“Gecko-style” dry adhesives on a flexible substrate

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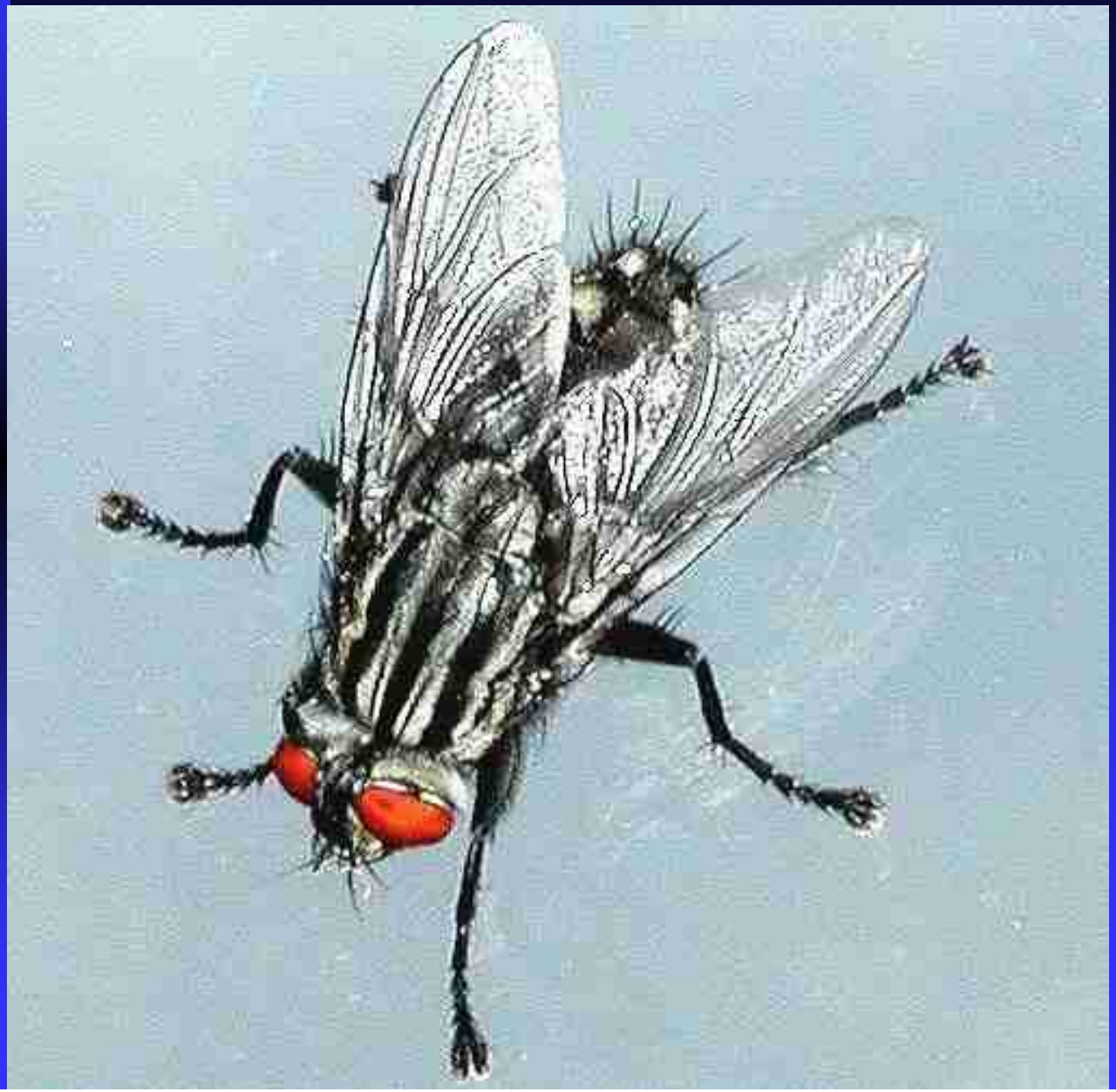
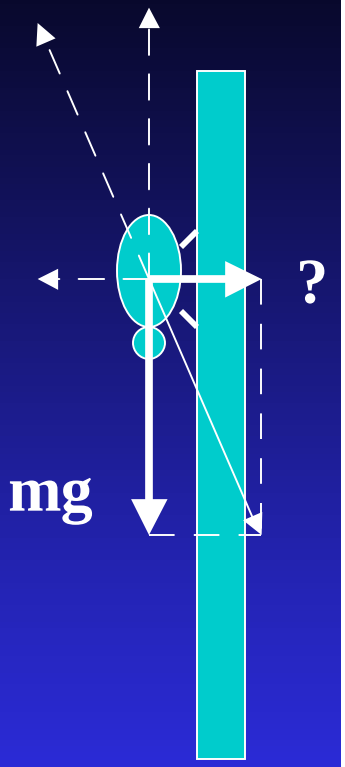
Outline

