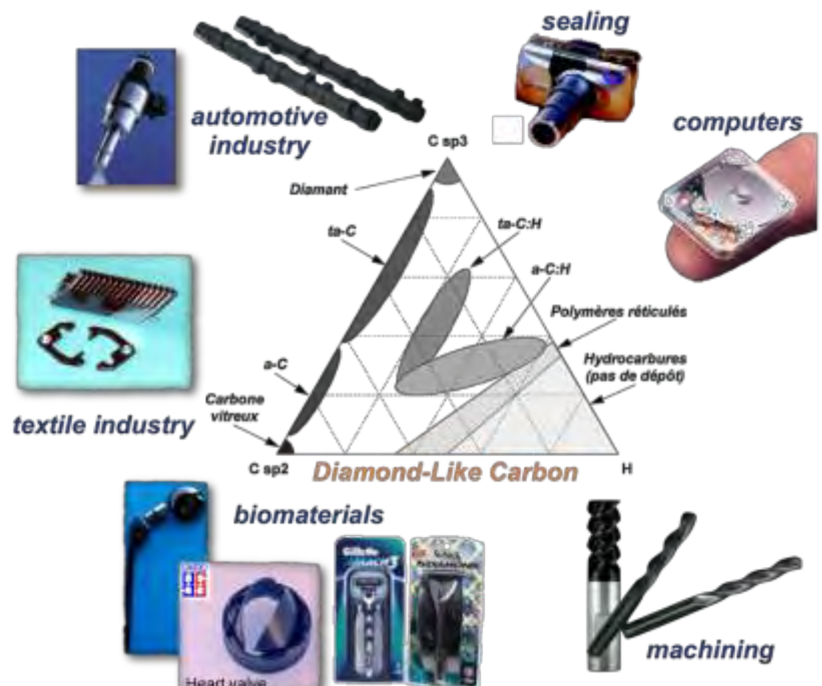
Hiroyuki MIKI & Julien FONTAINE

DLC coatings: a key-material for tribology

What are Diamond-Like Carbon coatings?

- ***Amorphous*** and ***metastable*** materials based on **C** and **H**
- Large range of compositions and properties: ***versatility***
- Combine ***wear resistance*** together with ***friction reduction***





Many successful industrial applications… but some limitations remain!

- Tribological performance depends on contact conditions (environment, …)
- DLC are electrically insulating (like most solid lubricants!)…

Goal of CarbonCoat project

Address some of the limitations of DLC coatings for tribological applications through **control of tribological interface**

- Requires **fundamental understanding of solid lubrication processes**
  ®contribution of LTDS (ECL)
- Requires **coatings deposition & optimization**
  ®contribution of IFS-ASEL (TU)
- Requires **control of tribological surfaces** (friction history, environment…)
  ®contribution of Tribology Lab (TU)

The CarbonCoat team

- Members:
  - ***IFS, Advanced Systems Evaluation Laboratory (TU):***
    Staff: H. Miki, T. Takeno, T. Takagi
    Students: T. Sugawara, Y. Saito
  - ***Tribology Lab (TU):***
    Staff: K. Adachi
  - ***Laboratoire de Tribologie et Dynamique des Systèmes (ECL)***
    Staff: J. Fontaine, S. Bec, M. Belin
    Post-docs & invited researchers: K. Ito, M. Goto
    Students: M. Ruet, F. Palazon, N. Ruty, V. de Chillaz

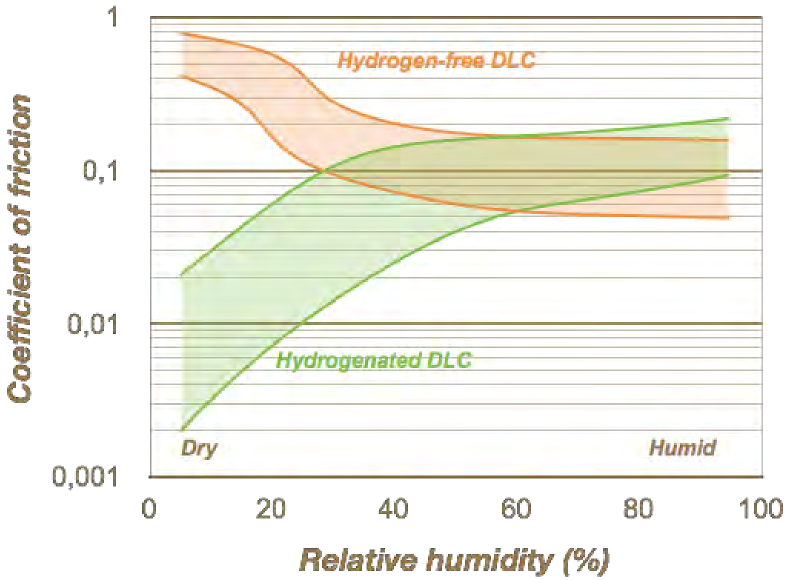
- Collaborators:
  - ***Japan Aerospace eXploration Agency (JAXA)***
    Staff: K. Matsumoto, M. Iwaki

Outline

1. Scope of CarbonCoat project
2. Background on DLC tribology
3. Towards the control of tribological interface…
    1. *Example of CN_x coatings: role of water vapor*
    2. *Example of Cu-DLC: role of metallic tribofilm*
    3. *Example of Ag-DLC: optimization of coating deposition*
4. Summary

DLC: low friction & high hardness

- *20 years of literature…* Depending on **DLC nature** and **environment** during sliding, **low to superlow friction** can be achieved… but not always!

