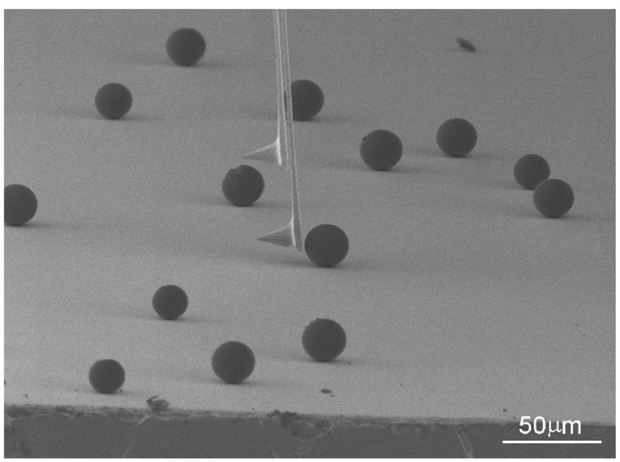
Microspheres in Acoustic Fields: Rolling Moment Resistance and Work-of-Adhesion Measurements

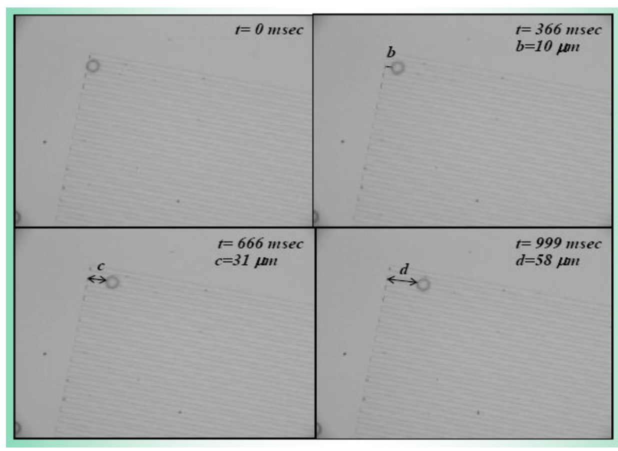
Çetin Çetinkaya

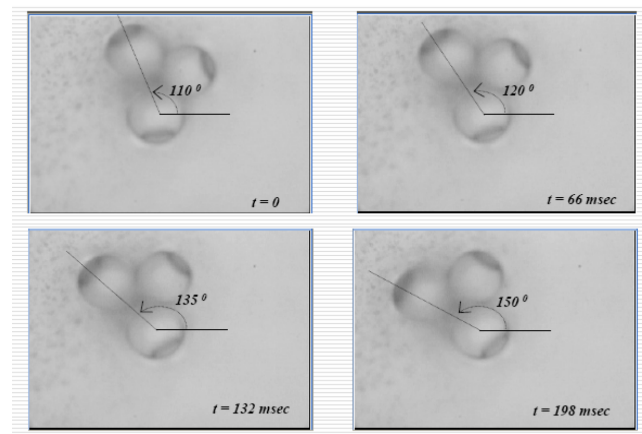
Photo-Acoustics Research Laboratory
Dept. of Mechanical and Aero. Engineering
Clarkson University
Potsdam, New York 13699-5725

Email: cetin@clarkson.edu
Phone: (315) 268-6514
Cell: (315) 276-8051
Fax: (315) 268-6695

