Solid Lubricants and Nanotribology

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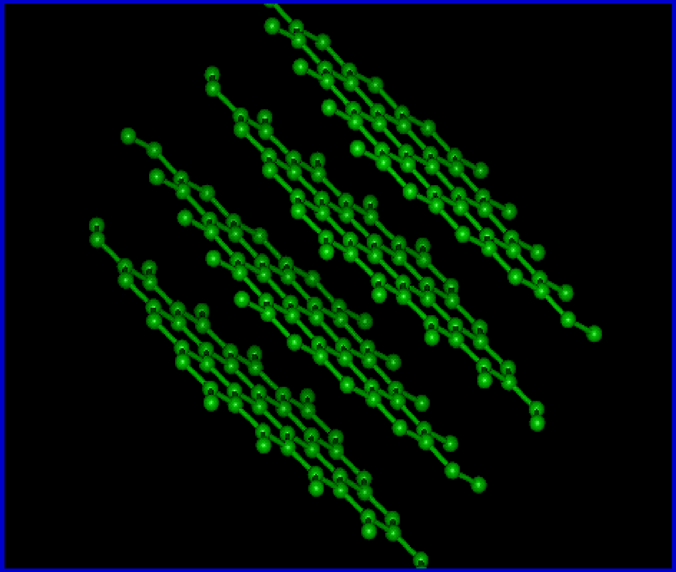
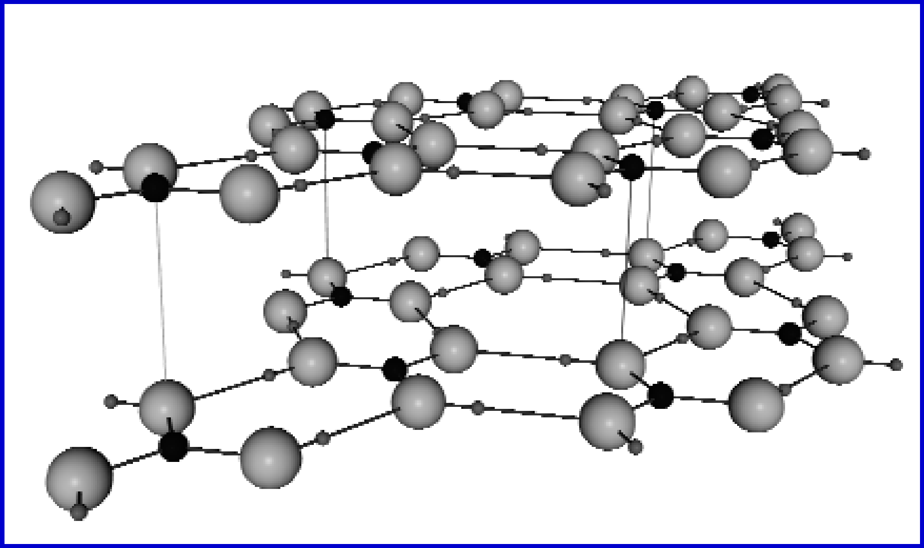
Solid Lubricants





C-C *sp*^{2} $\rightarrow$ interatomic distancee: 1.42 Å

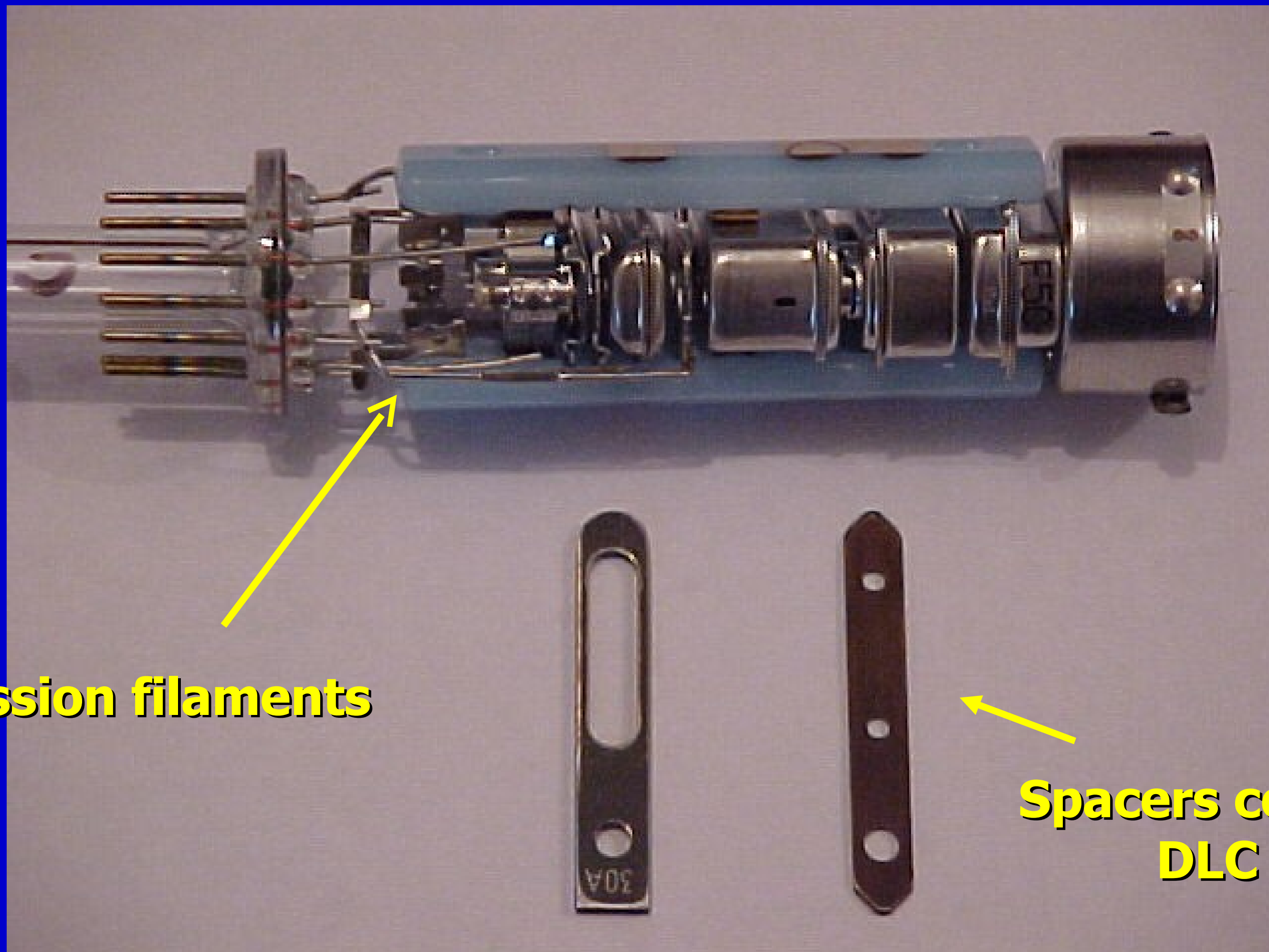
Distance between planes: 3.35 Å

Boric acid: H_3BO_3

Distance between planes : 3.18 Å

Surf. Eng. **15**, 291 (1999)

Cathode rays tubes



Macroscopic friction

AMONTON Laws (1698):

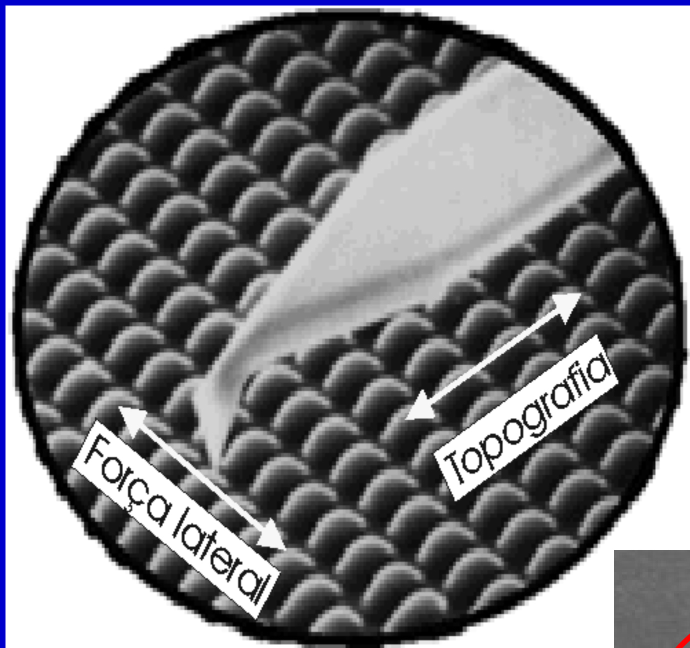
- **Friction is independent on the contact area.**

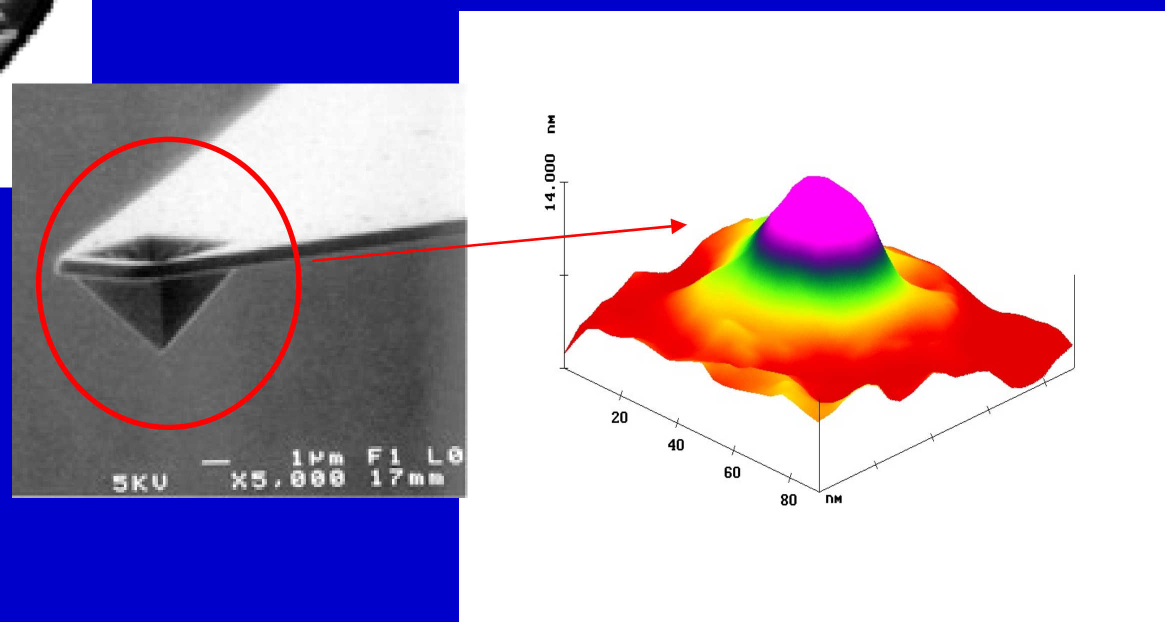
- **Friction is independent on the velocity.**

- **Friction is proportional to the normal force**

$$\mu = F_F / F_N$$

AFM: Nanotribology

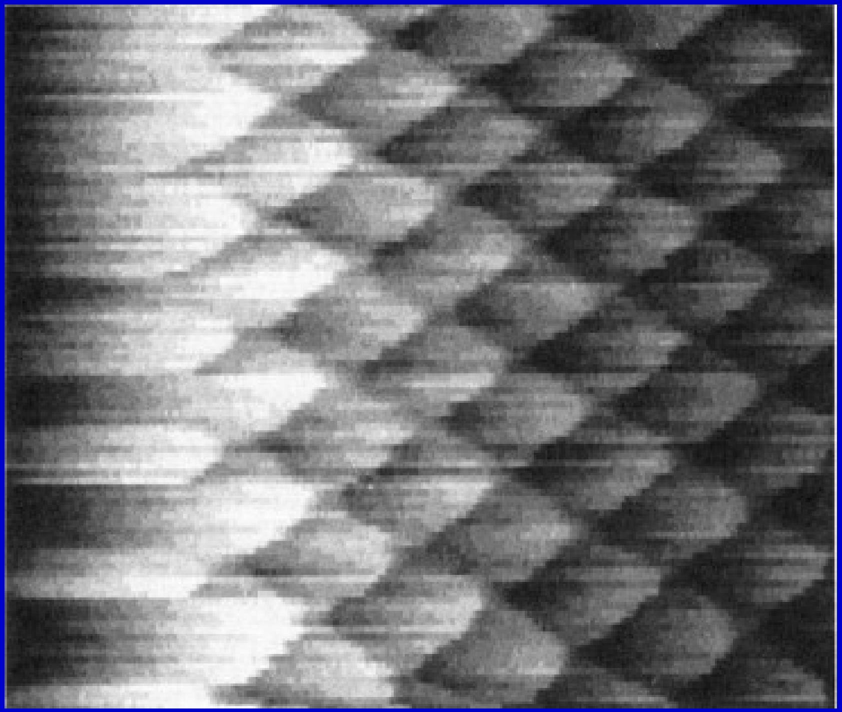




Stick and slip

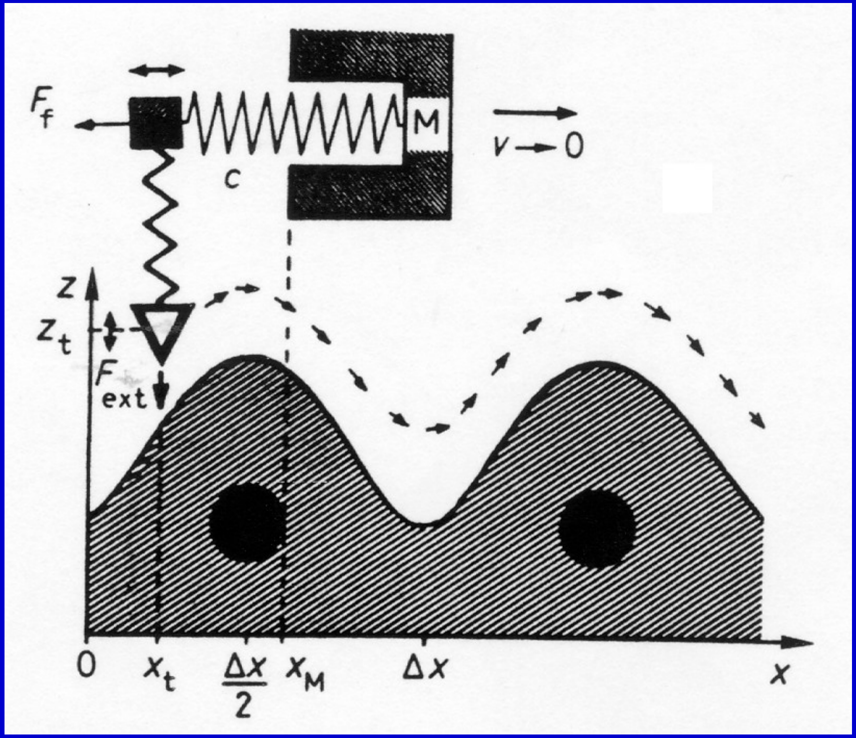
2 x 2 nm^2

Dark-light: 1.6 μN



C.M. Mate *et al*, PRL 59 (1987) 1942

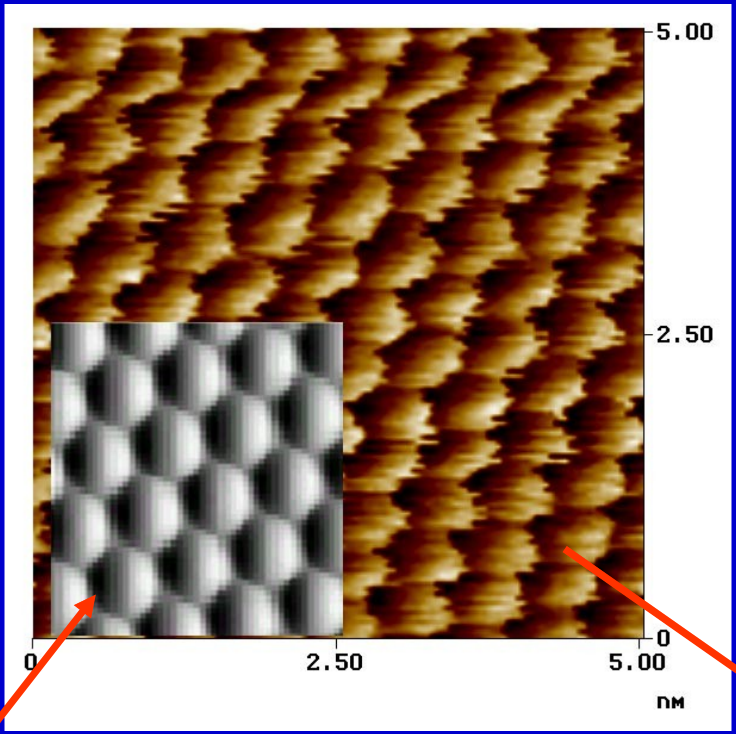
Tip movement



$$m\frac{\partial^2 x}{\partial t^2} = k_x(X - x) - \frac{\partial U_{BA}(x, y)}{\partial x} - \gamma\frac{\partial x}{\partial t},$$
$$m\frac{\partial^2 y}{\partial t^2} = k_y(Y - y) - \frac{\partial U_{BA}(x, y)}{\partial y} - \gamma\frac{\partial y}{\partial t},$$

$$U_{BA}(x, y) = U_0\left[\cos\left(\frac{2\pi x}{a_x}\right)\cos\left(\frac{2\pi y}{a_y}\right)\right].$$