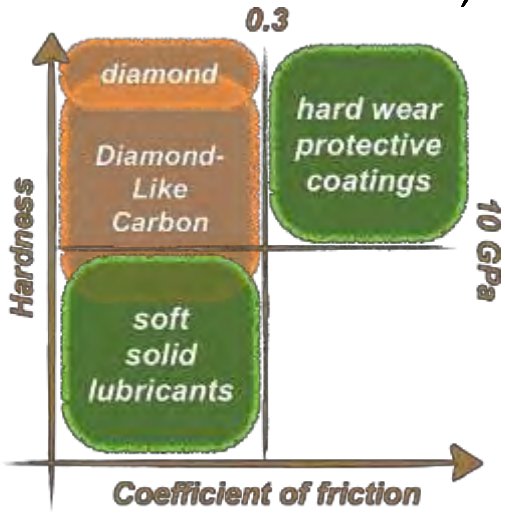


- ***Mechanical properties** of DLC coatings:*
  - Harder than steels
  - As elastic as steels
  - Higher H/E ratio (≈ strain to failure)

	a-C	a-C:H	ta-C	ta-C:H
Hardness (GPa)	10 - 20	<5 - 30	25 - >70	25 - 60
Elastic modulus (GPa)	150 - 200	50 - 250	200 - 650	150 - 300
H/E ratio	0.08 - 0.1	0.1 - 0.16	0.1 - 0.2	0.16 - 0.2

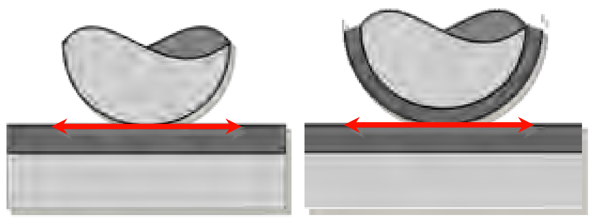
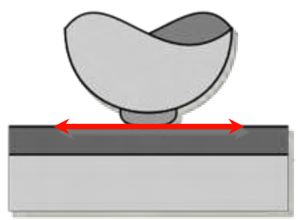
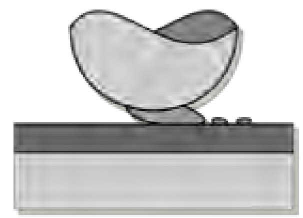
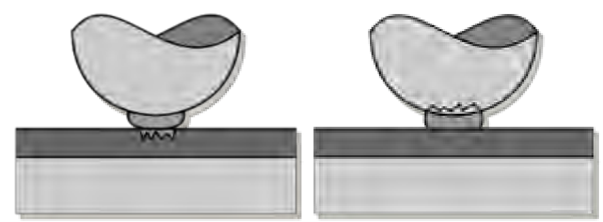
Tribological paradox of DLC coatings

- ***Comparing DLC to other tribological coatings:***
  - Hard coatings: difficult to shear ⇒ high friction, low wear
  - Soft coatings: easy to shear ⇒ low friction, high wear



- ***How can DLC coatings be hard and easy to shear?***
  - Key-role of top surface of DLC and counterface?
  - Build-up of some tribofilms, or surface modifications?

Accommodation of sliding velocities

	*At least one interface with **weak adhesion***	***Strong adhesion** whatever the interface*
No Tribofilm	 ***Sometimes observed*** *W-DLC against sapphire (Singer & al.)* *DLC against DLC (Erdemir & al.)*	 ***Required for tribofilm build-up!*** *Influence of ball surface composition* *a-C:H (IBM) in UHV (Donnet, Fontaine & al.)*
Tribofilm	 ***Low friction & wear*** *Huge number of papers !* ***Superlow friction possible*** ***a-C:H (IBM) in UHV*** *(Donnet, Fontaine & al.)*	 ***Shearing of tribofilm*** *W-DLC against sapphire* *(Singer & al.)*  ***Seizure of tribofilm*** *a-C:H (IBM) in UHV (Donnet, Fontaine & al.)*