Microspheres in Acoustic Fields: Rolling Moment Resistance and Work-of-Adhesion

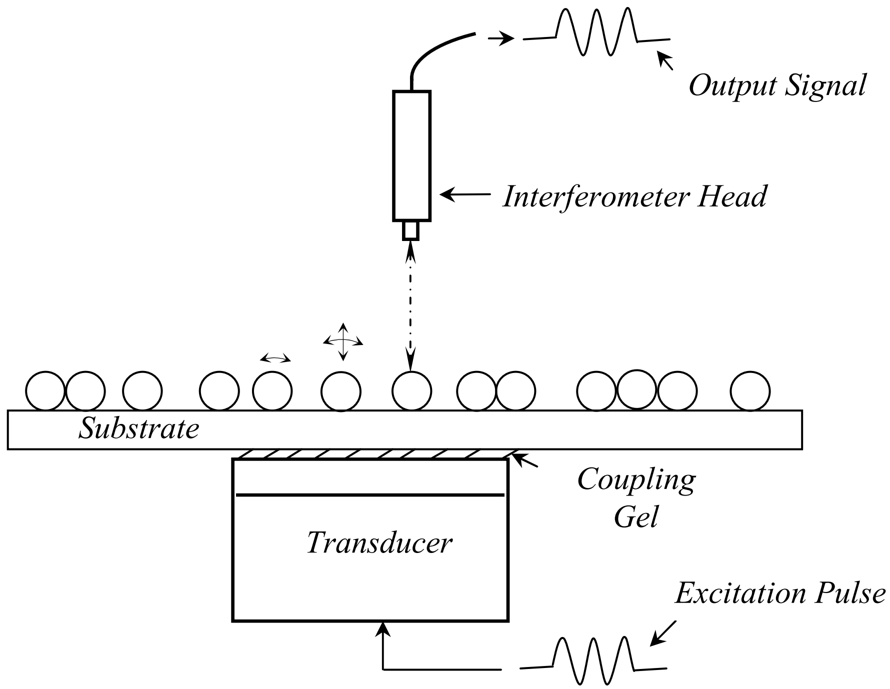


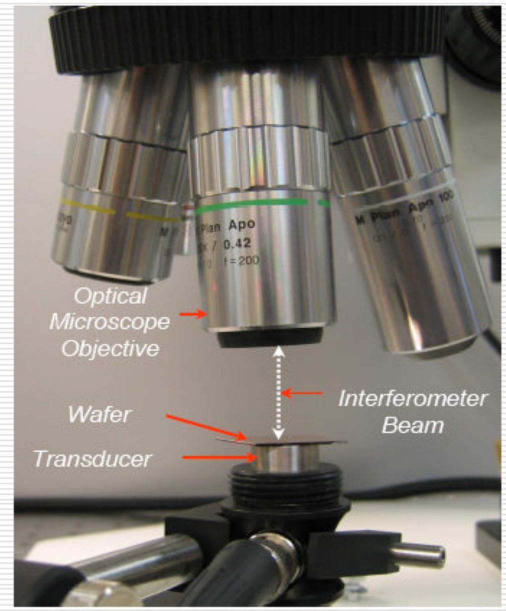


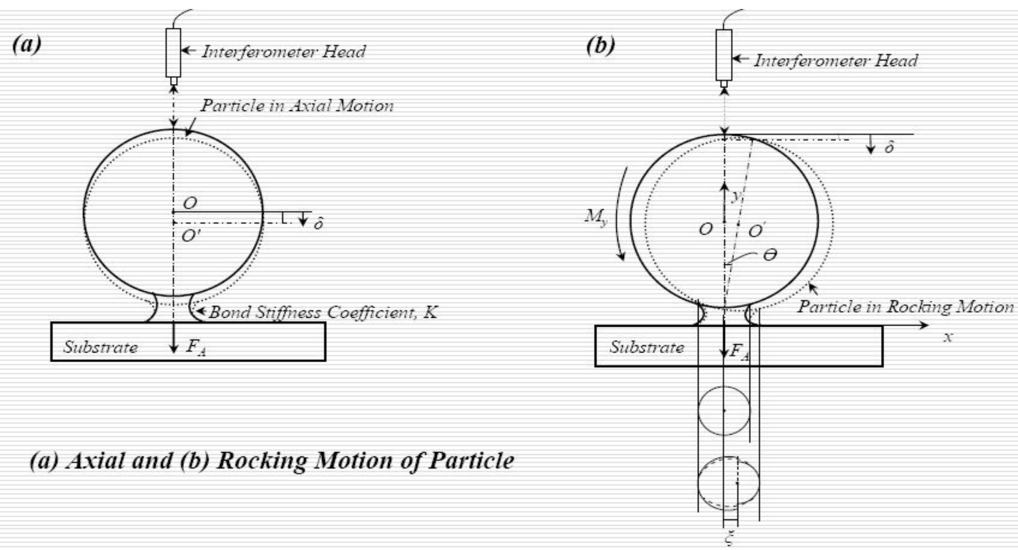


M. D. M. Peri and C. Cetinkaya, *Applied Physics Letters*, Vol. 86, 2005.

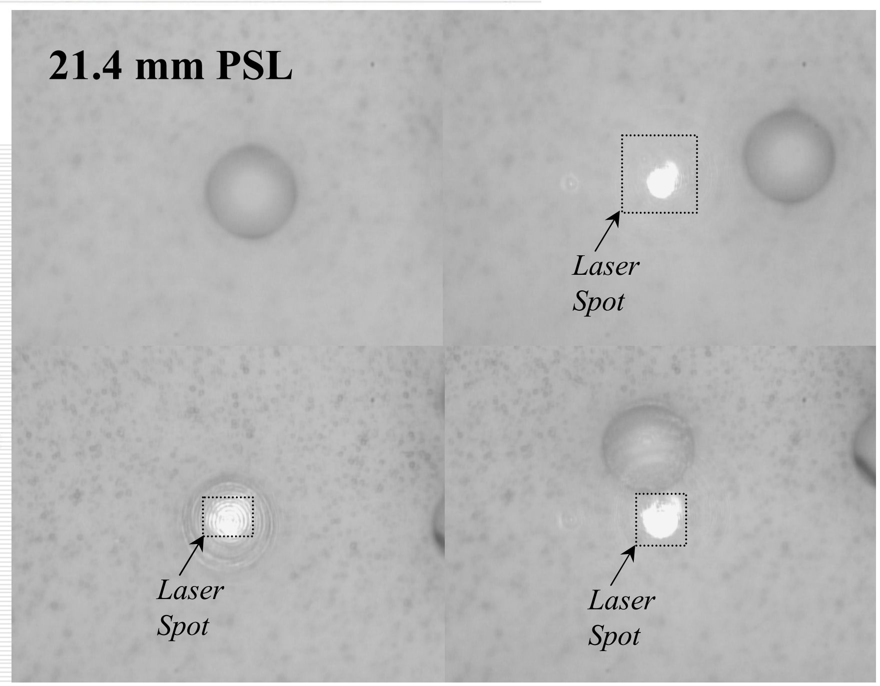
Vibrational Motion of Particles in Acoustic Fields