H_3BO_3



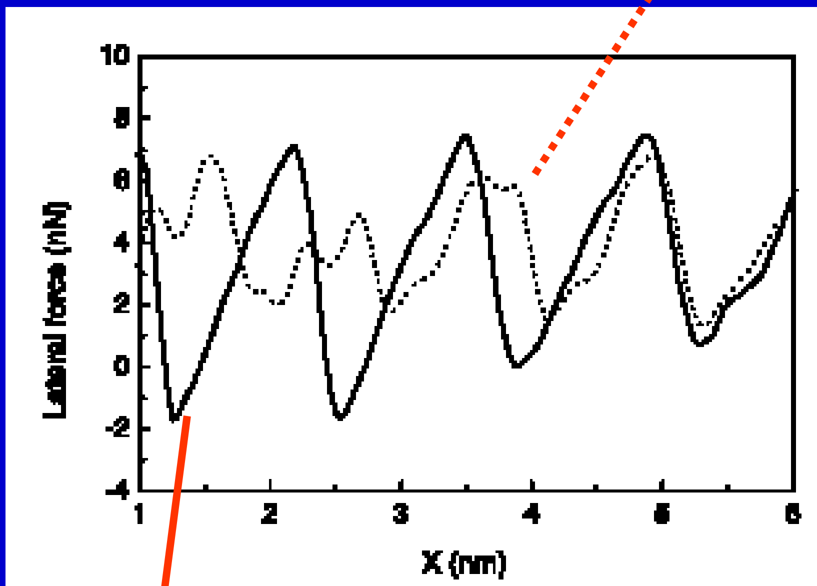
simulation

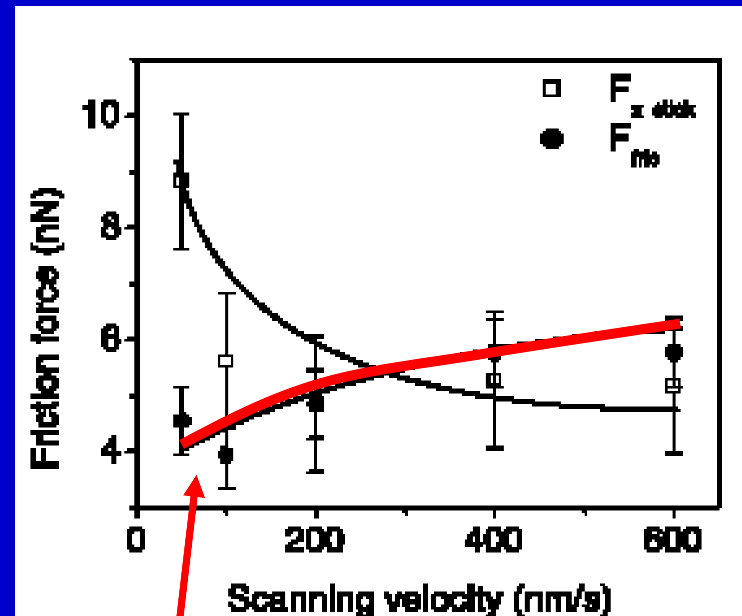
friction force map

A.R. Rivas, R. Prioli, R.M. Zamora, Ultramicroscopy 97 (2003) 315

Stick and slip amorphous surfaces

500 nm/s





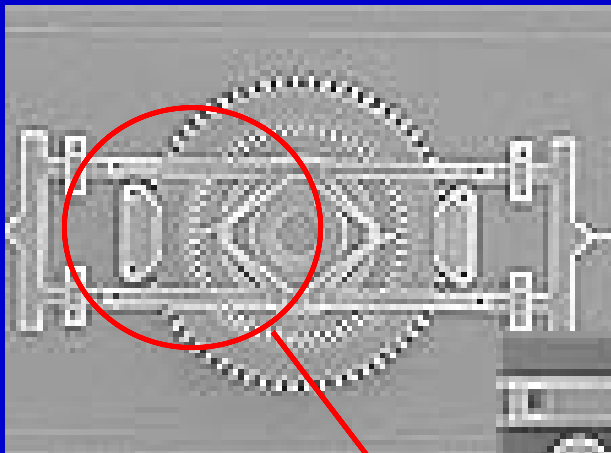
50 nm/s

$F_F = (F_x^{max} + F_x^{mim})/2$

R. Prioli, A.R. Rivas, F.L. Freire Jr., Appl. Phys. A 76 (2003) 565

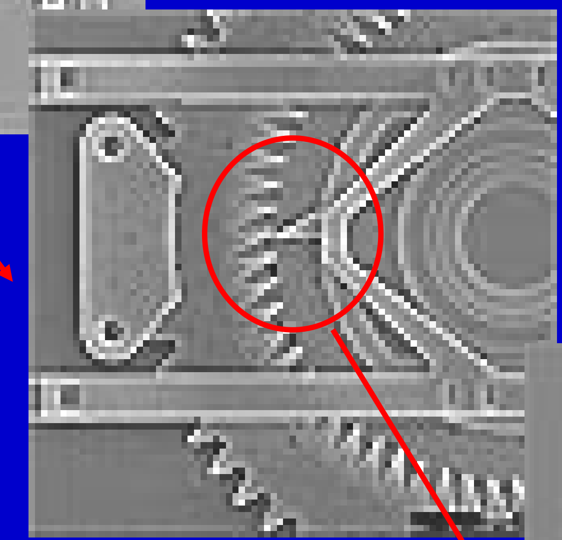
Dependence with velocity and normal force

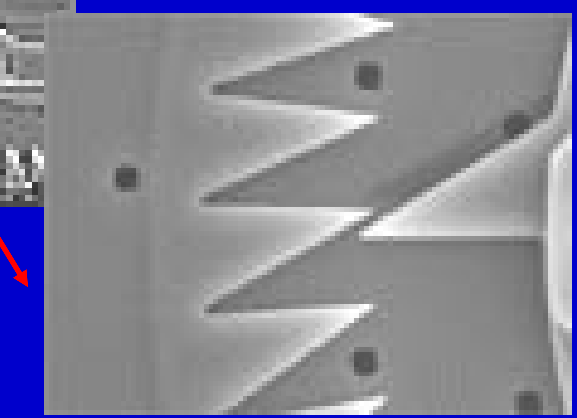
Nanotribology applications



Energy dissipation processes

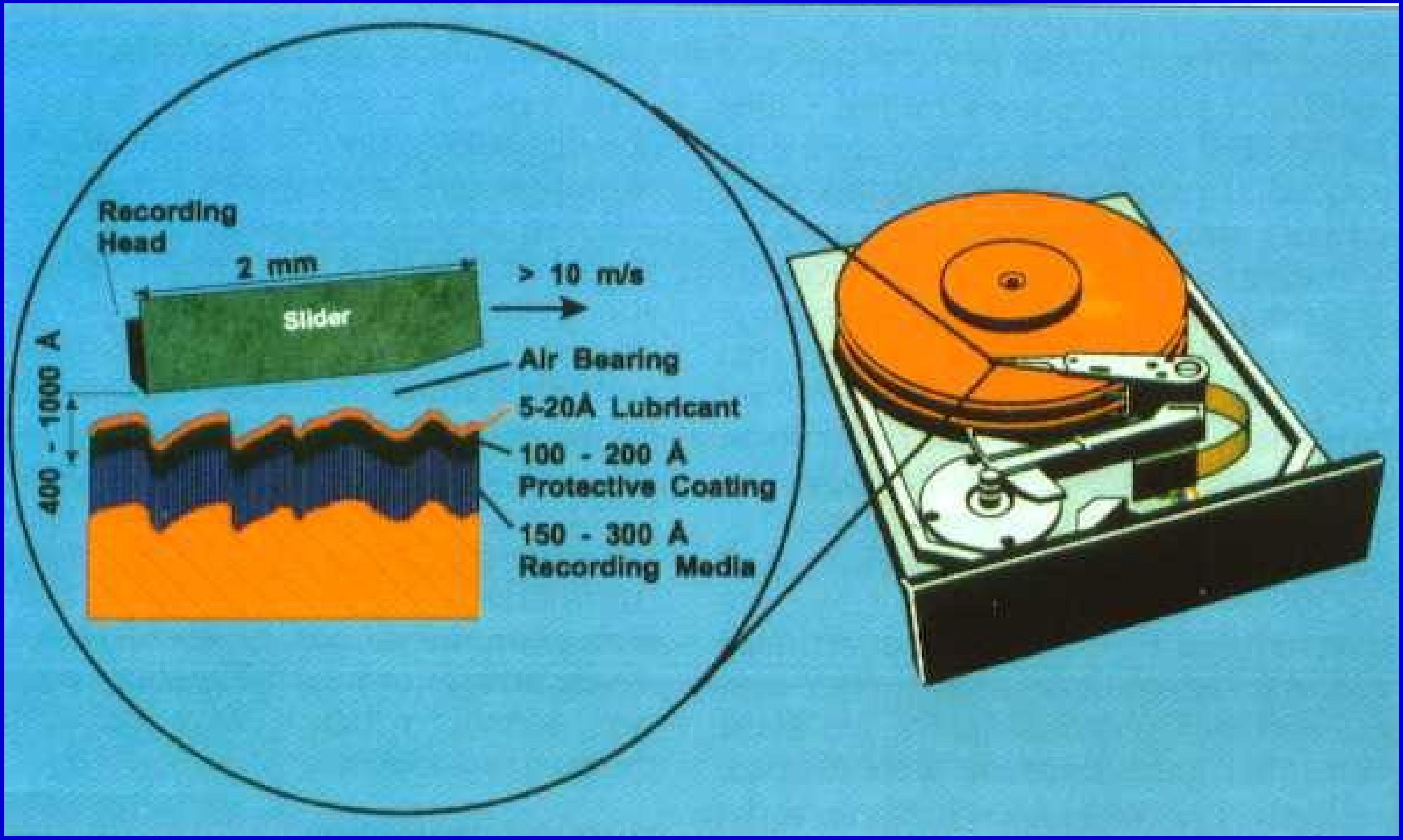
Adhesion forces



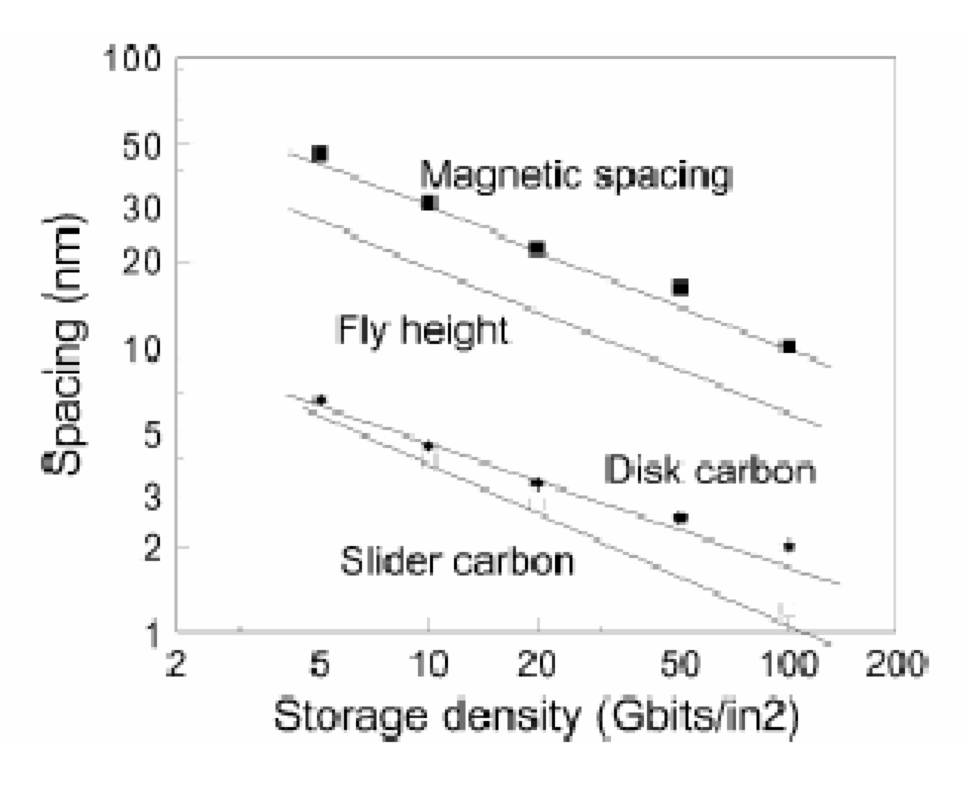


MEMS and NEMS

Hard magnetic disks

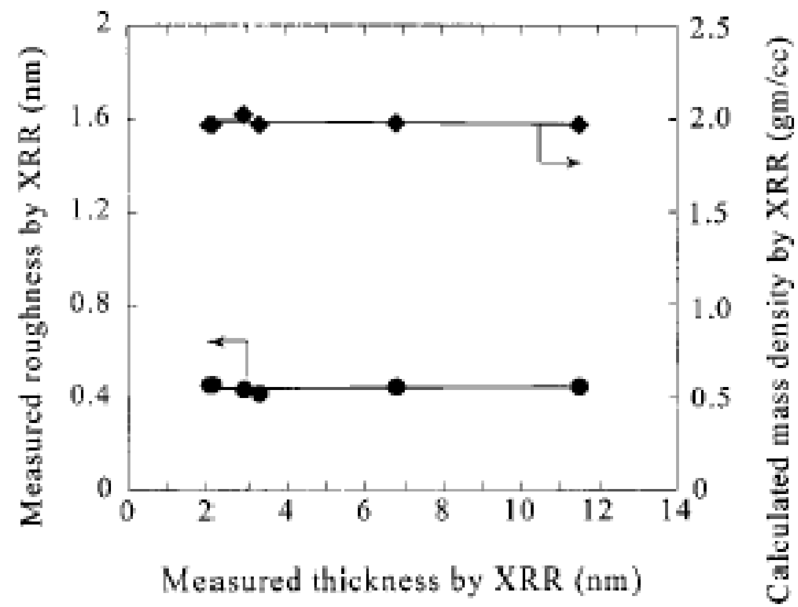


Hard magnetic disks: road map



http://www.almaden.ibm.com/st/projects/lubricants/

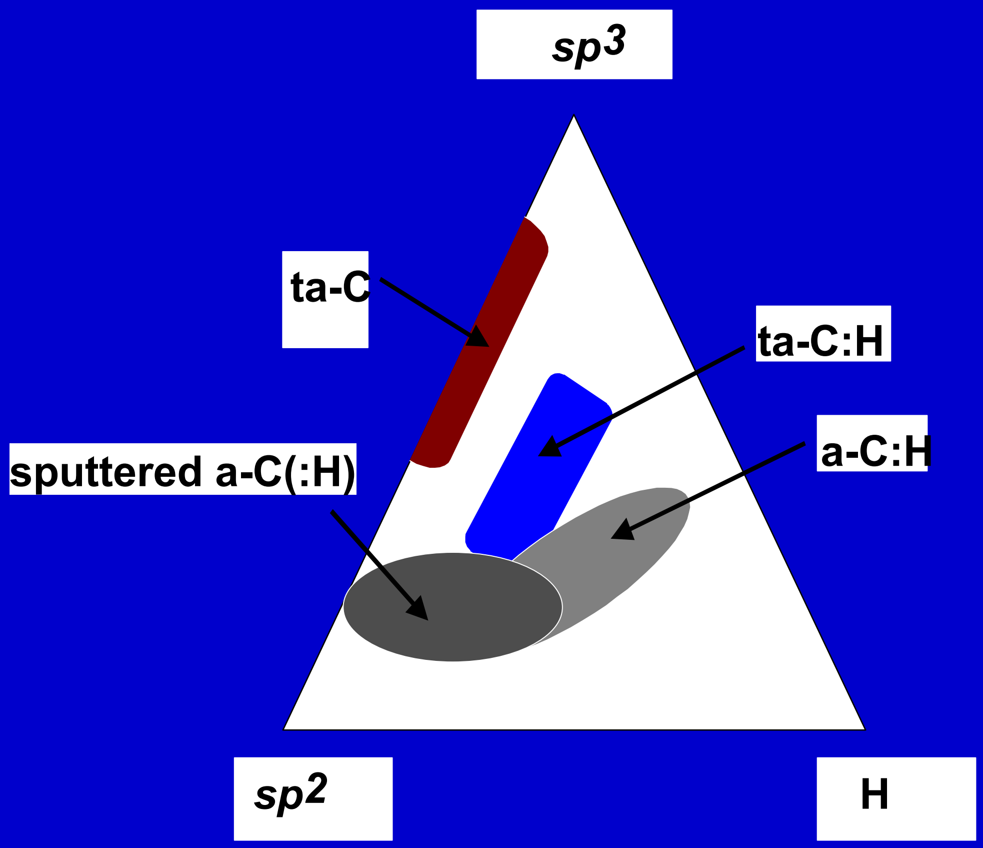
Metrology of 1–10 nm thick CN_x films: Thickness, density, and surface roughness measurements



a-CN_x films deposited by pulsed dc magnetron sputtering

Dejun Li, Yanfeng Chen, Yip-Wah Chung, F. L. Freire Jr.
J. Vac. Sci. Technol. A 21 (2003) L19

Carbon-based films:



Influence of humidity and velocity

- AFM calibration.
- hidrofilic and hidrofobic surfaces.
- results.