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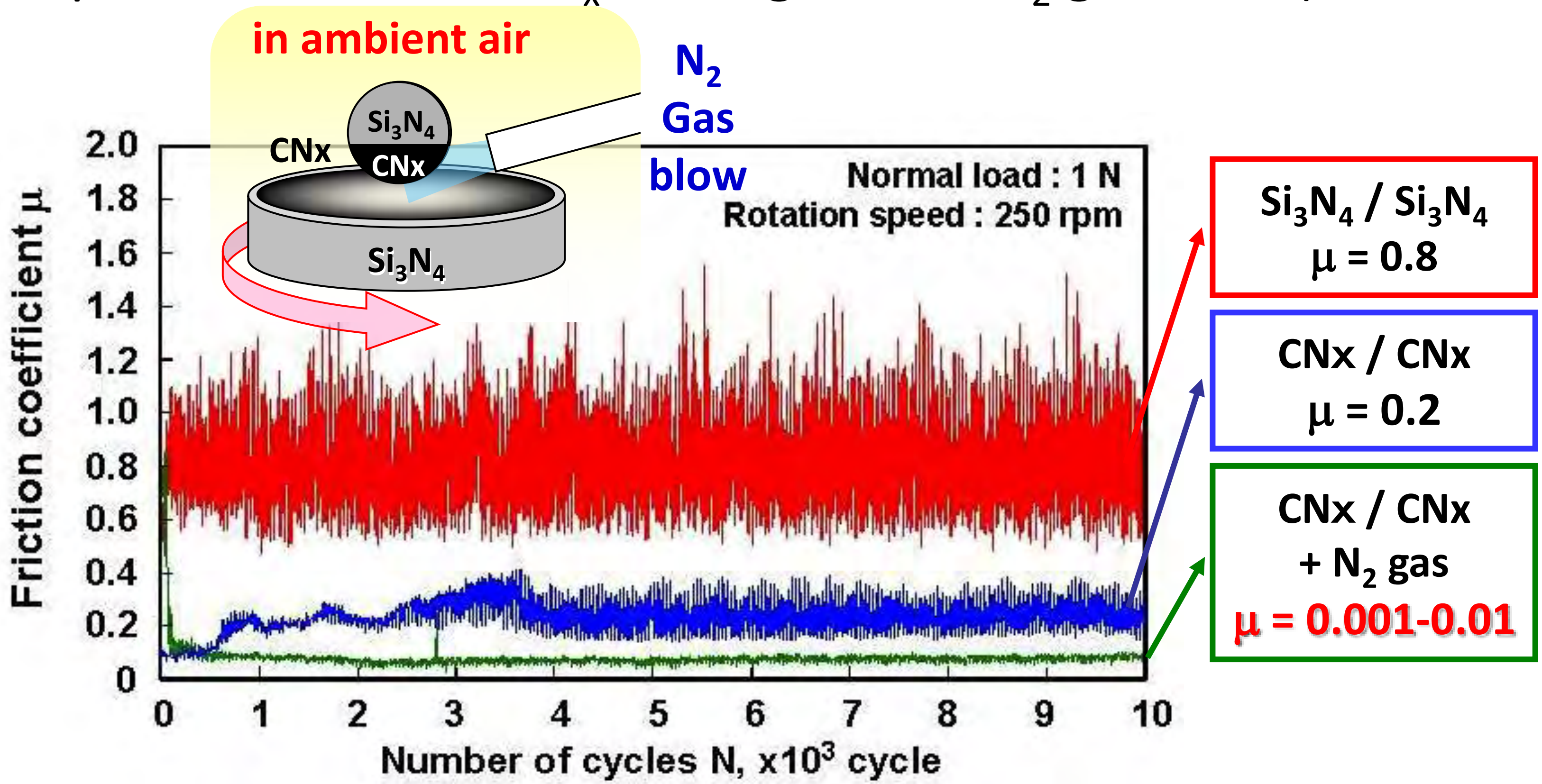
Solid lubrication by CN_x coatings

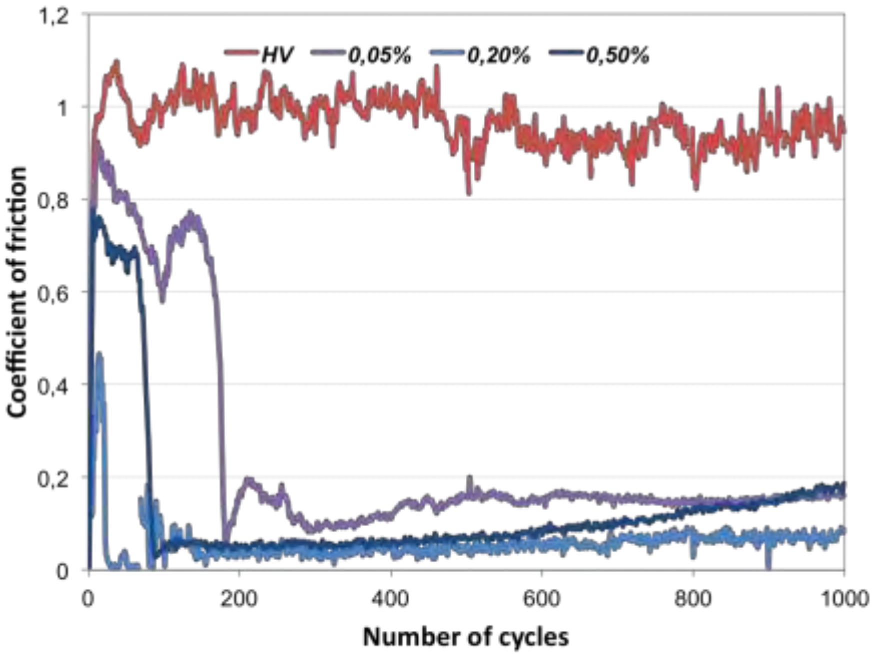
- Superlow friction of CN_x coatings under N_2 gas blow (K. Adachi)