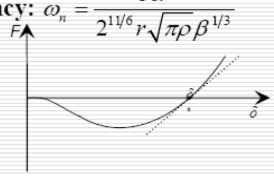
(a) Axial and (b) Rocking Motion of Particle



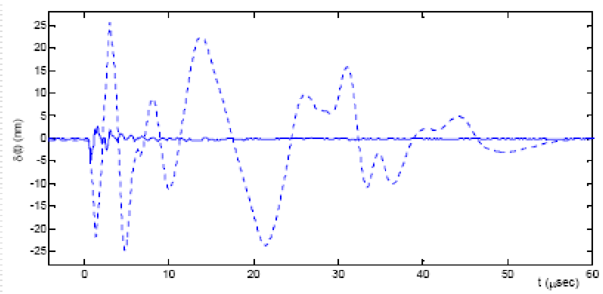
Axial Vibration vs. Rocking Motion

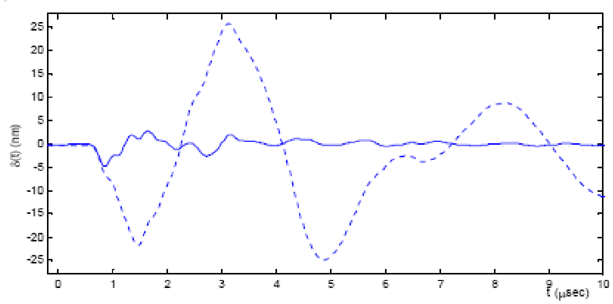
$$F_A = \frac{1}{\beta} r^{3/2}\,\delta^{3/2} - \sqrt{\frac{2\alpha}{\beta}}\, r^{3/4}\,\delta^{3/4} \qquad M = 6\pi W_A (D/2)^2\,\theta$$