R. Prioli. M.E. H. Maia da Costa, F.L. Freire Jr. , Tribology Letters 15 (2003) 177

R.M.R. Zamora, C. S. Tasayco, R. Prioli, F.L. Freire Jr., Phys. Stat. Sol. A 201 (2004) 550; Surface Science (submitted)

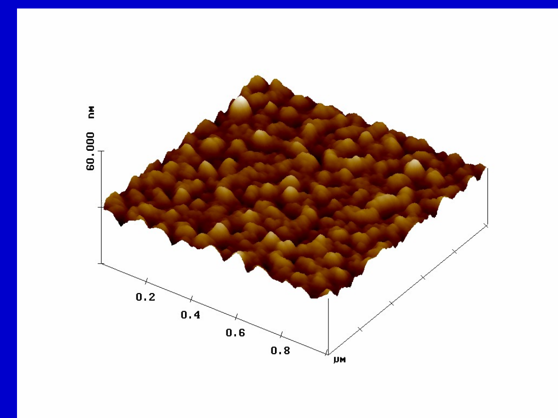
Influence of surface wettability

- **Hydrophobic films**

Amorphous carbon films **Contact angles (°)**

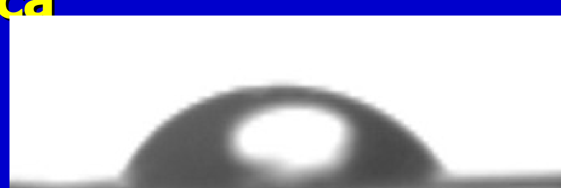
a-C:F **70 - 95**

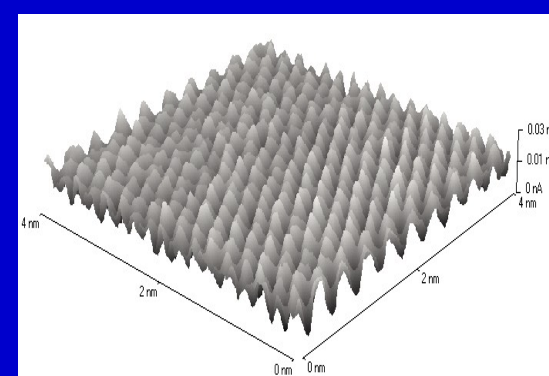
a-C:H:N **60 - 78**



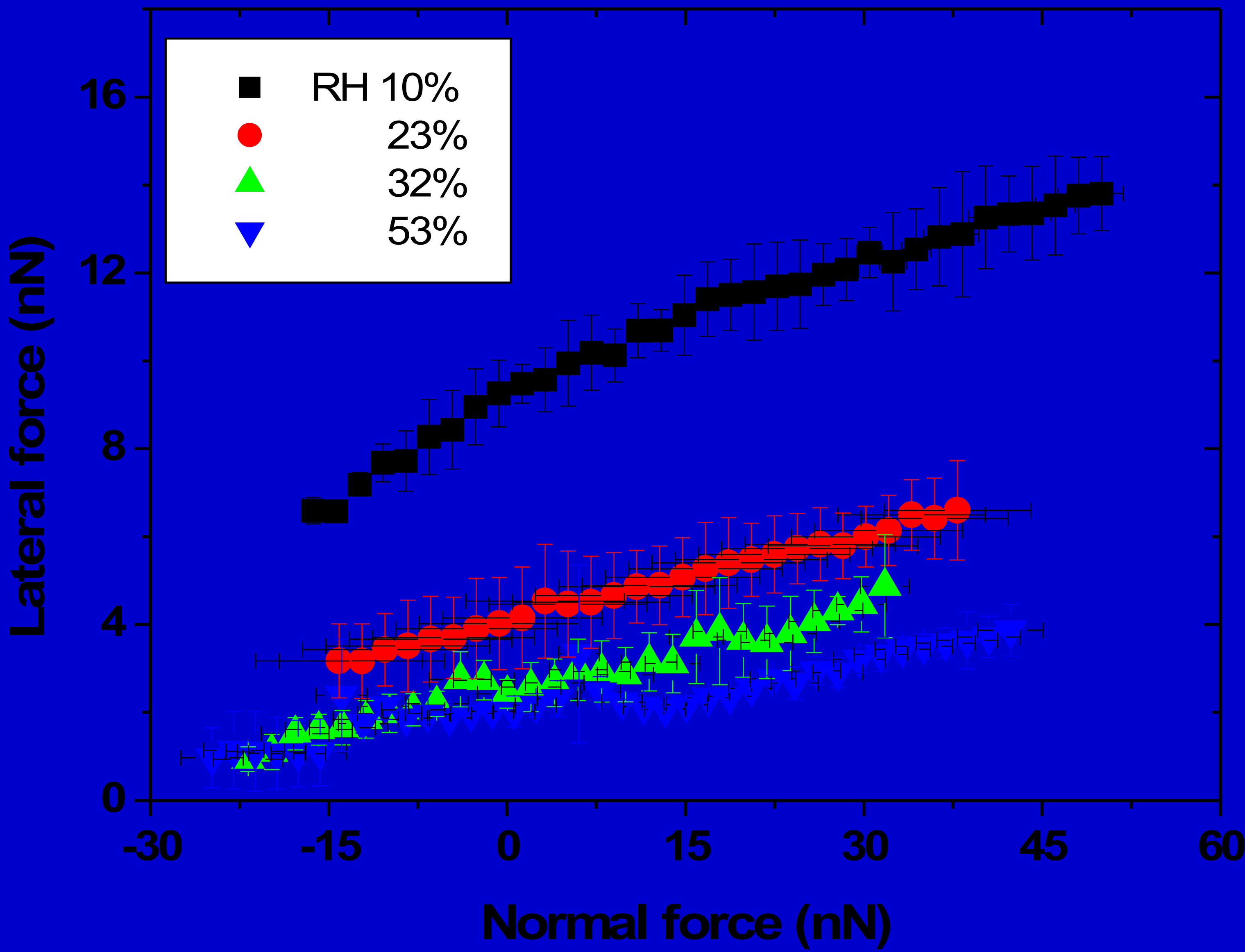
Hydrophilic surfaces

mica **5 - 10**

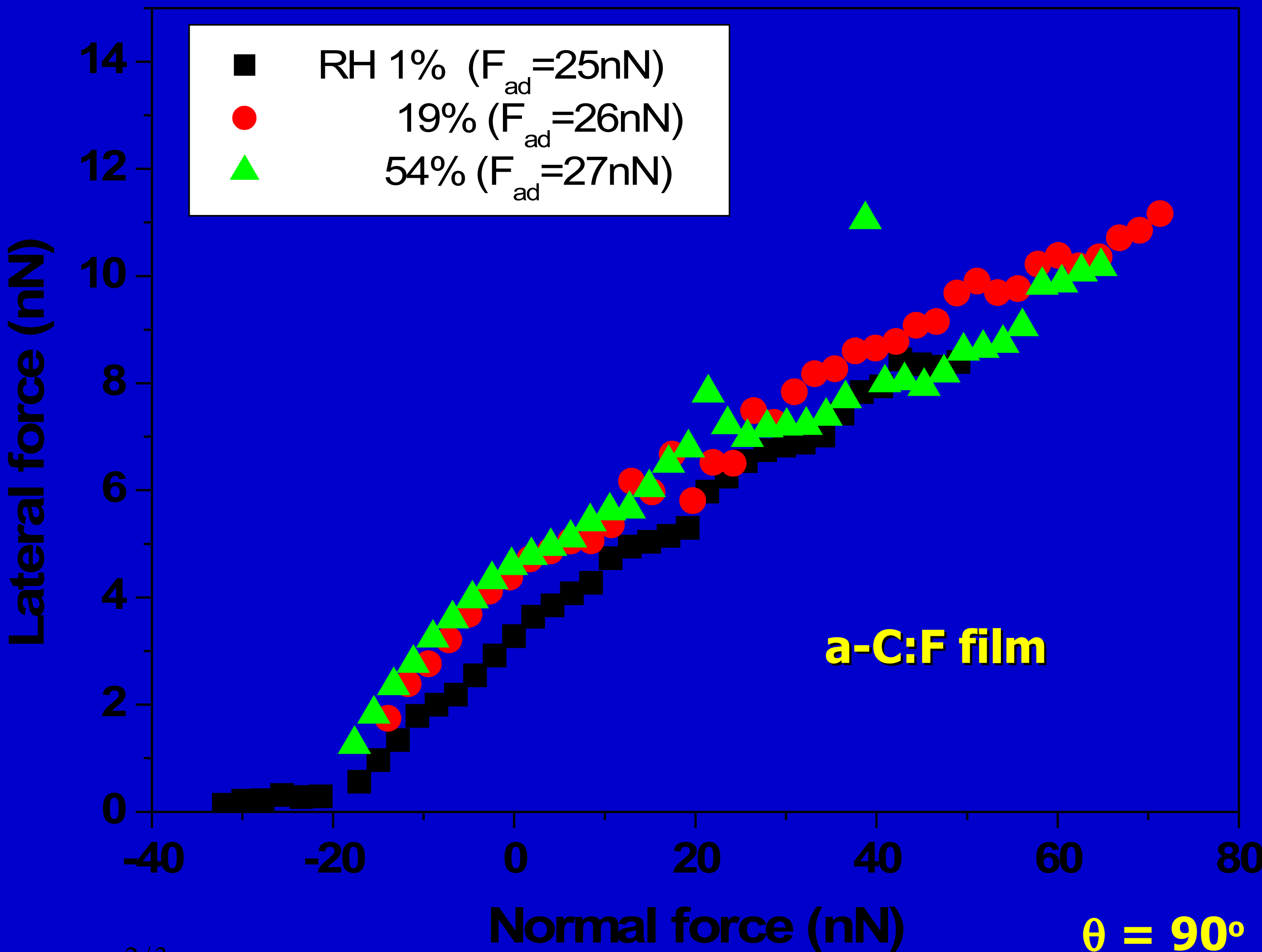




Hydrophilic mica

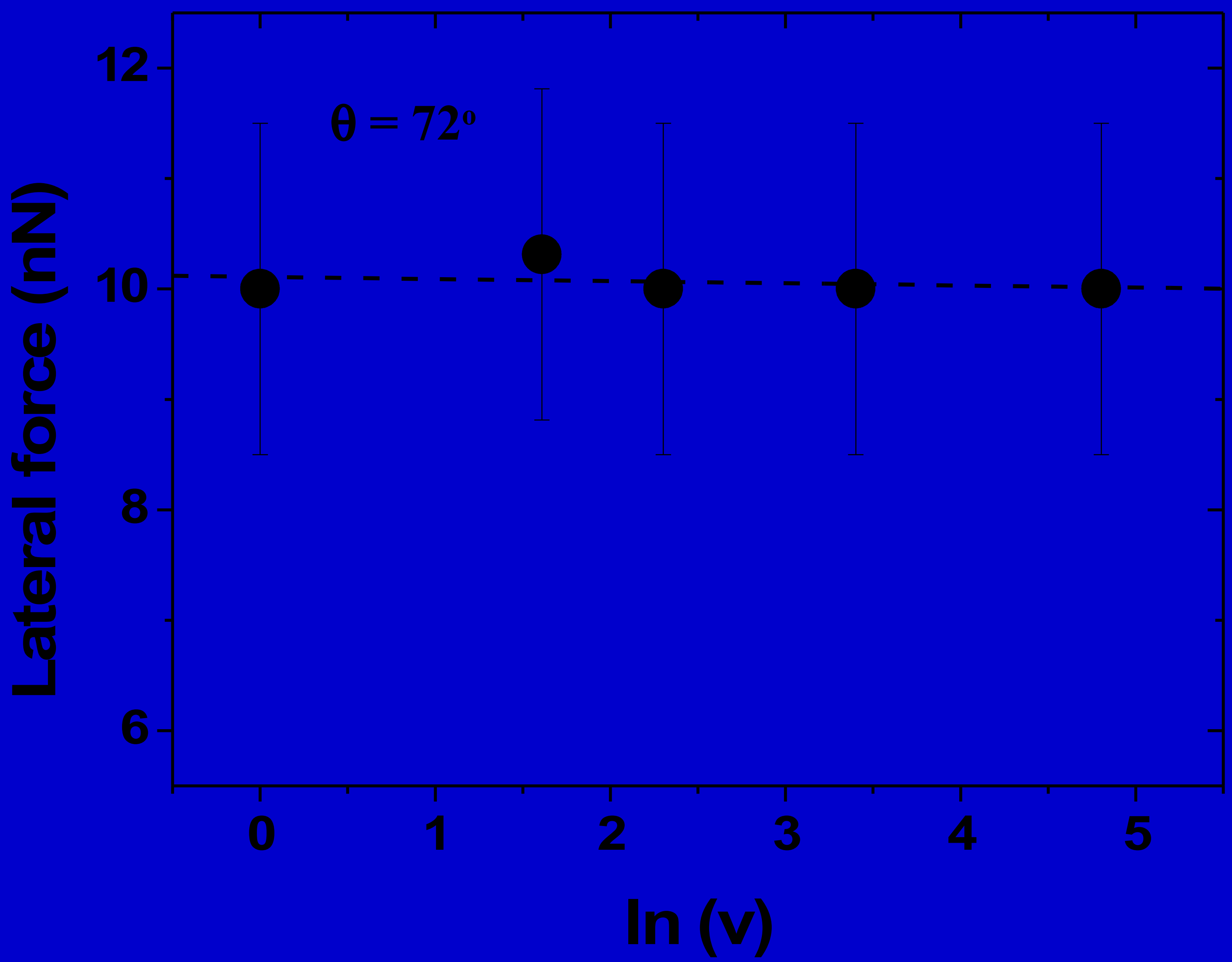


Hydrophobic amorphous carbon

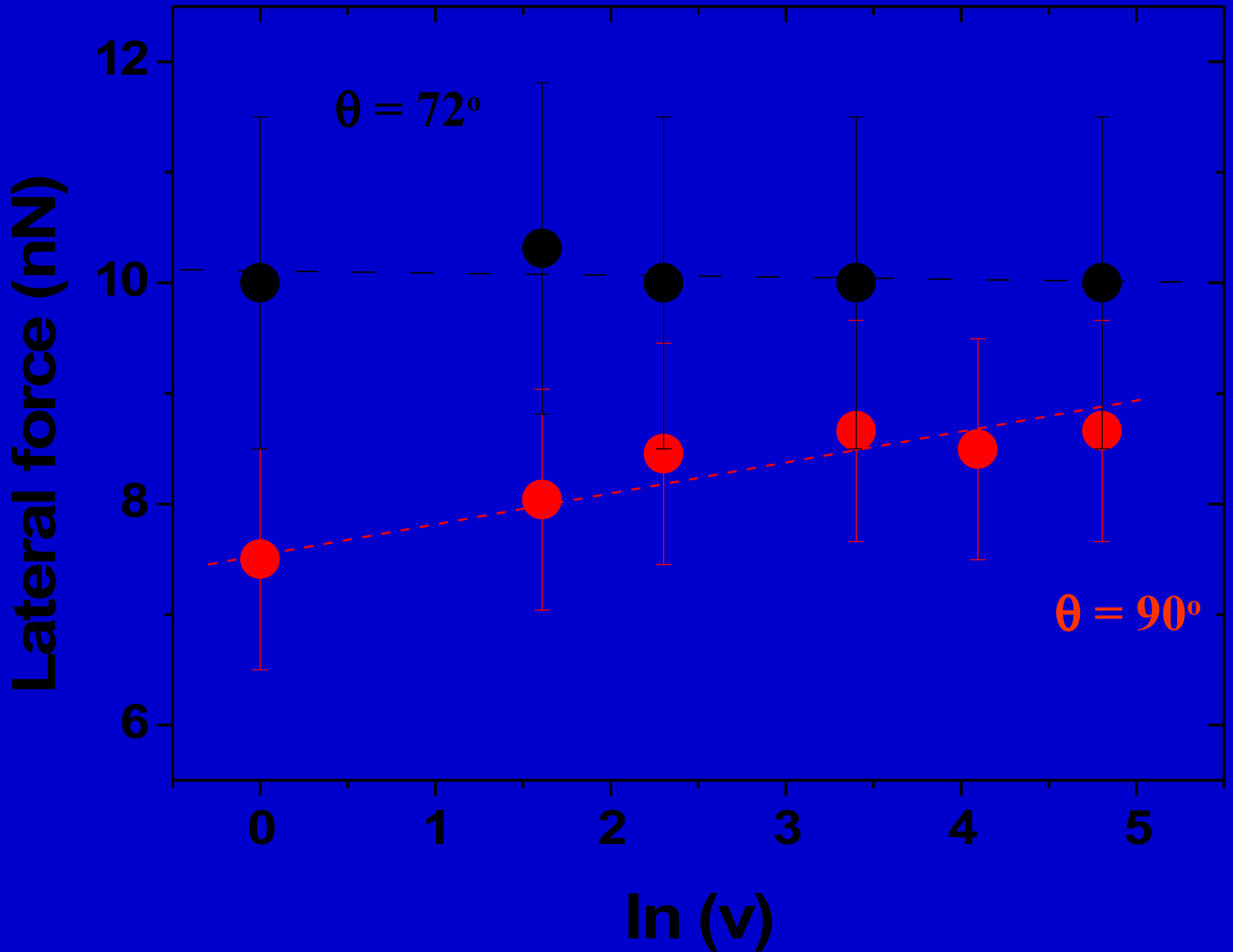


$\theta = 90^o$

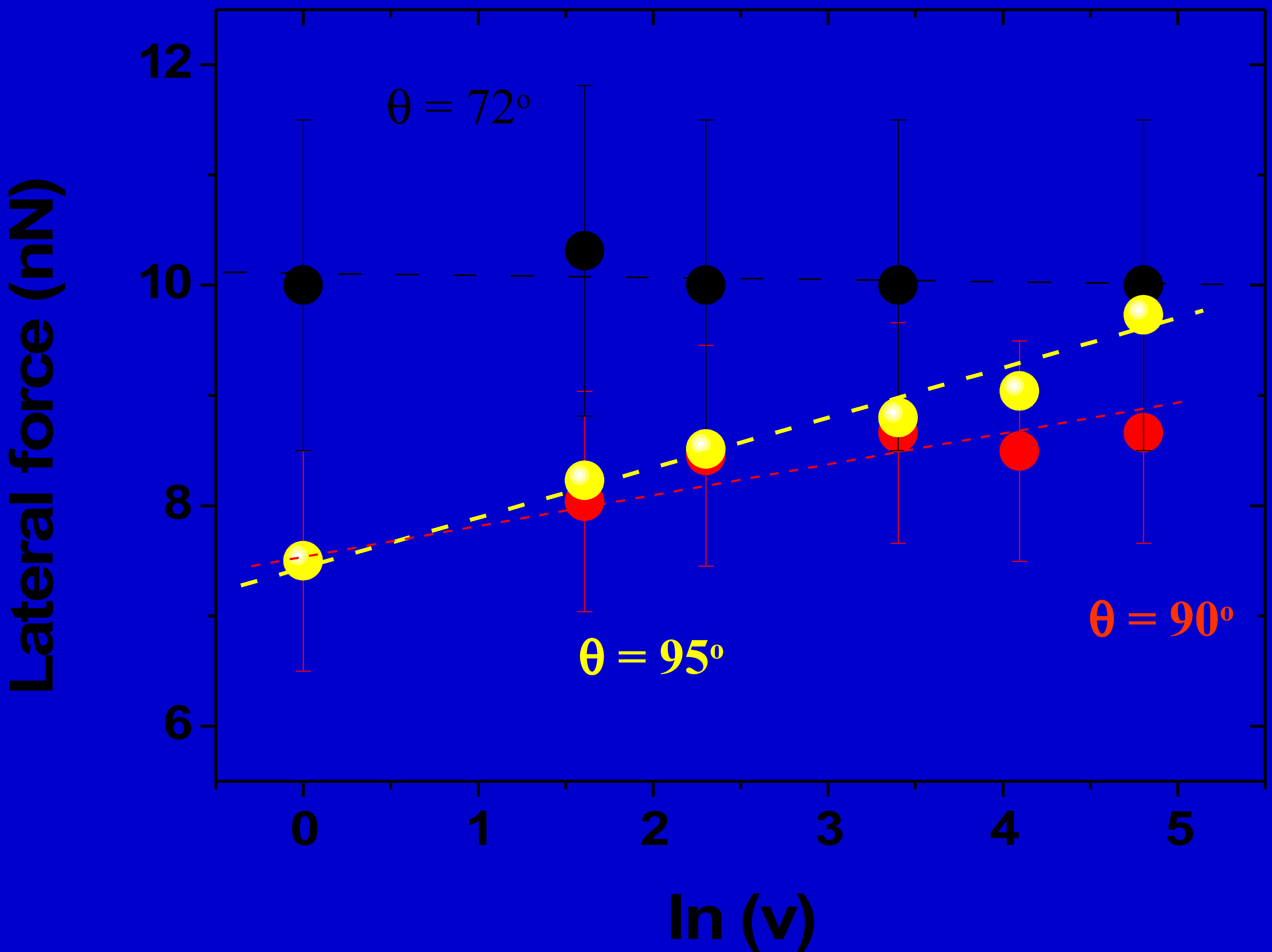
$$F_L = CF_N^{2/3} + \alpha F_N$$



θ = 72°
12
10
8
6
0
1
2
3
4
5
Lateral force (nN)
ln (v)



θ = 72°
θ = 90°
Lateral force (nN)
12
10
8
6
0
1
2
3
4
5
ln (v)



Lateral force (nN)
12
10
8
6
0
1
2
3
4
5
ln (v)
θ = 72°
θ = 95°
θ = 90°

Friction model