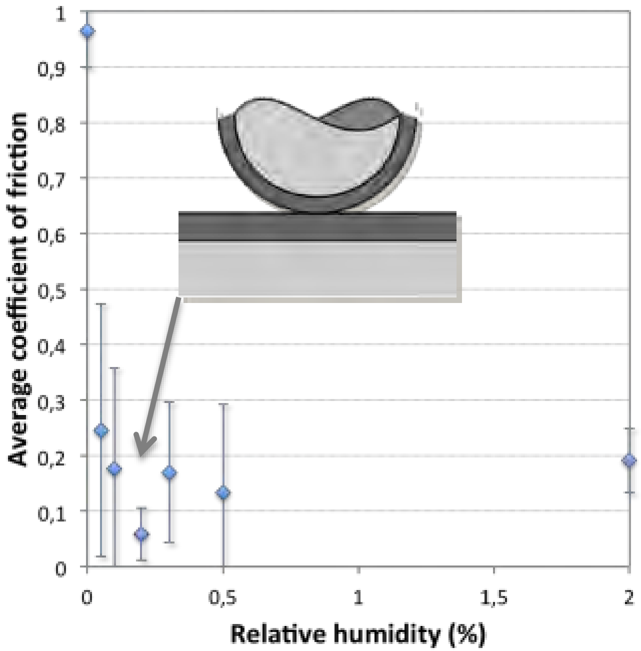


- However, coefficient of friction strongly depends on:
  - friction history, pre-sliding in different gas or with different counterface
  - storage environment after coating deposition

Solid lubrication by CN_x: water vapor effect?

- Role of surface chemistry seems critical…
- Experiments in vacuum and various pressures of water vapor





- A minimum friction of 0.05 is found at 0.2% RH

  ⇒ *some water is needed, but not too much!*
- It is thus possible to avoid large adhesive phenomena and favor **interface sliding**

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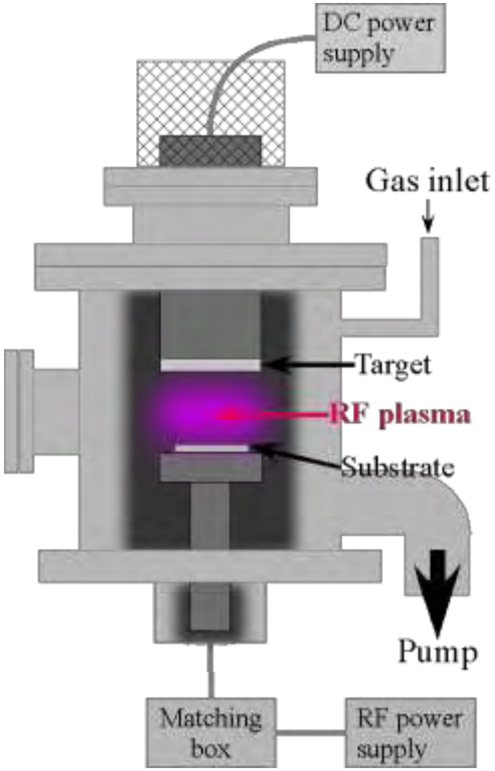
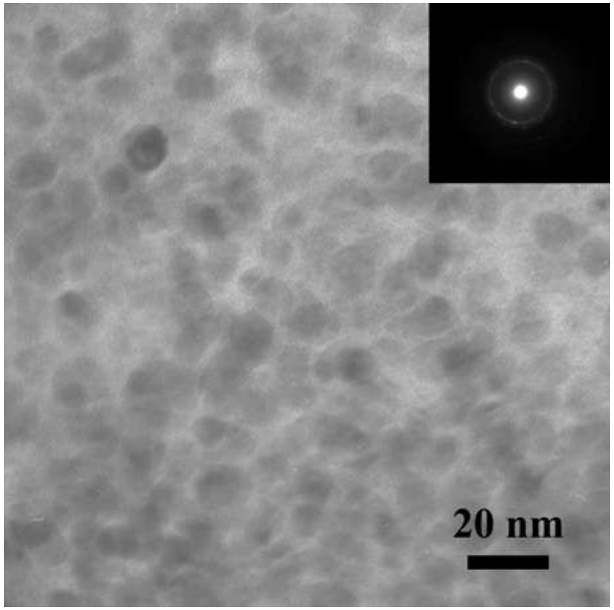
Metal-DLC nanocomposite coatings