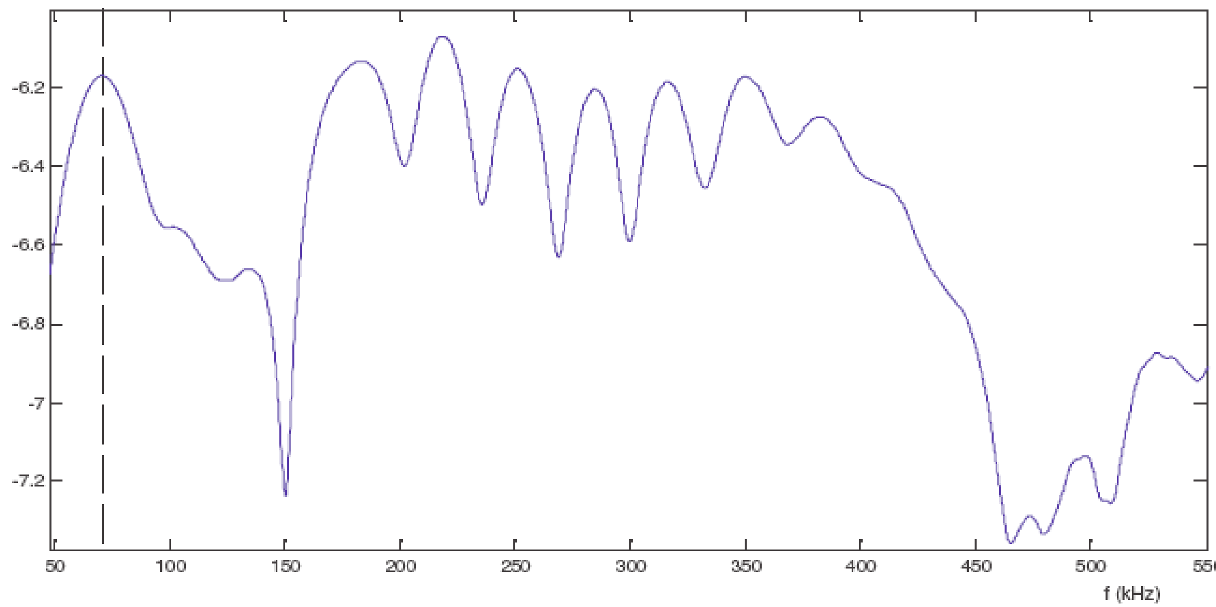
Axial Motion	Rocking Motion
Natural Frequency: $\omega_n = \frac{3\alpha^{1/6}}{2^{11/6} r \sqrt{\pi\rho}\,\beta^{1/3}}$	Natural Frequency: $\omega_n = \frac{1}{r^{3/2}}\sqrt{\frac{45}{4}\frac{W_A}{\rho}}$
$\alpha = 3\pi W_A r$ $\beta = r/K$	W_A is the work of adhesion ρ is the density of the particle r is the radius of the particle.
W_A is the Work of adhesion K is the stiffness of adhesion bond ρ is the density of the particle r is the radius of the particle.	**Remark: Independent of elastic properties of material.** Dominik C. and Tielens A.G.G.M., *Philosophical Magazine A*, 72, No.3, 783-803, 1995.



- PSL on Si substrate
- Work of adhesion (literature): 23.5 mJ/m^2
- Axial resonance frequency: 1.83 MHz
- Rocking frequency (calculated): 72.4 kHz
- Measured rocking frequency: 64.1 kHz
- Measured work of adhesion: 18.4 mJ/m^2