VOLUME 88, NUMBER 18 PHYSICAL REVIEW LETTERS 6 MAY 2002

Kinetics of Capillary Condensation in Nanoscopic Sliding Friction

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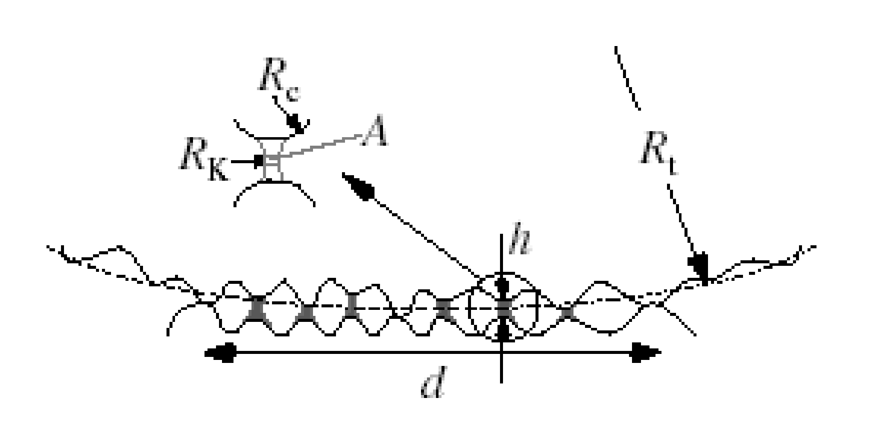
(Received 20 December 2001; published 18 April 2002)

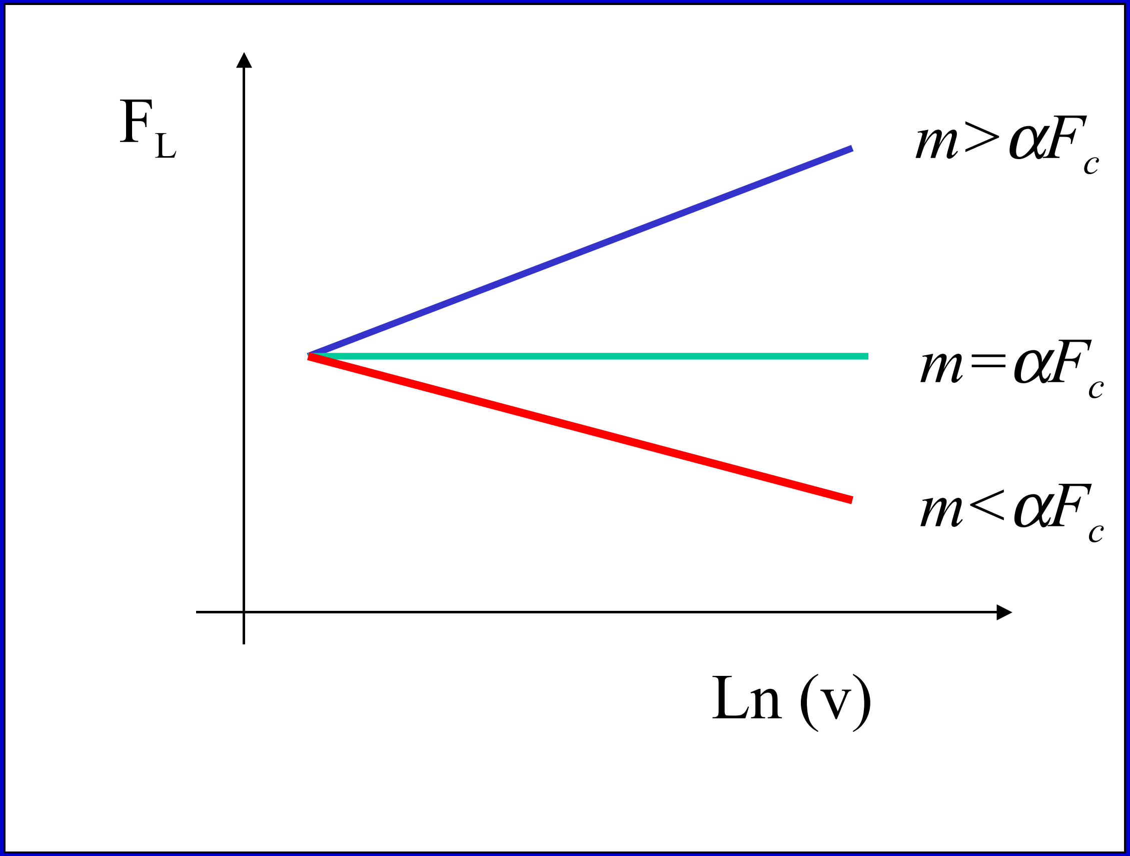


$$F_F = \mu(F_N + F_{ss}) + \mu[F_c f(t)] + m \ln\left(\frac{v}{v_B}\right)$$

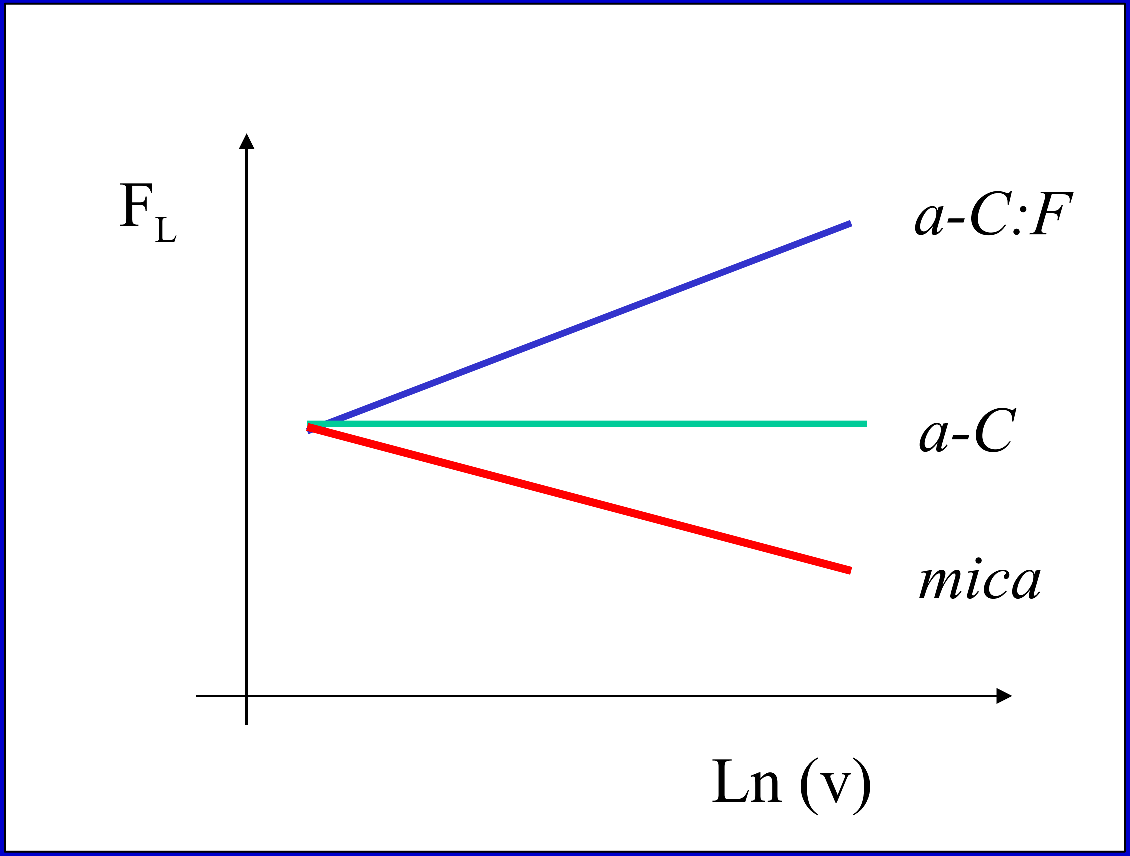
$$= \mu(F_N + F_{ss}) - \mu[2\pi R_t \gamma(\cos\theta_s + \cos\theta_t)]$$

$$\times \left(\frac{1}{\lambda A \rho} \frac{1}{\ln \frac{P_s}{P}}\right) \ln\frac{v}{v_A} + m \ln\left(\frac{v}{v_B}\right),$$

$$F_L = \mu F_N + \left[m - \alpha F_C\right]\ln(v)$$



$$F_L = \mu F_N + \left[m - \alpha F_C\right] \ln(v)$$



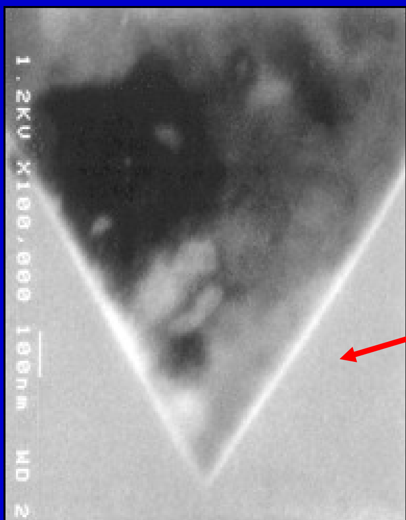
Conclusions:

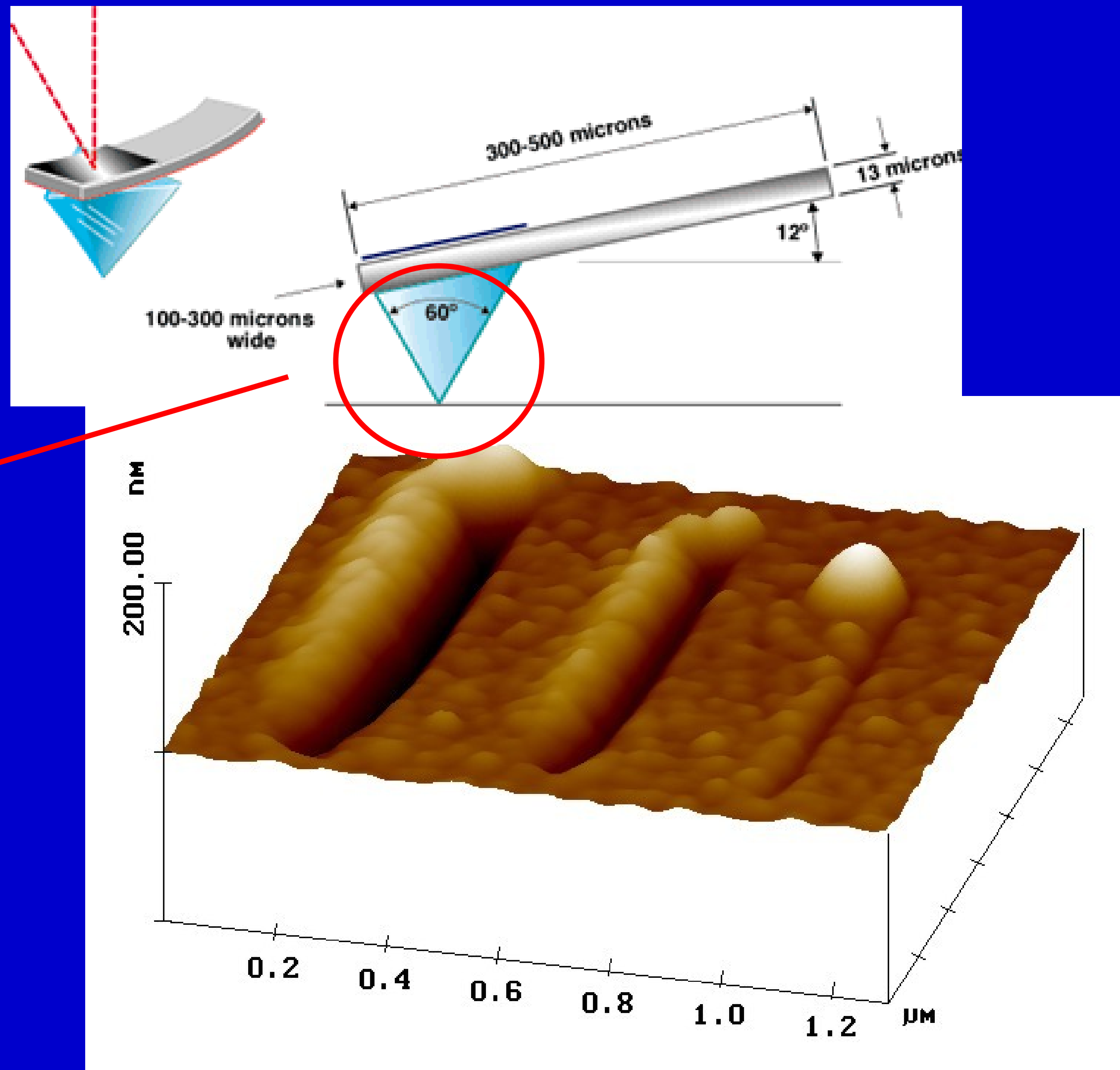
- **The velocity dependence of friction is strongly influenced by the capillary condensation of water.**

↕

- **The friction can be correlated with the surface hydrophobicity.**

Wear at nanometer scale





Films:

→ deposited by PECVD in C_2H_2-CF_4 atmosphere: a-C:H and a-C:F

a-C:H Hardness → 20 GPa; $sp^3/sp^2 \sim 1$; H = 20 at.%

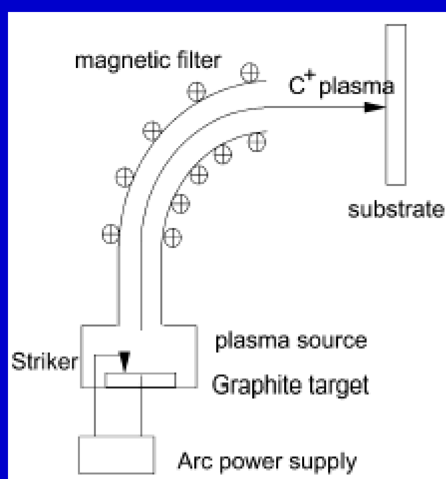
a-C:F Hardness → 5 GPa; F = 23 at.%

→ deposited by filtered arc: ta-C and nanostructured carbon films

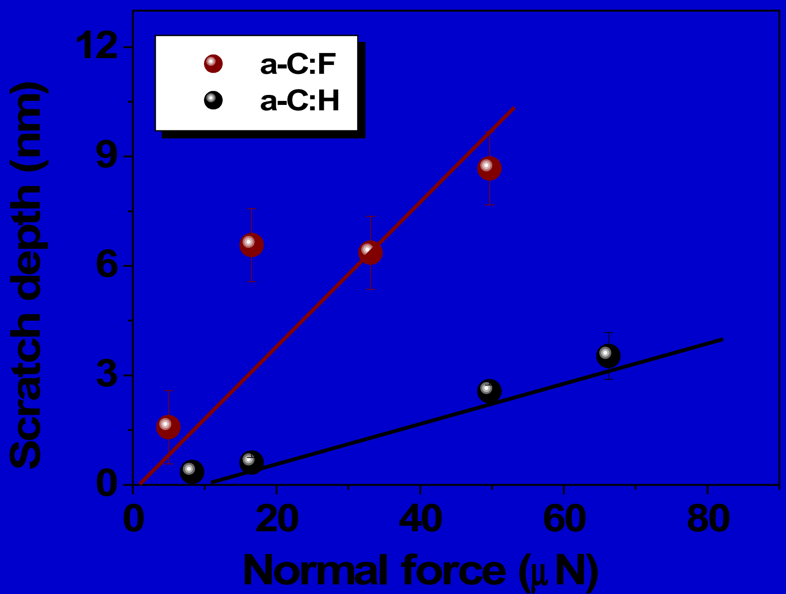
ta-C Hardness → 80 GPa; $sp^3/sp^2 \sim 4$

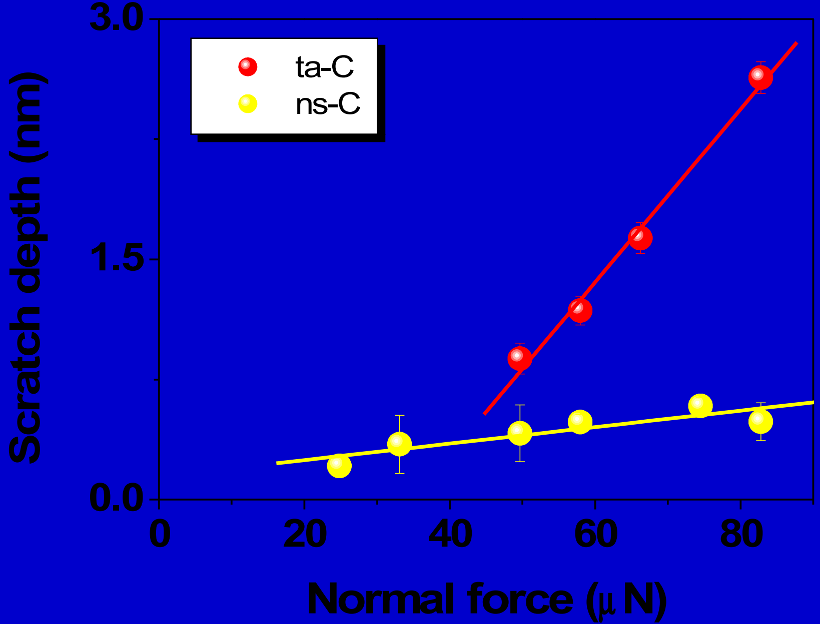
ns-C Hardness → ? (high elastic recovery); $sp^3/sp^2 \sim 0$

F.L. Freire Jr., R. Prioli, M. Chowala, Diamond and Related Materials, 12 (2003) 2195



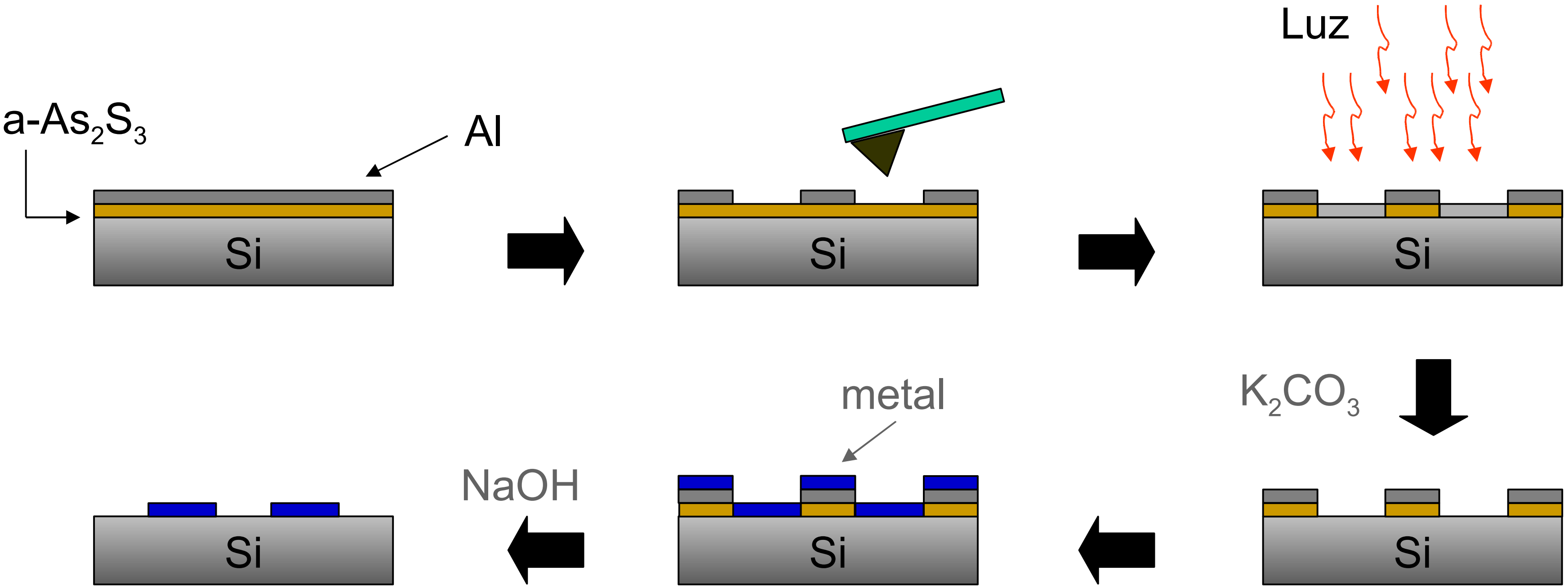
Scratch test



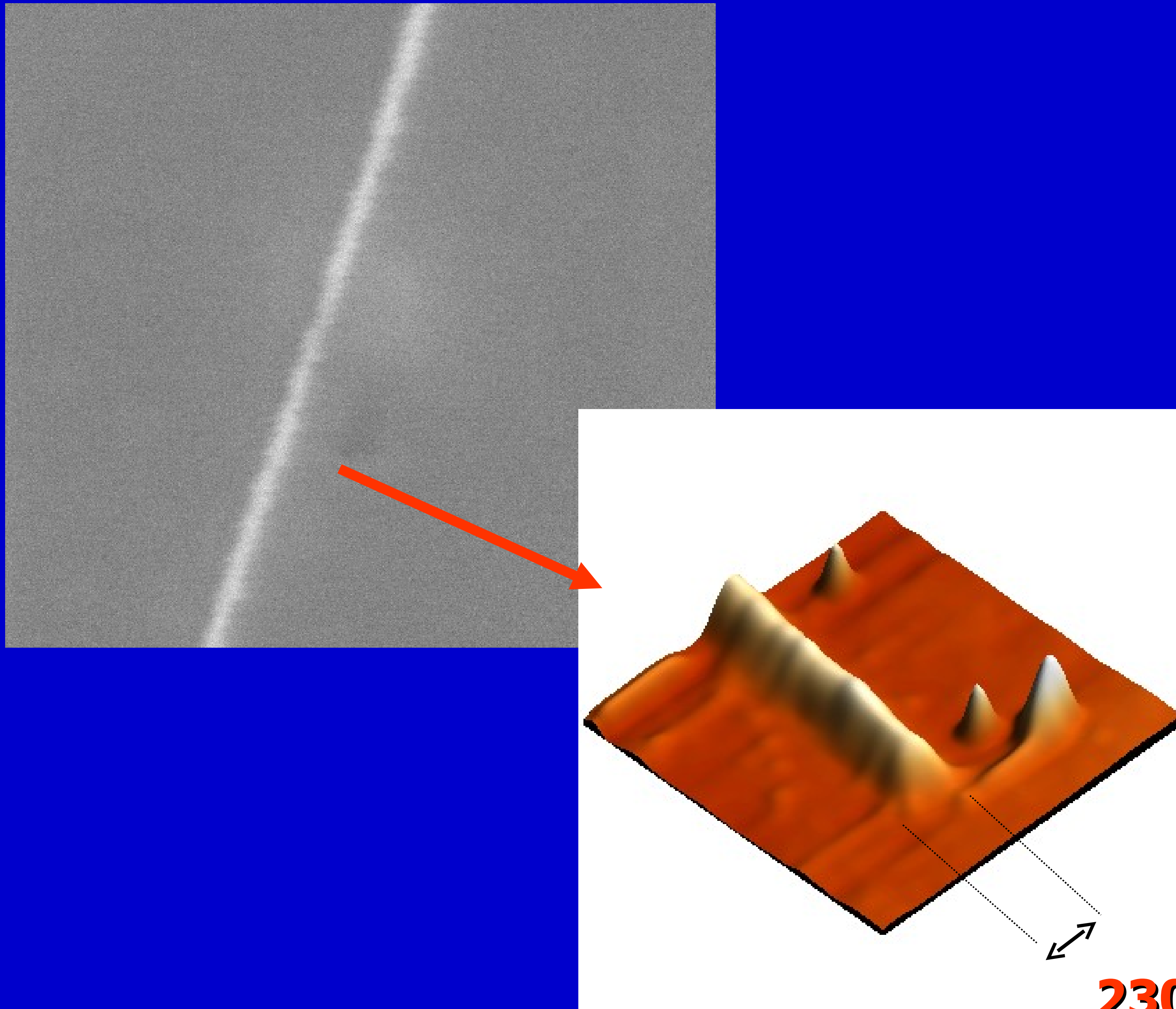


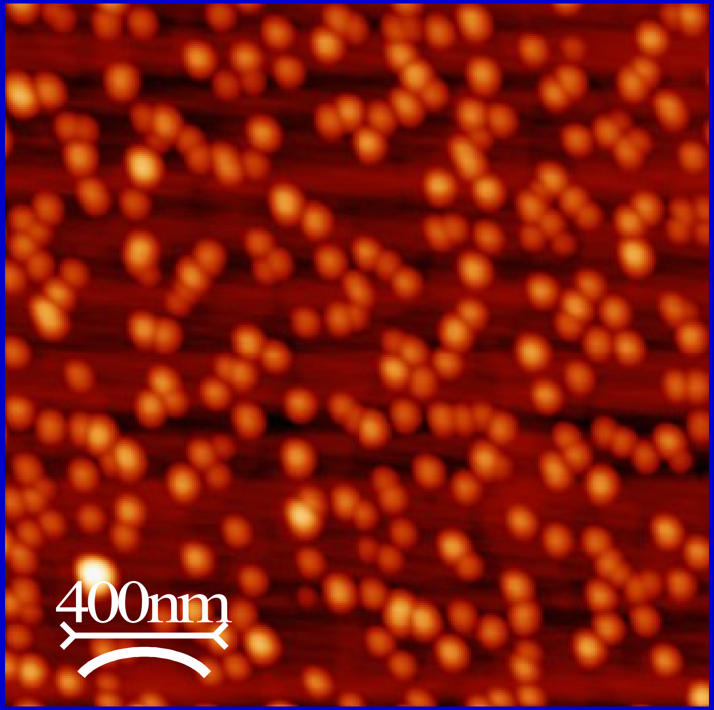
F.L. Freire Jr., R. Prioli, M. Chowala, Diamond and Related Materials, 12 (2003) 2195

nanolitography

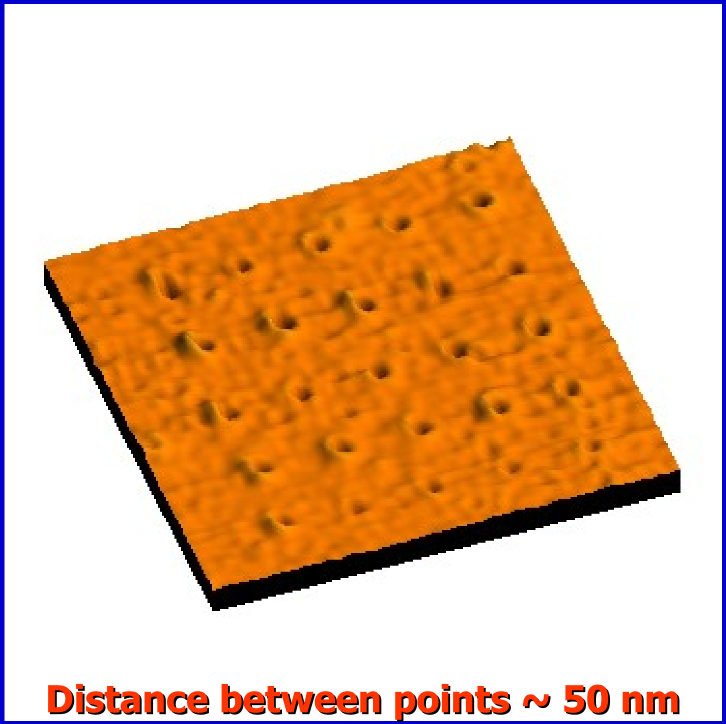


scheme

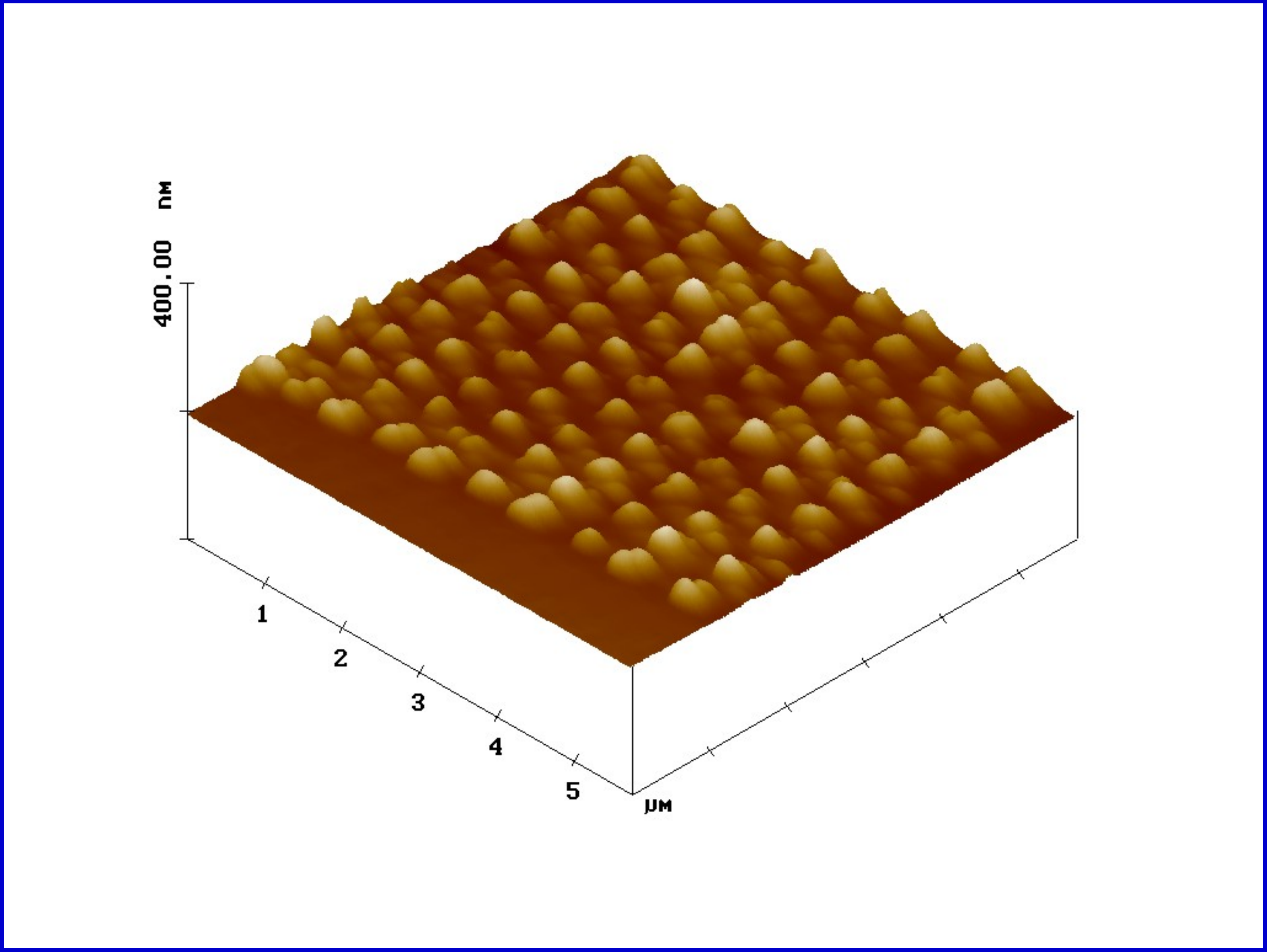

230 nm



Atomic force microscopy of InAs on InP



Defects induced by AFM tip on the surface of InP



InAs quantum dots grown onto InP

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Dra. Valéria Nunes

PHd students:

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Robert Zamora
Henrique Fonseca Filho
Cristiano Camacho
Paola Ayala
Carlos Sanchez Tasayco

M
MSc student:

Clara Muniz

Collaborators:

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Prof. Manish Chowala (Rutgers University, USA)
Prof. Yip Wah Chung (Northwestern University, USA)

CNPq, CAPES and FAPERJ

In order to fit our experimental data with Riedo's model we need to calculate or measure the parameters v_a, v_b, m, P_s, P etc.

$$v_a = \frac{2a}{t_a}$$

(contact diameter)
(time to built up a capillary bridge 25 μs)

***a* is obtained with the use of the Johnson-Kendal-Robertson**

$$F_{ad} = -\frac{3}{2}\pi R W_{12}$$

$$\frac{1}{E} = \frac{(1-\nu_{tip}^{2})}{E_{tip}} + \frac{(1-\nu^{2}_{s})}{E_s}$$

$$a^3 = \frac{R}{E}\left[F + 3\pi R W_{12} + \sqrt{6\pi R W_{12} F + (3\pi R W_{12})^2}\right]$$

Calibração de Força Lateral

	μ MICA	μ HOPG
PUC	0.062	0.009
LIU [1]	0.095	0.011
ELISA [2]		0.009
RUAN [3]		0.006
LABARDI [4]	0.027	0.013
WARMACK [5]	0.086	
Average	0.068	0.01
σ	0.034	0.002

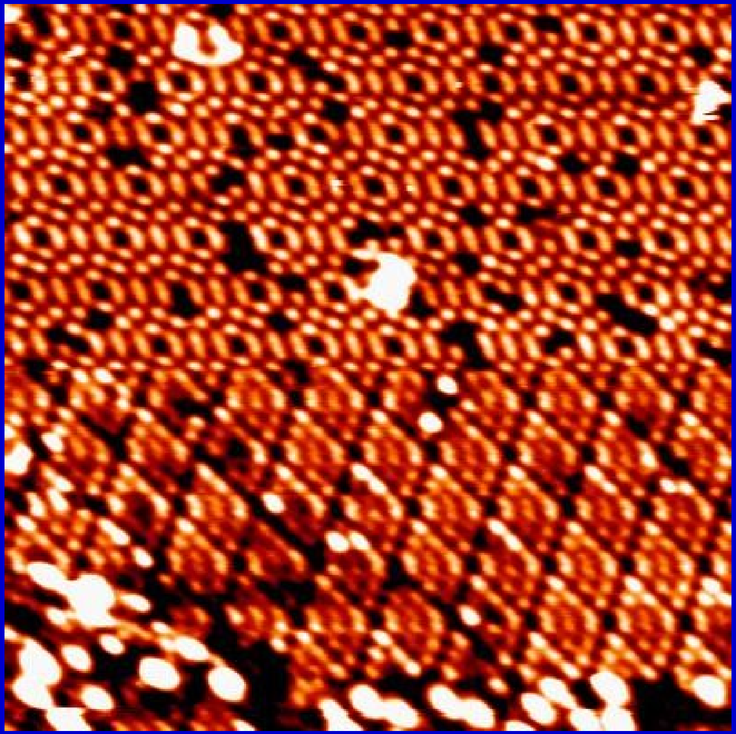
[1] - E.Liu et.al., Wear 192,141 (1996)

[2]- E.Riedo et. al., Surface Sci. 477, 25 (2001)

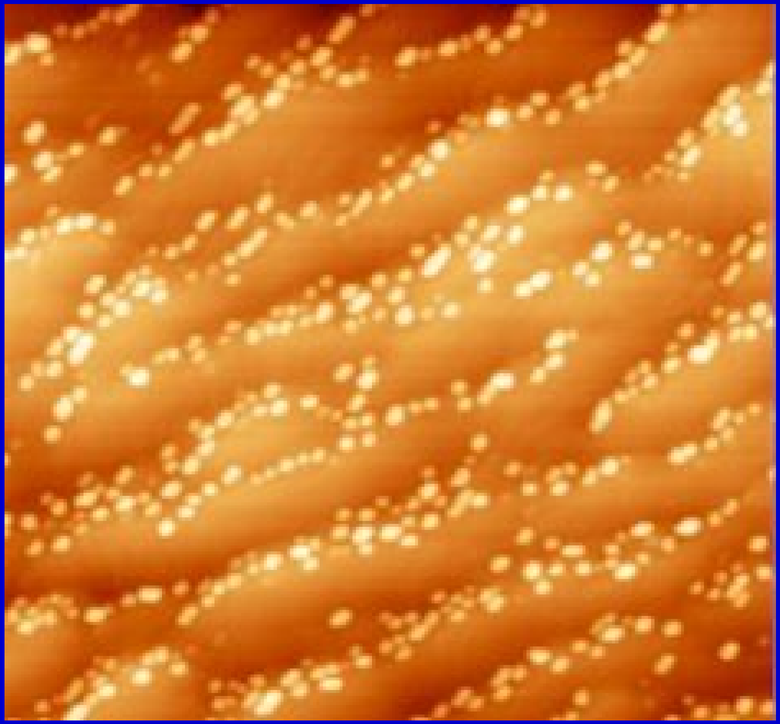
[3] - J.A.Ruan et. al., J. of Tribology 116, 378 (1994)

[4] - M.Labardi et.al., Appl. Phys. A 59, 3 (1994)

[5] - R. J. Warmack et. al., Rev. Sic. Instrum. 65, 394 (1994)