- Combination of chemical and physical processes: ***RF-PECVD + DC PVD***
- Hydrocarbon precursors: CH_4, C_2H_2, ...
- Various targets: *metals, non-metals*
  W, Cr, Co, Ni, Nb, Mo, V, In, Cu, ...



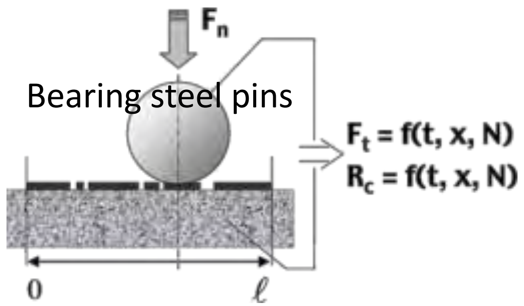


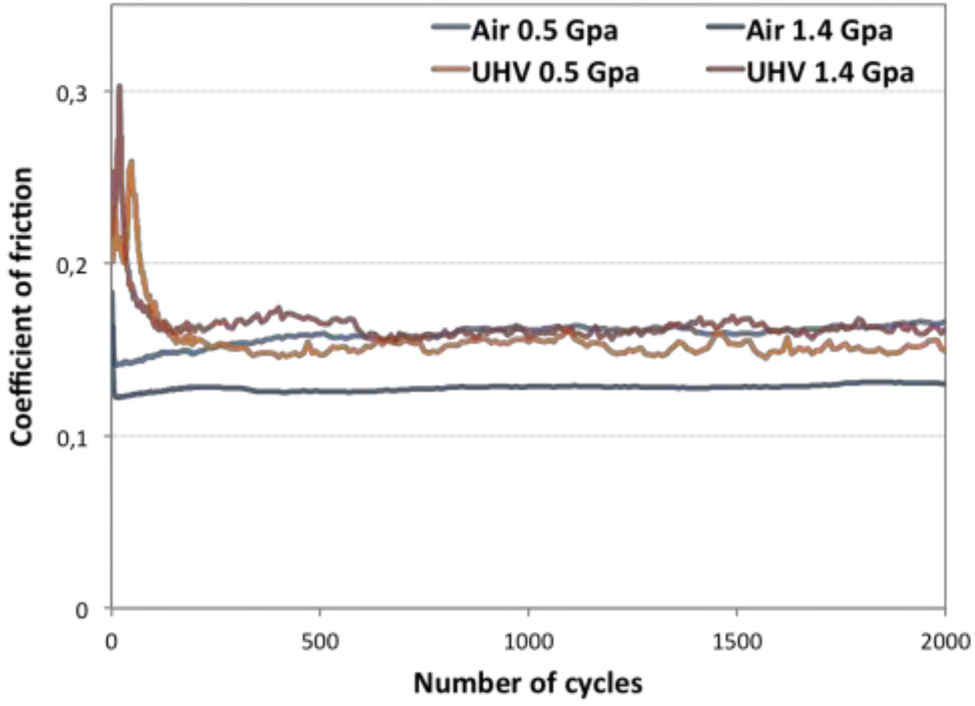
Example with Cu-DLC (50W – 0.7 sccm C_2H_2)

⇒ ***Nanocomposite*** *structure is achieved*

Effect of contact conditions on Cu-DLC friction

- *Effect of environment:* **ambient air or UHV**
- *Effect of contact pressure:* **0.5 & 1.4 GPa** (theoretical!)
  - Change of load for ambient air: 0.5 & 10 N @ 3 mm radius
  - Change of pin radius for UHV: 1.5 & 8 mm @ 3 N load





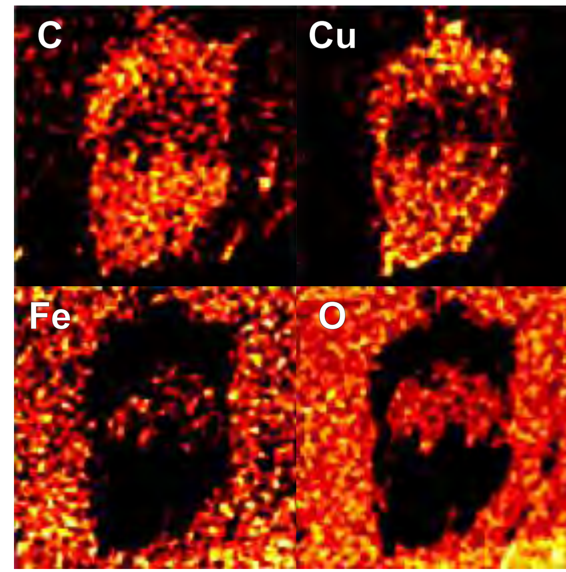
⇒ Similar coefficients of friction are achieved!