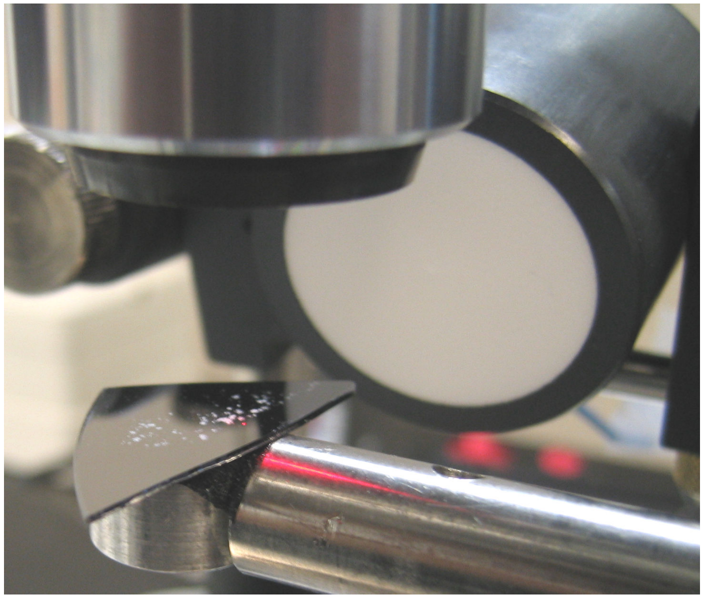




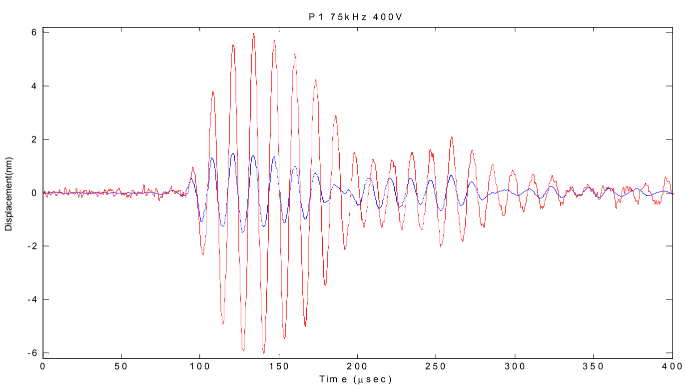


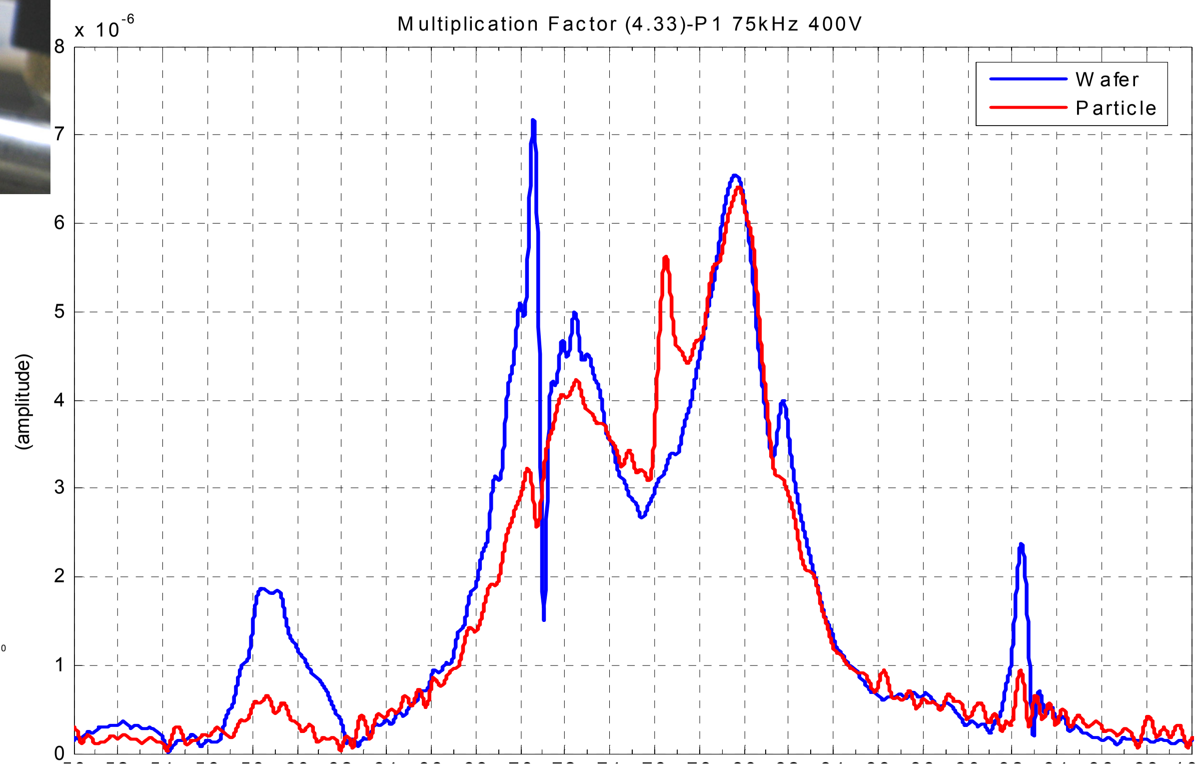
M. D. Murthy Peri and C. Cetinkaya, *Journal of Colloid and Interface Science*, Vol. 288, 2005.
M. D. Murthy Peri and C. Cetinkaya, *Philosophical Magazine A*, Vol. 85, No. 13, 2005.