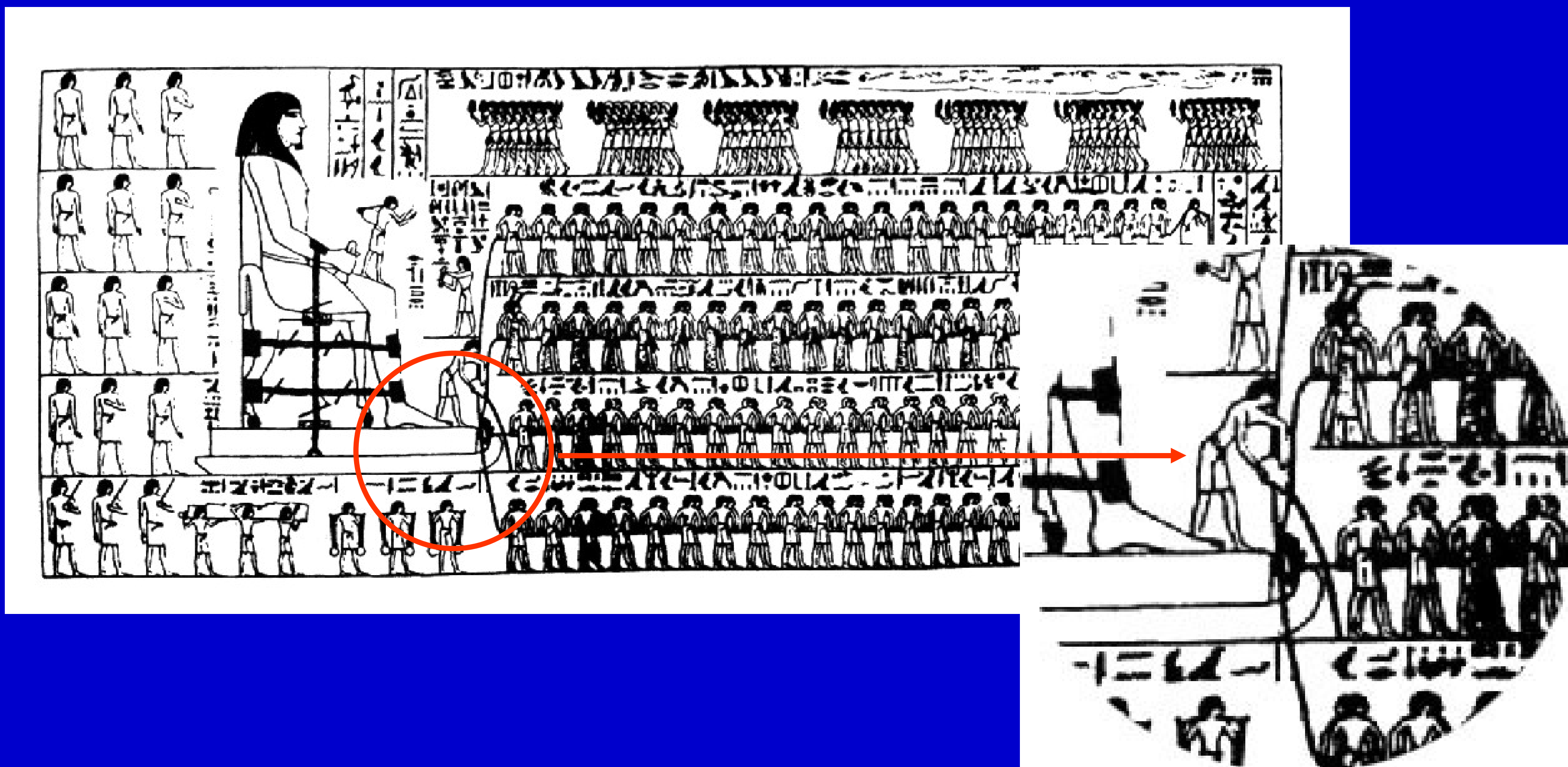


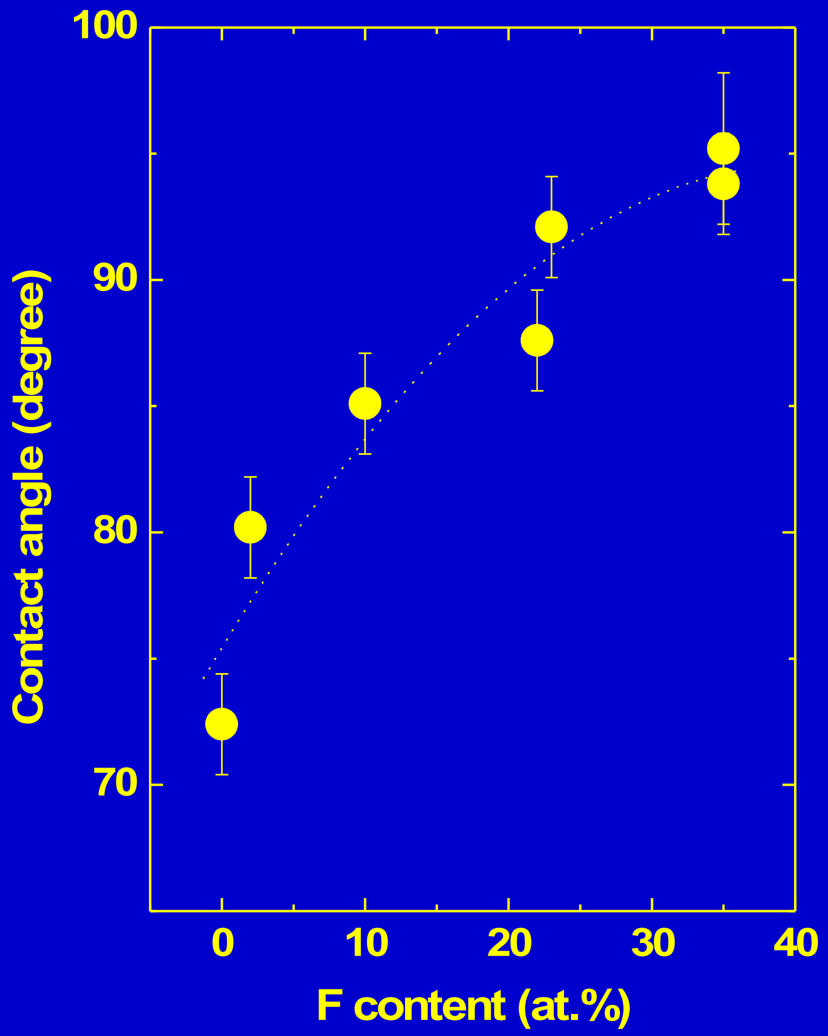
STM –UHV Si reconstructed 7x7

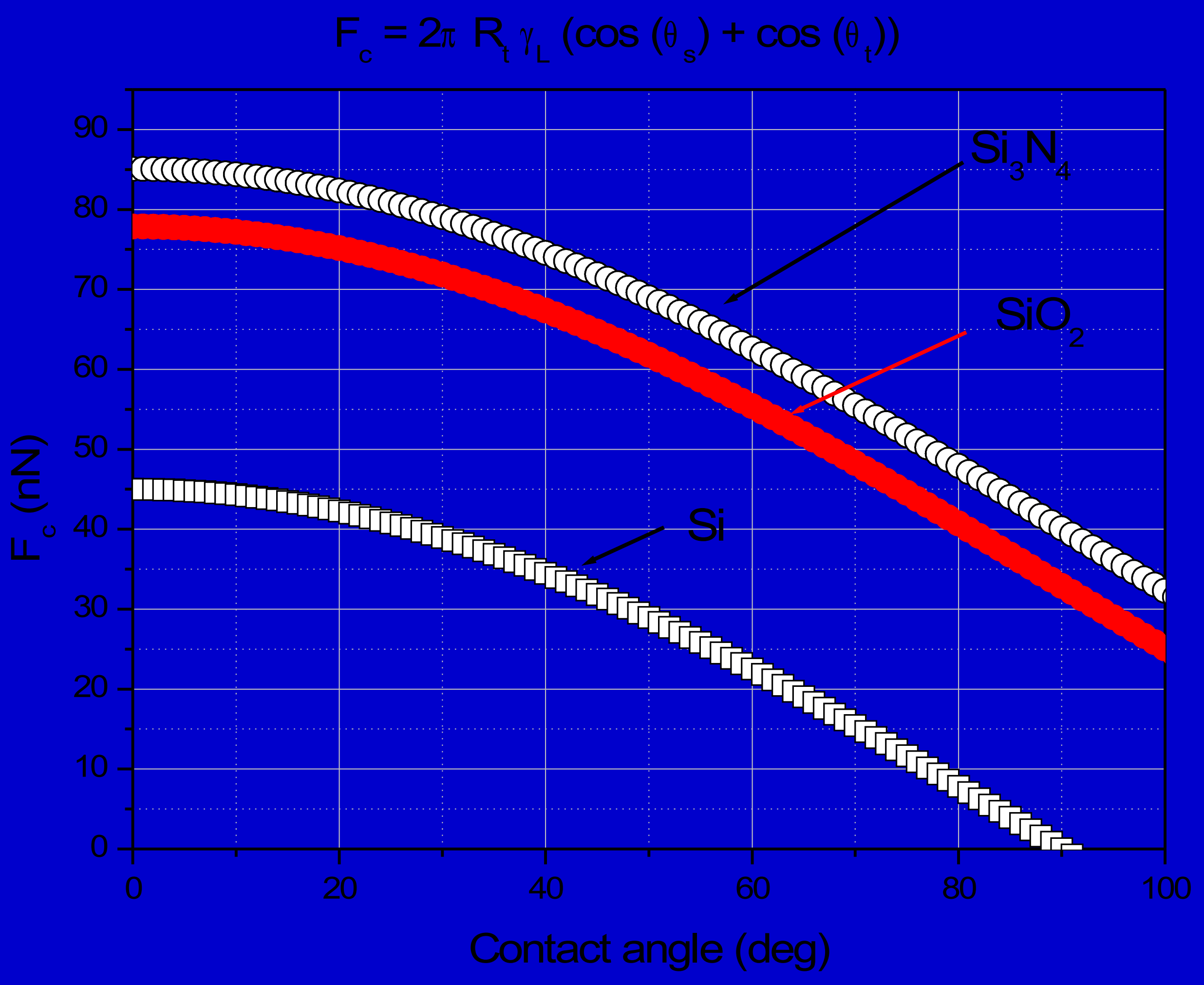


AFM dots

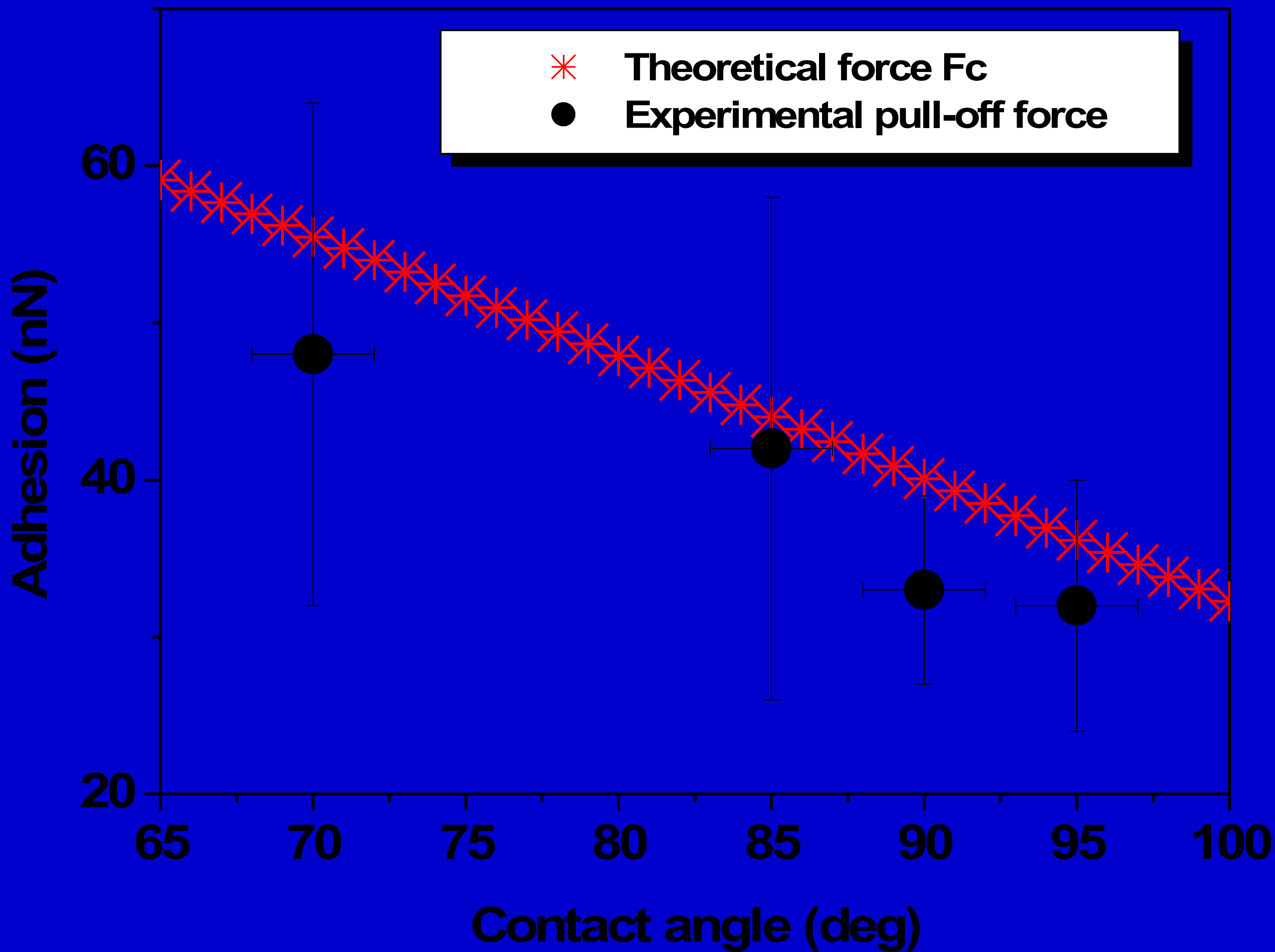
Tribologia

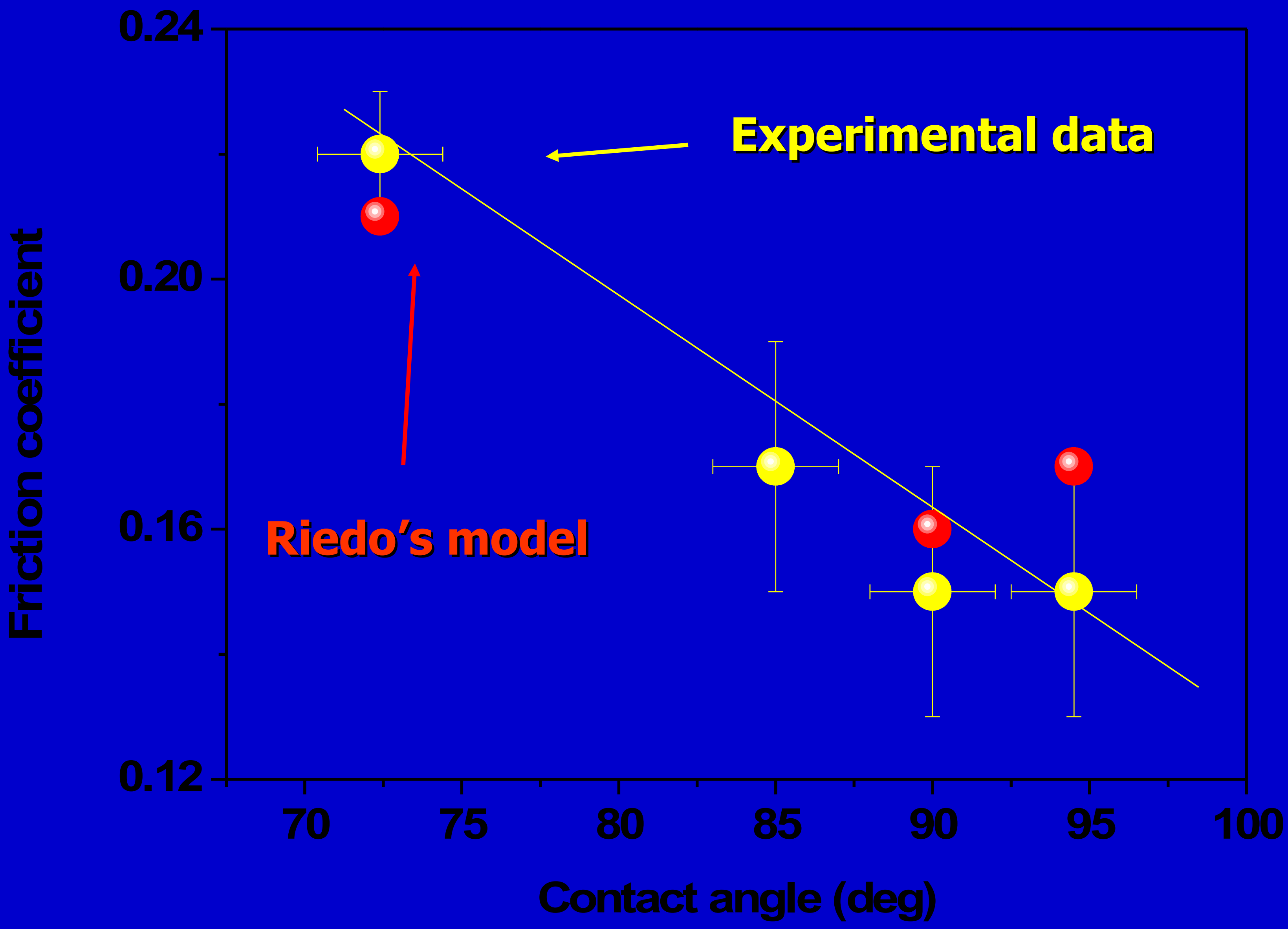



100
90
80
70
Contact angle (degree)
0
10
20
30
40
F content (at.%)



$F_c = 2\pi R_t \gamma_L (\cos(\theta_s) + \cos(\theta_t))$
Si_3N_4
SiO_2
Si
F_c (nN)
Contact angle (deg)
0
10
20
30
40
50
60
70
80
90
0
20
40
60
80
100


Theoretical force Fc
Experimental pull-off force
Adhesion (nN)
20
40
60
65
70
75
80
85
90
95
100
Contact angle (deg)

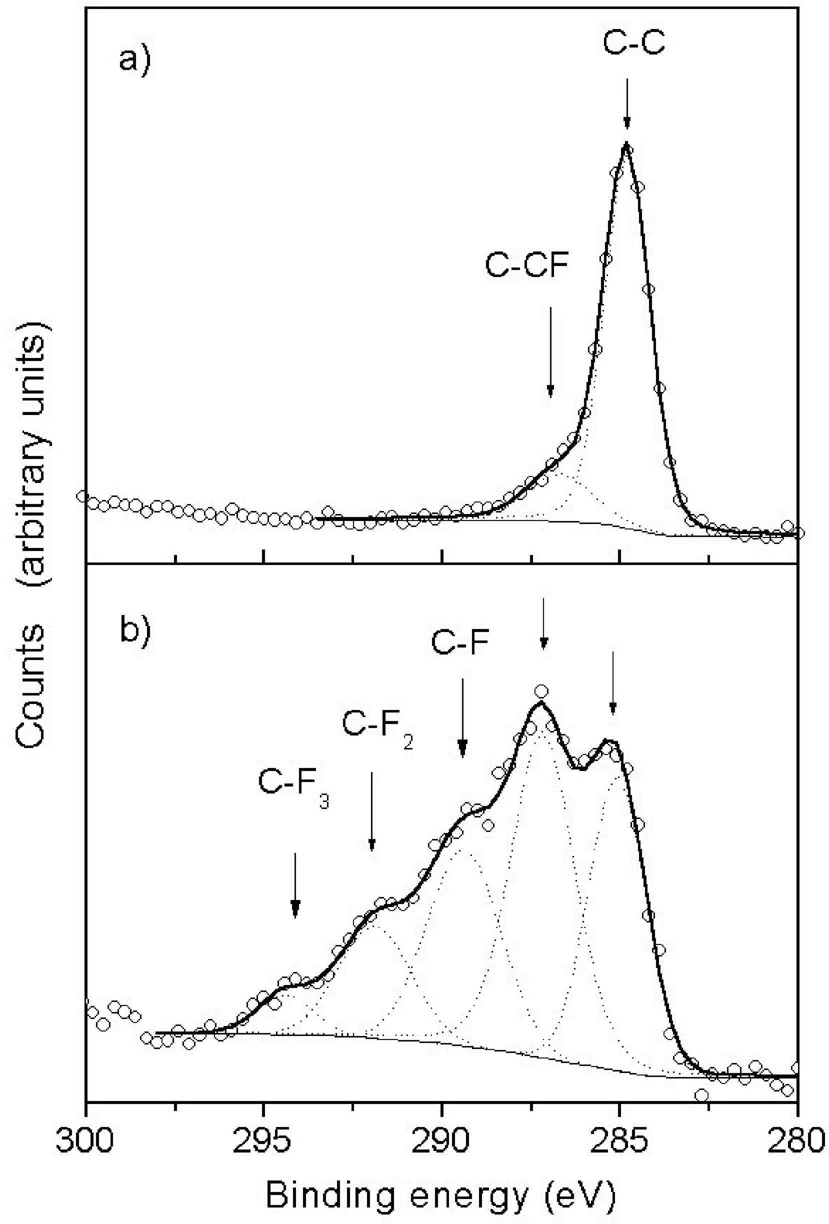


Experimental data
Riedo's model
0.24
0.20
0.16
0.12
70
75
80
85
90
95
100
Friction coefficient
Contact angle (deg)

Films deposited by rf-PECVD using C_2H_2-CF_4 mixtures

C_2H_2 partial pressure (%)	Composition (at.%)				Atomic density (10^{23} atoms/cm^3)
	C	H	F	O	
100	77	22	0	1	1.3
90	76	21	2	1	1.2
77	74	15	10	1	1.1
50	73	4	22	1	0.9
33	70	2	23	5	0.7
25	60	2	35	3	0.6
20	60	2	35	3	0.7

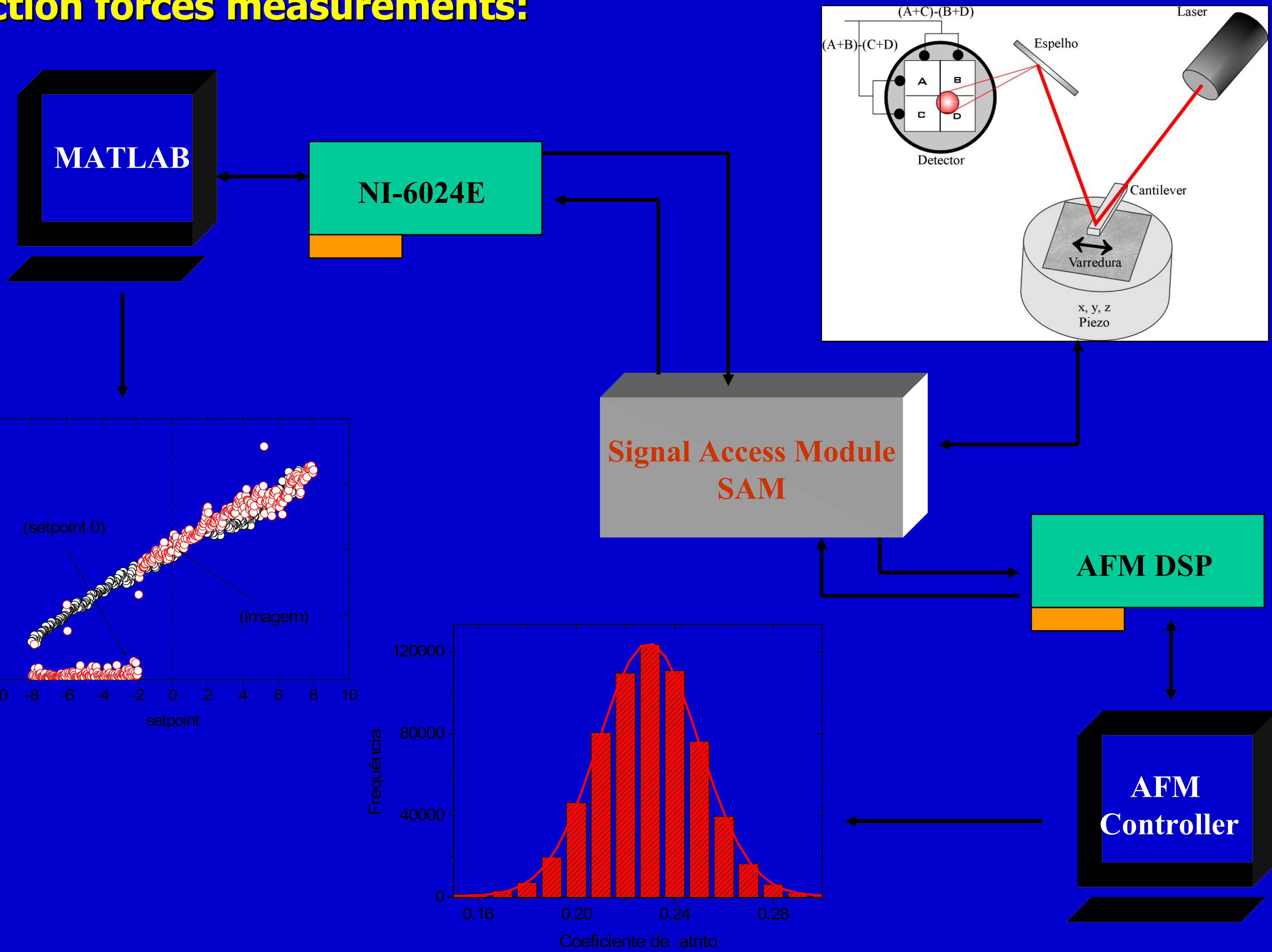
Chemical composition and atomic density by IBA


a)
C-C
C-CF
b)
C-F
$C-F_2$
$C-F_3$
Counts (arbitrary units)
300
295
290
285
280
Binding energy (eV)

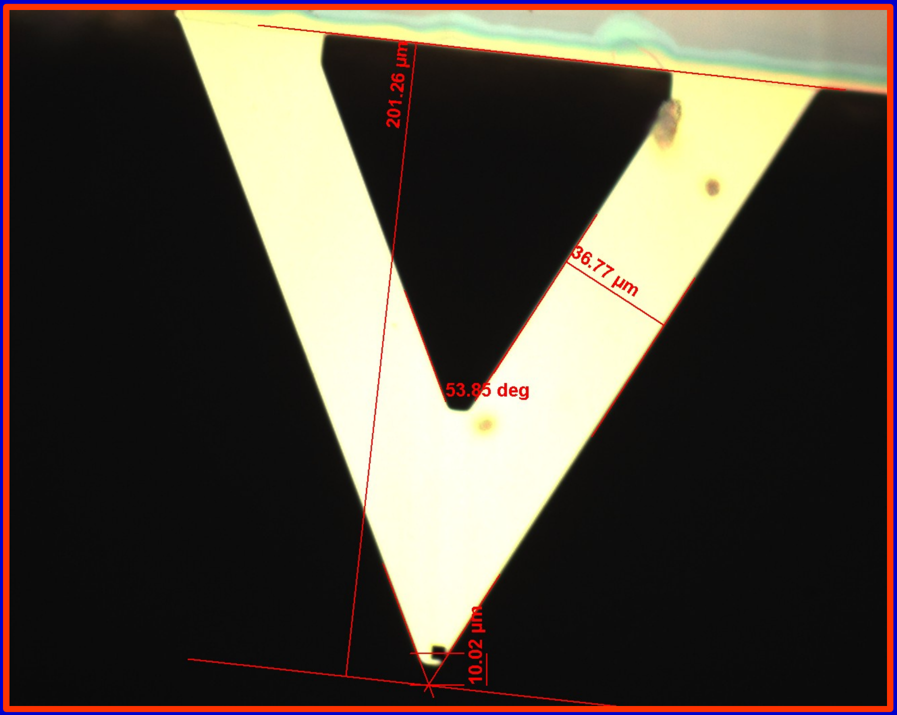
F = 10 at.%

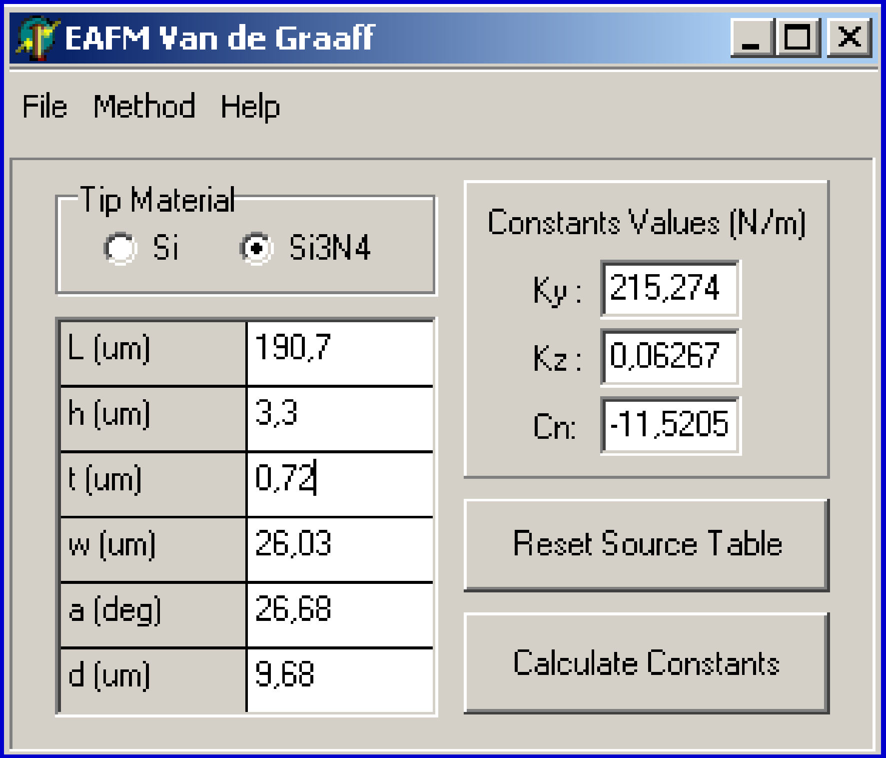
F = 35 at.%

Friction forces measurements:

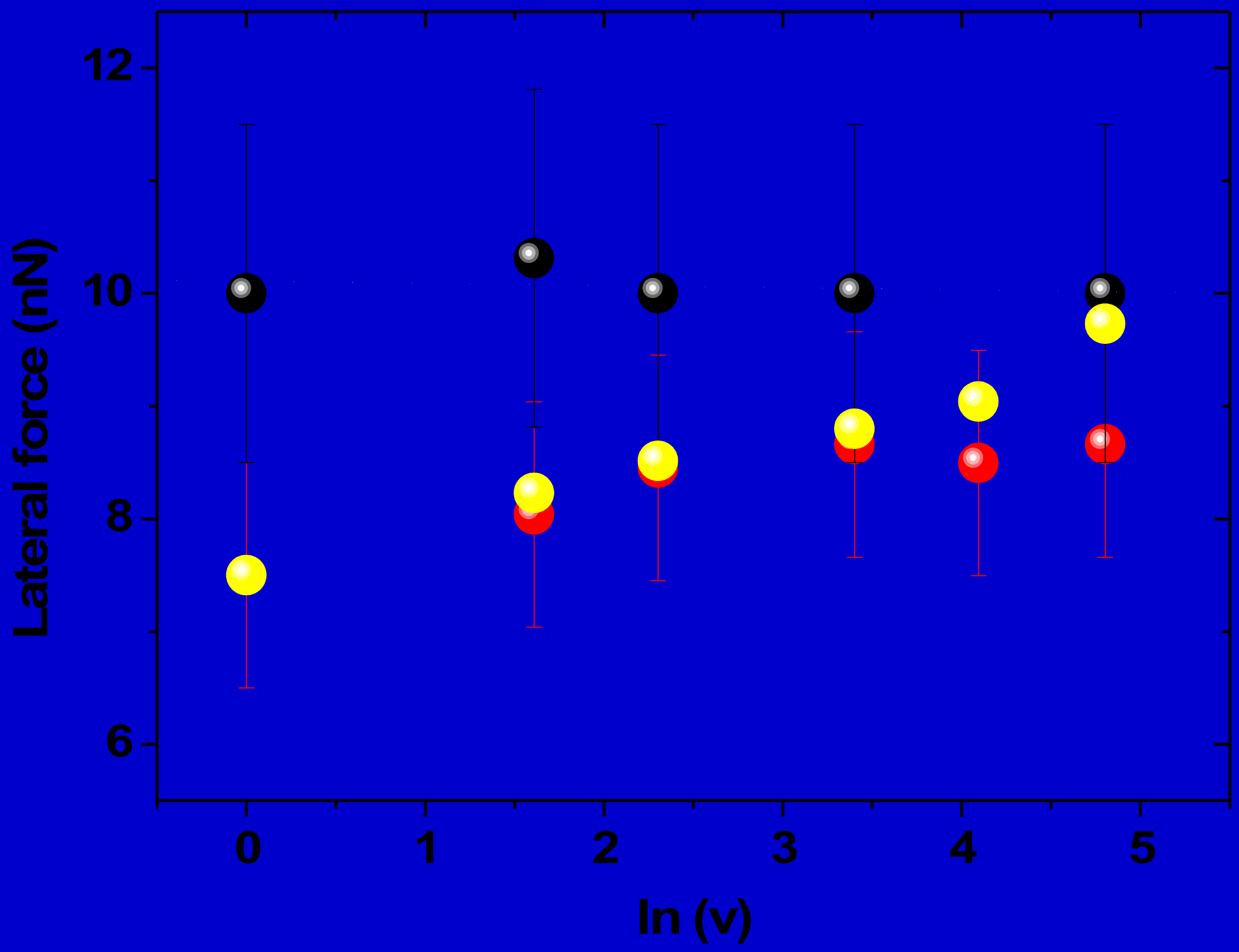


Cantilever calibration

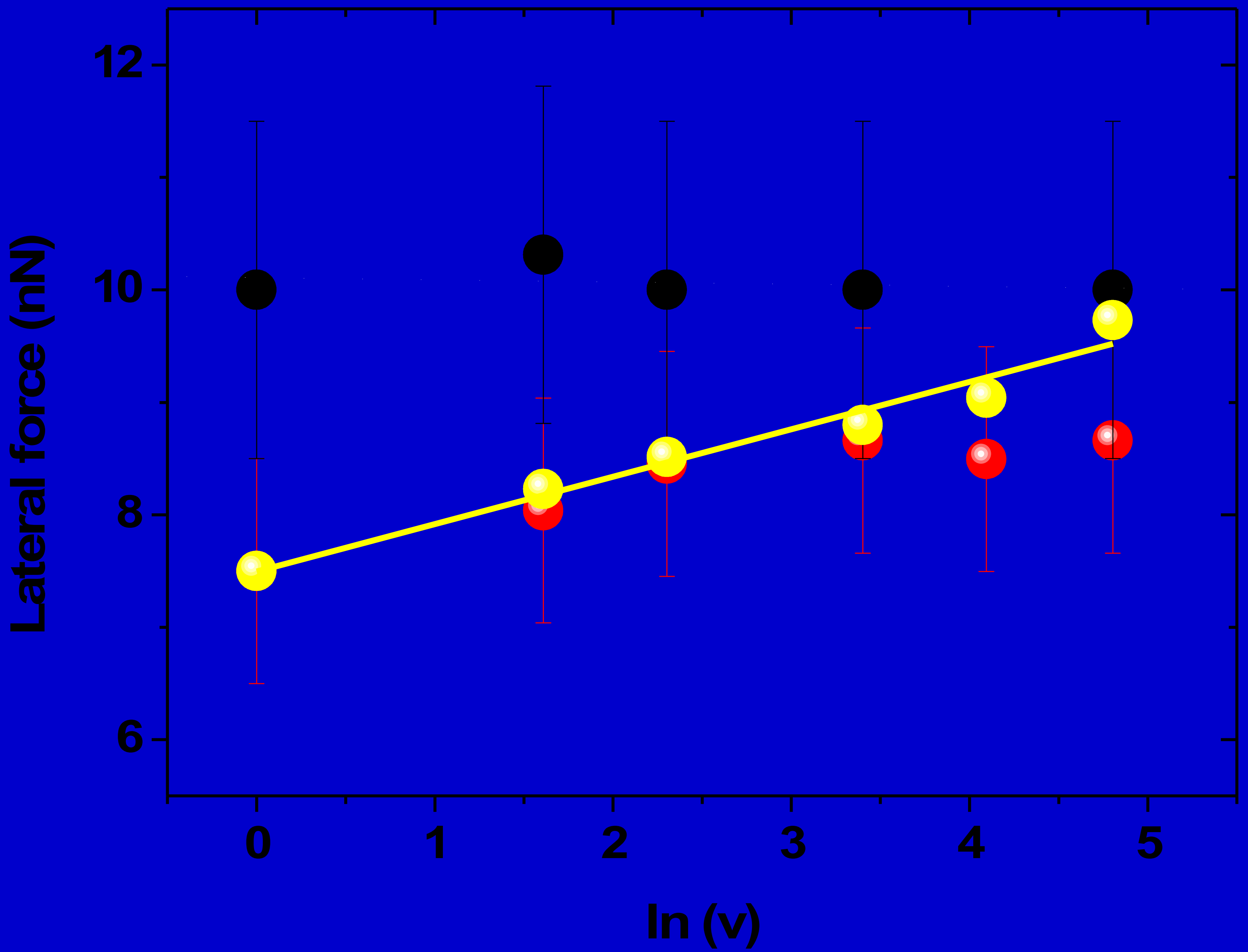




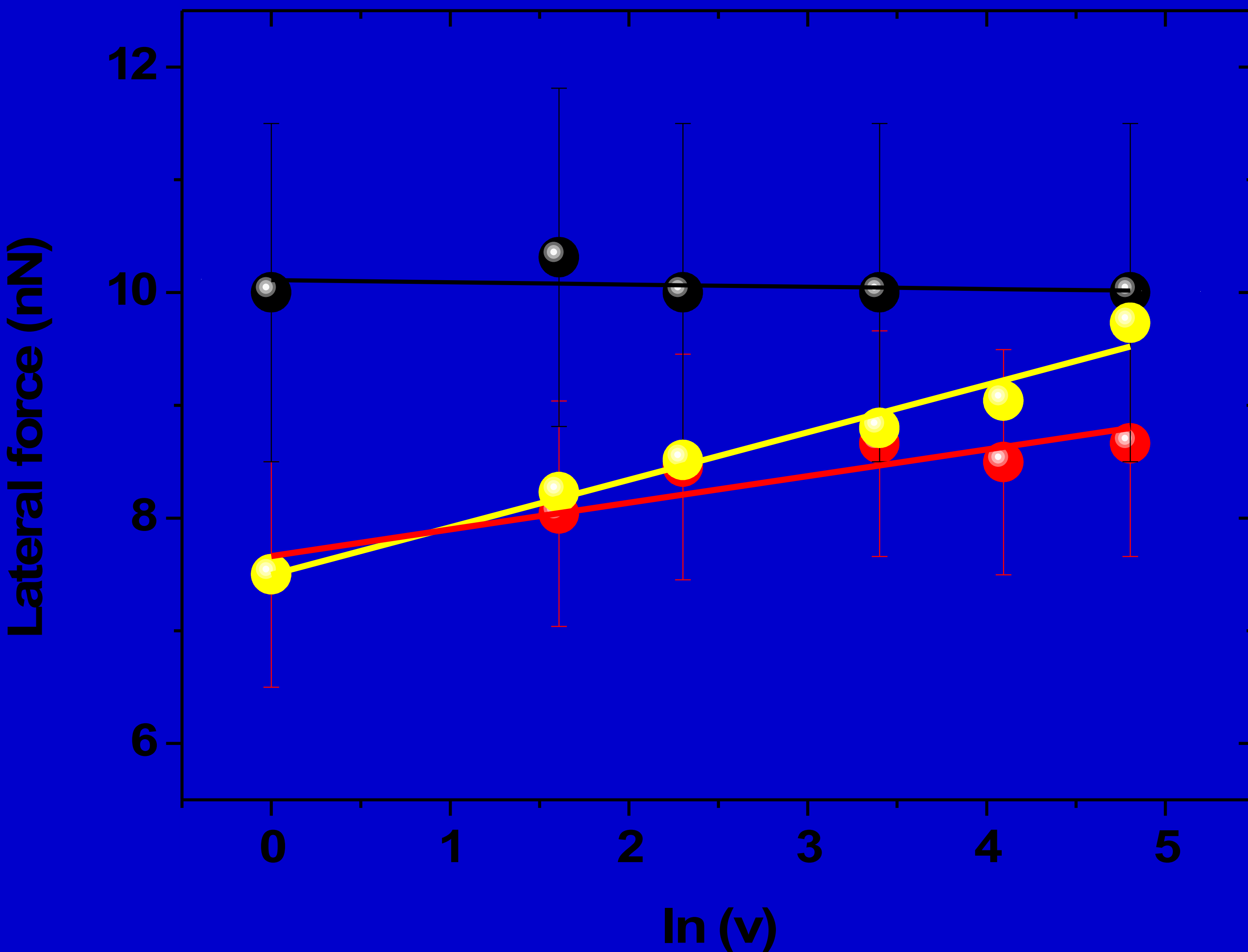
E. Liu, B. Banplain, J.P. Celis, Wear 192 (1996) 141



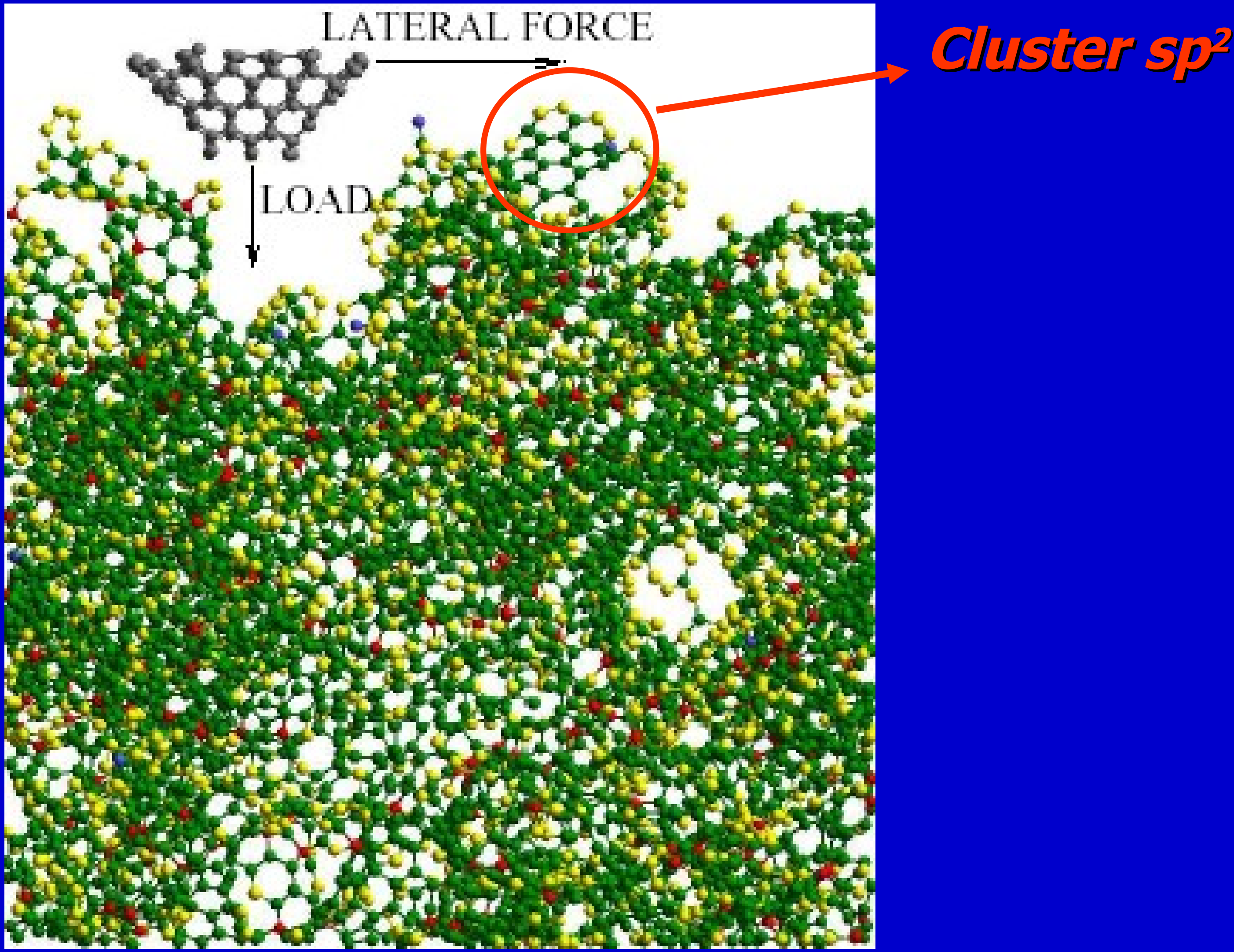
Lateral force (nN)
12
10
8
6
0
1
2
3
4
5
ln (v)



Lateral force (nN)
12
10
8
6
0
1
2
3
4
5
ln (v)



12
10
8
6
Lateral force (nN)
0
1
2
3
4
5
ln (v)


LATERAL FORCE
LOAD
Cluster sp²