Tribofilm build-up: selective transfer of Cu

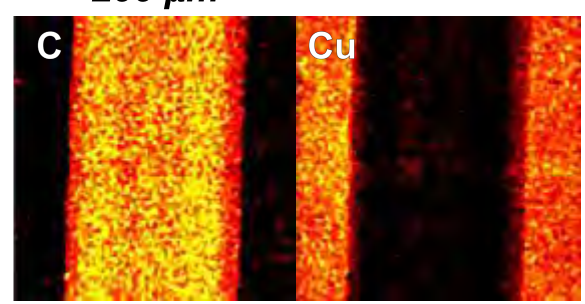
- Elemental maps of surfaces after friction under UHV (1.4 GPa)
  - *Tribofilm by EDX (µm range):* lots of Cu, some C
  - *Tribofilm by Auger (nm range):* lots of C and Cu
  - *Cu-DLC by Auger (nm range)*: more C and less Cu

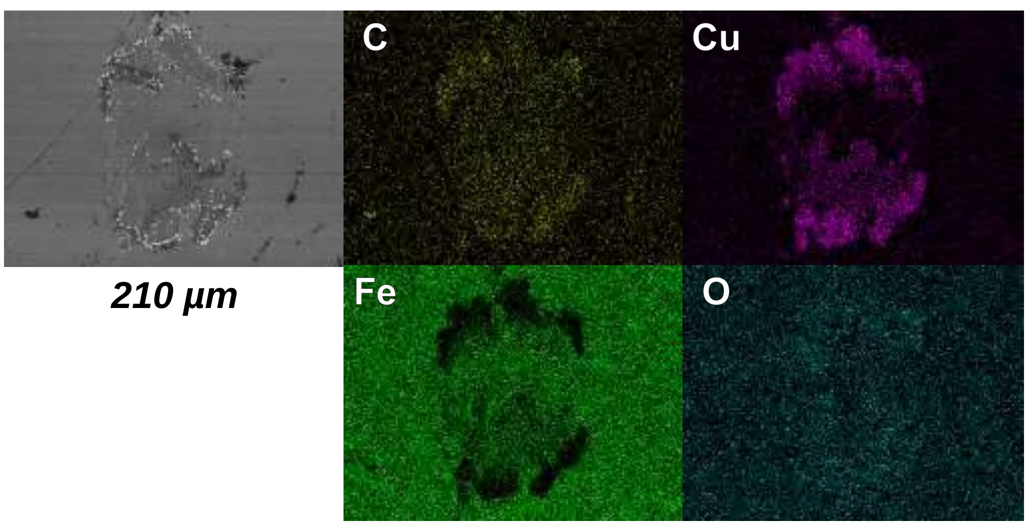
- ***Cu is preferentially removed…***
  … but then C can be transferred

180 µm Pin surface



200 µm Cu-DLC



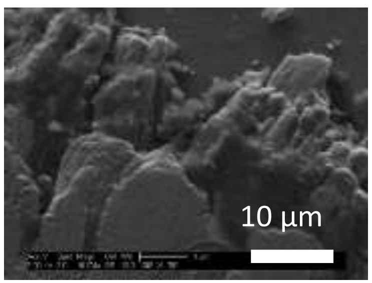


210 µm

Tribofilm evolution: Cu flow

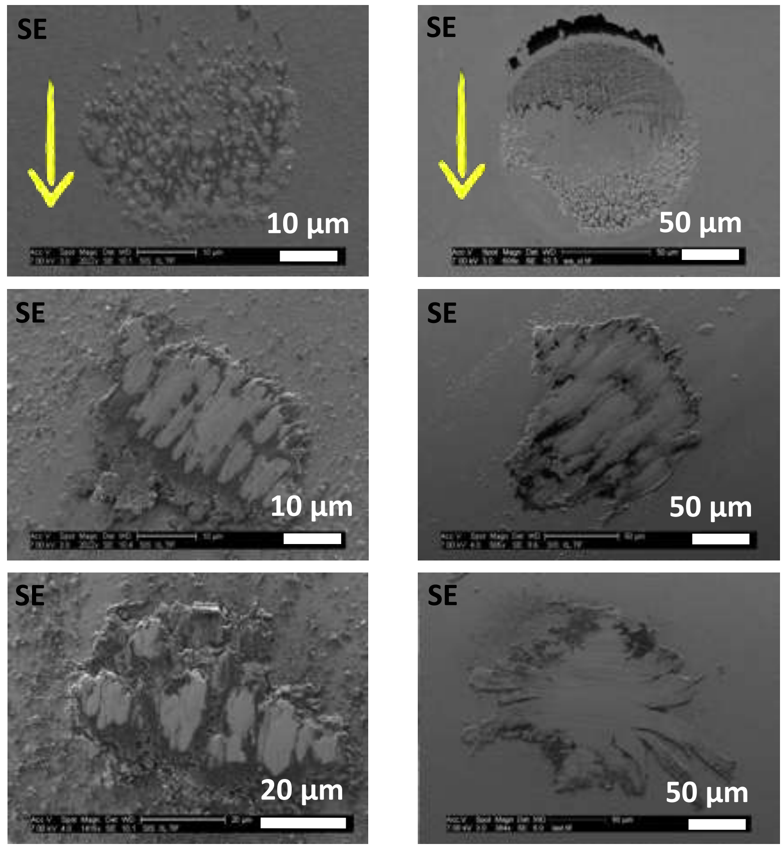
Evolution of tribofilm at different contact pressures in ambient air