Air-Coupled Excitation of Rocking Motion



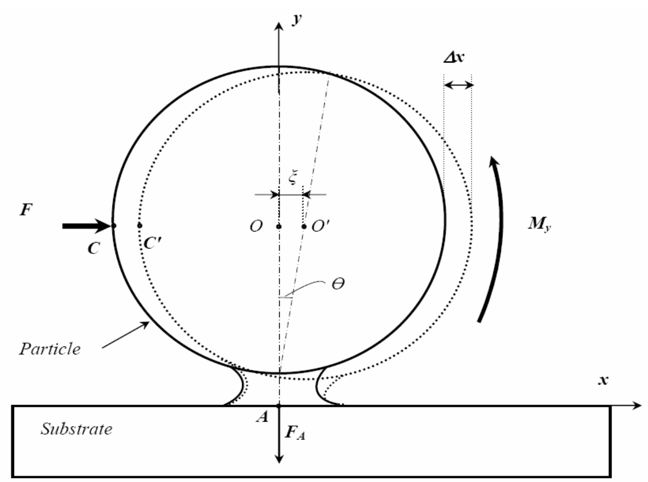
- Air-coupled excitation at 75kHz
- The rocking frequency is calculated as 72.4 kHz
- Measured rocking amplitude: θ_{max}~ 0.06 deg
- Measured rocking frequency: 76.5 kHz
- Measured work of adhesion: 26.16 mJ/m^2
- Further Research: Shifts of resonance frequencies indicate nonlinearity and/or dissipation (capillary effect)