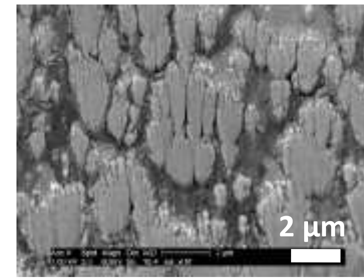
Low pressure:
Cu islands grow



P_{max}=0.5 GPa | P_{max}=1.4 GPa

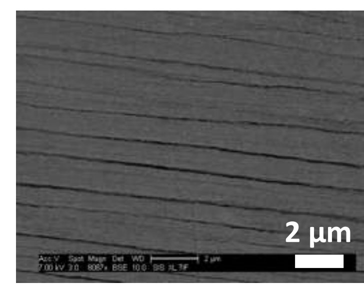
1 single pass | 200 cycles | 2000 cycles





Cu-rich islands appear very quickly

High pressure:
Cu flows out



The shear of metallic tribofilm seems to control friction

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Optimization of Ag-DLC coatings

Deposition parameters & specimen specifications

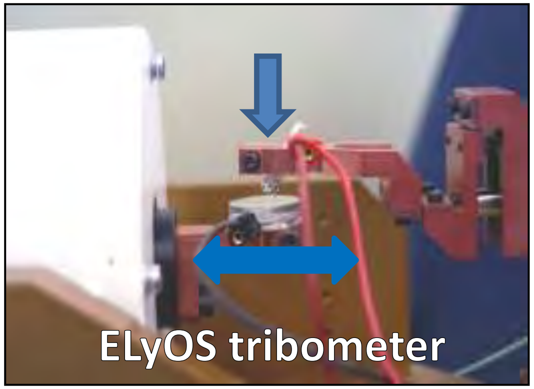
Metal	**Silver**
Substrate	JIS SUS440C
Ar cleaning time	10 minutes
Deposition time	30 minutes
Bias voltage	- 400 V
Sputter power	0.1 kW

ID	Ar flow [sccm]	C_2H_2 flow [sccm]	Ar/C_2H_2 ratio	Metal concentration [at.%]
Ag-spt	10.0	0.0	0.0	100
Ag01	10.0	1.0	0.1	84
Ag02	10.0	1.5	0.15	79
Ag03	10.0	2.0	0.2	75
Ag04	10.0	2.8	0.28	62
Ag05	5.0	1.6	3.2	under investigation
Ag06	5.0	1.8	3.6	under investigation
Ag07	5.0	2.0	4.0	55

Key parameter

Various composition/structures can be achieved!

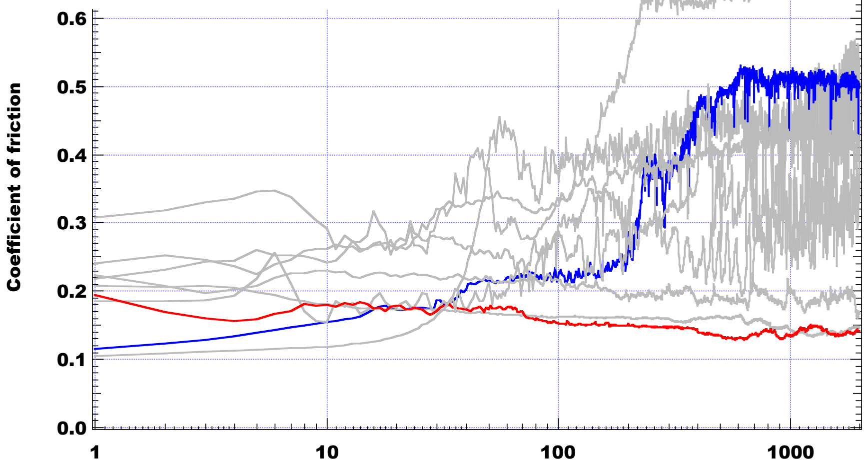
Optimization required, with use of ELyOS tribometer (designed at LTDS for IFS)



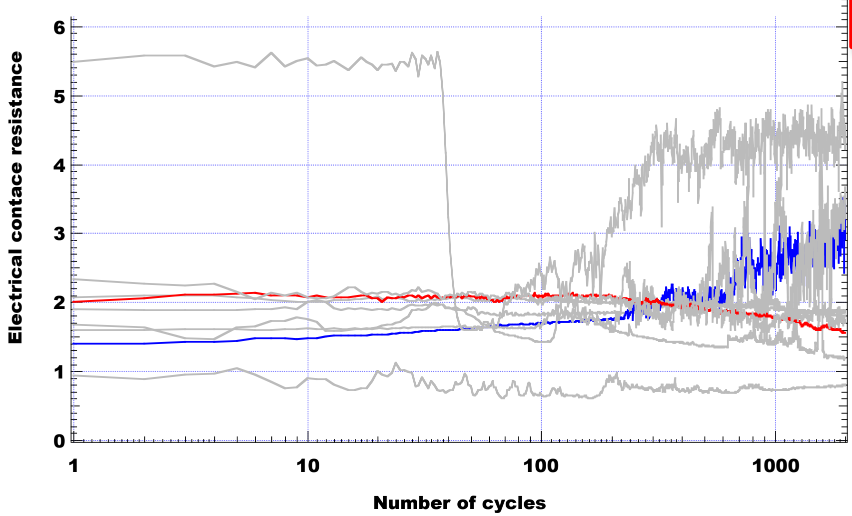
Ball material	Steel
Environment	Air
Temperature	20～25℃
Humidity	40～60%
Number of cycle	2000
Liner speed	2 mm/s
Normal load	1 N
Track length	3 mm

Comparison of Ag-DLC coatings

Coefficient of friction

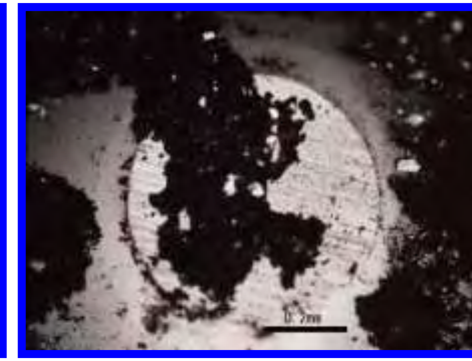


Electrical contact resistance



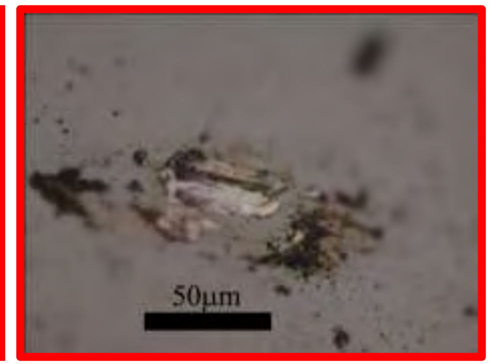
Optical images after 2000 cycles

Ag01 — *Plate* / *Pin*



Large wear of the coating and the pin

Ag06 — *Plate* / *Pin*



Mild wear of coating & tribofilm build-up

→ Optimized coating!

Next step (under progress): ECL students study tribological behavior of optimized coating

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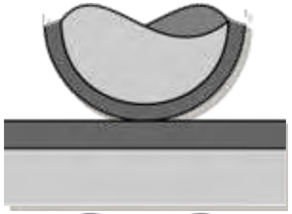
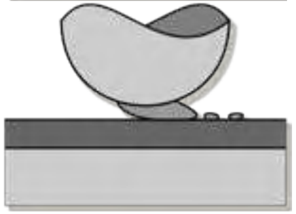
Summary

- ***Control of friction** of carbon-based coatings achieved thanks to:*
  - Control of sliding conditions & surface interactions
  - Control of interface material through selective transfer
- *Two different **solid lubrication processes** can be evidenced:*
  - **Interface sliding** thanks to weak adhesion



  - Metallic **tribofilm flow**



- *Under progress or coming soon:*
  - Further investigations of friction process
    characterization of tribofilms: structure, chemistry, mechanics…
  - Role of metal nature - *included metal & metallic counterface*

People exchanges & achievements

Number of exchanges

	2010	2011
France → Japan	5	3
Japan → France	4	1
Invited stay (Total)	4	1

As of Feb.24 2011

F. Palazon from ECL got the prize!!!
"Best poster award" from ICFD

ICFD conference 2010 in Sendai hosted by IFS-GCOE

Achievements

- *5 presentations at International conferences*
- *6 research funds*
- *2 proposals under review (JSPS research fund)*

Thank you for your attention!

ご清聴ありがとうございます。

Merci de votre attention!