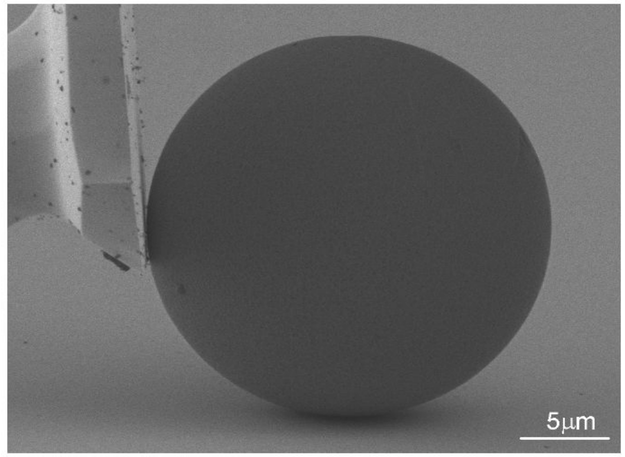


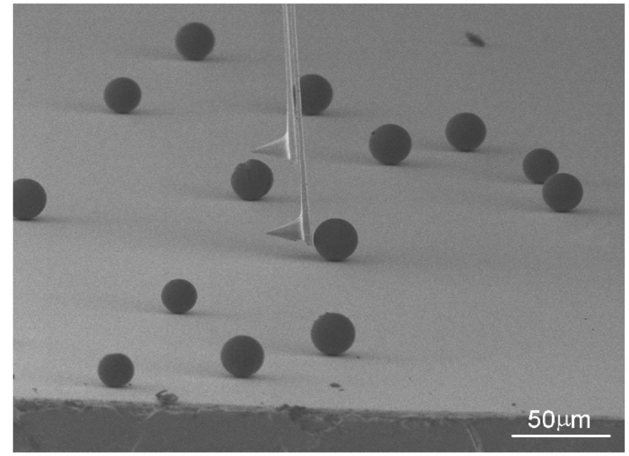


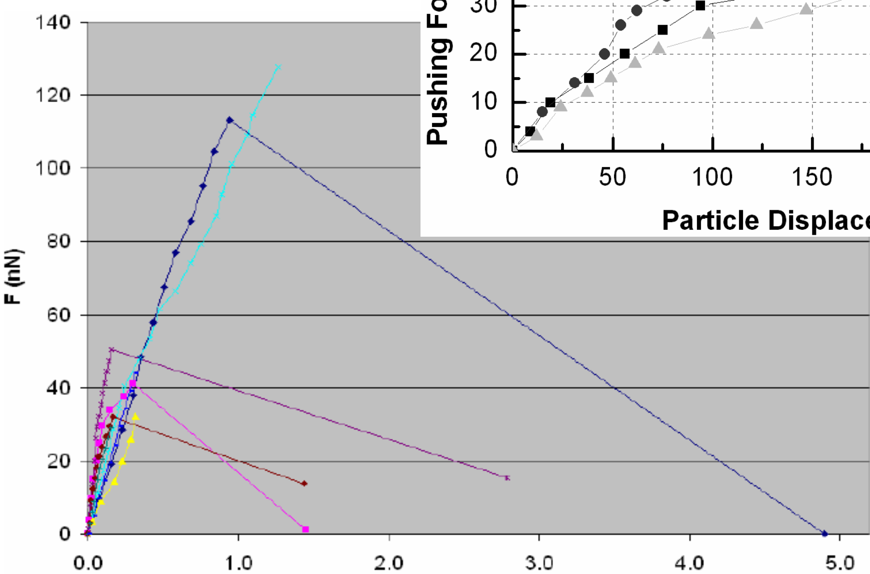
M. D. Murthy Peri and C. Cetinkaya, under review for publication in Applied Physics Letters.

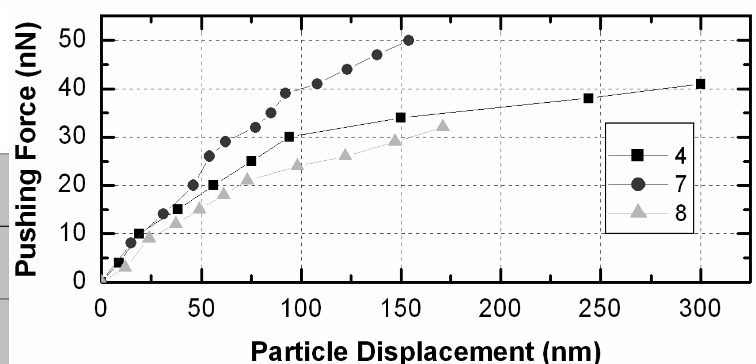
Contact Experiments: Rolling Moment Resistance











- Adhesion measurement based on detachment is difficult;
- Particle has to be glued to a cantilever;
- Detachment force is much larger than rolling force;

Particle #	Slope 0-50 nm (Pre-Rolling) (N/m)	Slope beyond 50 nm (Rolling) (N/m)	Critical Angle of Rotation ($\times 10^{-3}$ rads)	Work of Adhesion ($\times 10^{-3}$ J/m^2)
1	0.13	0.13		No Pre-Rolling
2	0.38	0.06	8.8	20
3	0.09	0.09		No Pre-Rolling
4	0.17	0.17		No Pre-Rolling
5	0.46	0.19	8.6	24
6	0.32	0.11	6.8	17
7	0.23	0.14	7.0	12
8	0.14	0.14		No Pre-Rolling
Theoretical Prediction	0.442			23.5

W. Ding, A. Howard, M.D. Peri and C. Cetinkaya, under review for publication in *Philosophical Magazine* .

Conclusions and Remarks

- Experimental evidence on existence of rolling resistance moment in a non-contact way, for the first time, has been presented;
- Work-of-adhesion of PSL particles on silicon substrates are measured in a non-contact manner;
- Acoustic excitation of PSL particle has been demonstrated;
- A contact method work-of-adhesion measurement method that does not require any size information prior to testing has been developed and presented; Critical rolling distances are reported.
- Reference papers are listed in this document for further examination.