We did not make experiments with fly, butterfly, gecko, and man. Our work was based on passive observation of their behavior and experiments with non living materials

- Insects and geckos can walk along smooth surface in any direction
- AFM, Van der Waals and capillary forces
- Technology of gecko hair array
- Investigation of the gecko hair array parameters
- Optical properties of the gecko and butterfly hair array
- Conclusion

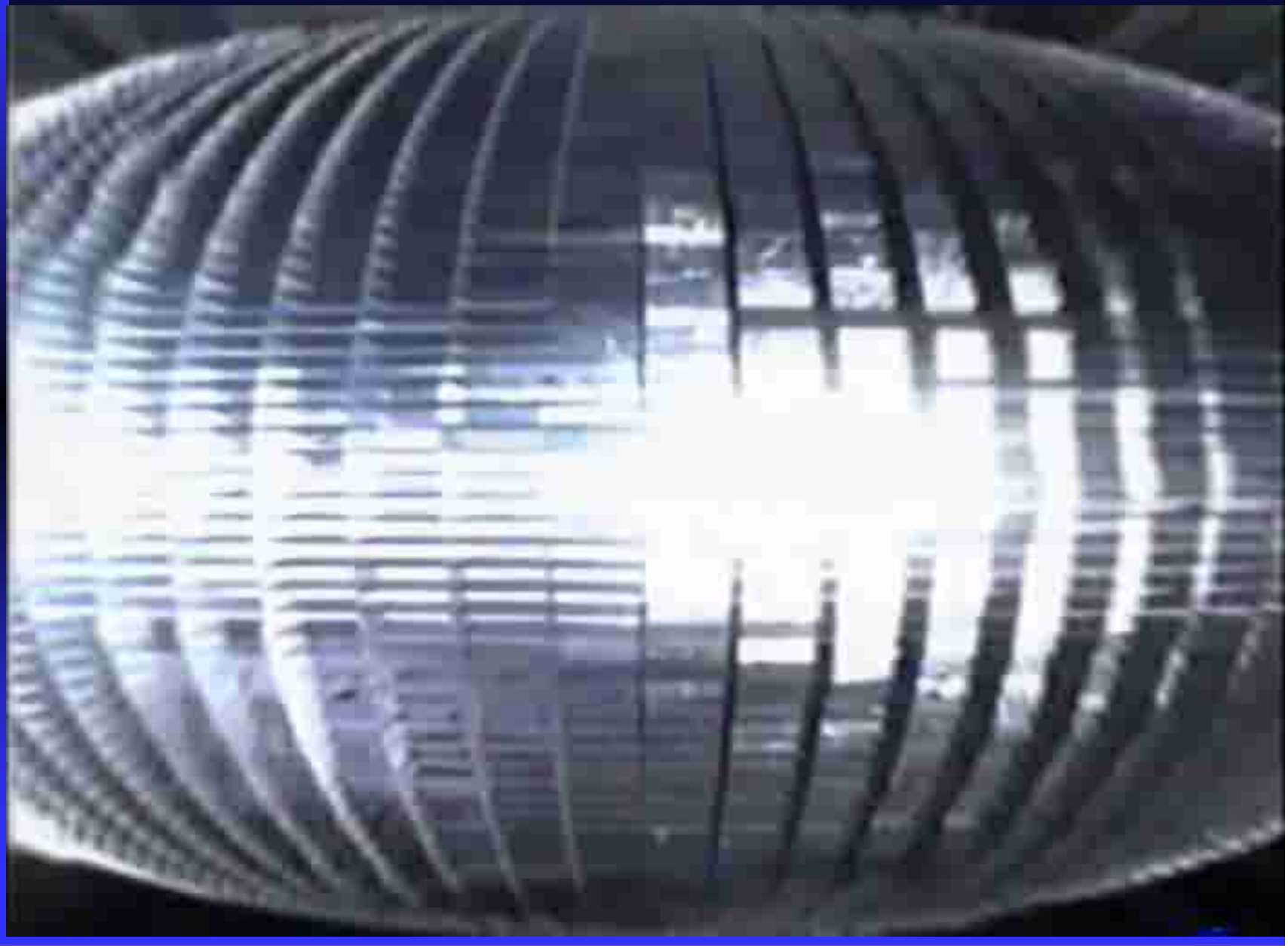
Fly on glass





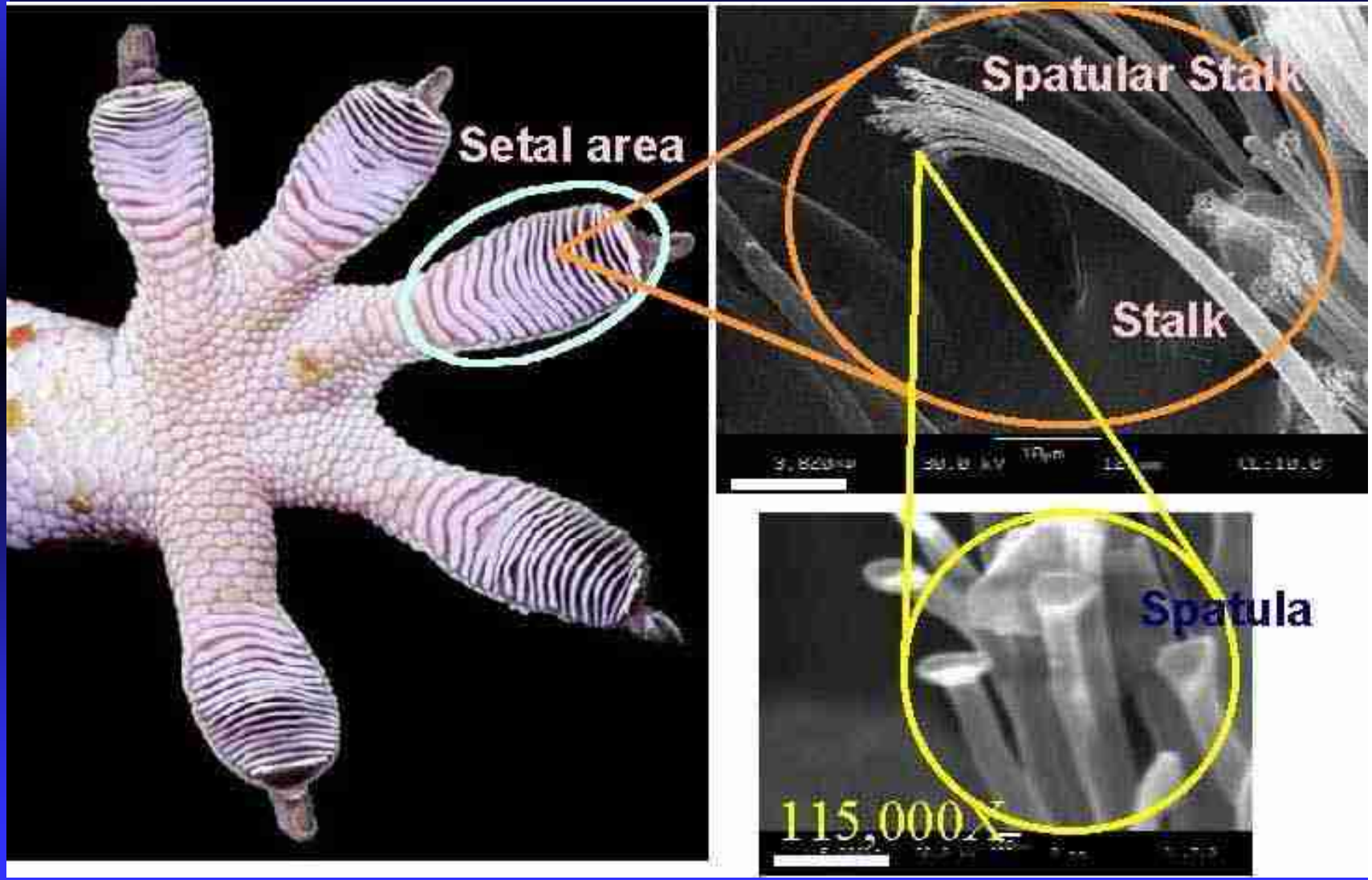
Gecko

How can gecko walk?



Structure of the natural gecko hair

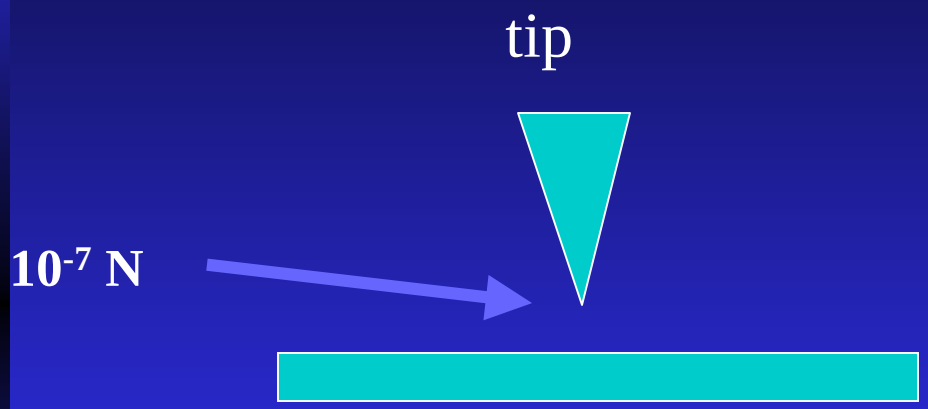
M.Sitti, R.Fearing, J. of Adhesion
Sic.&Technol, 2003



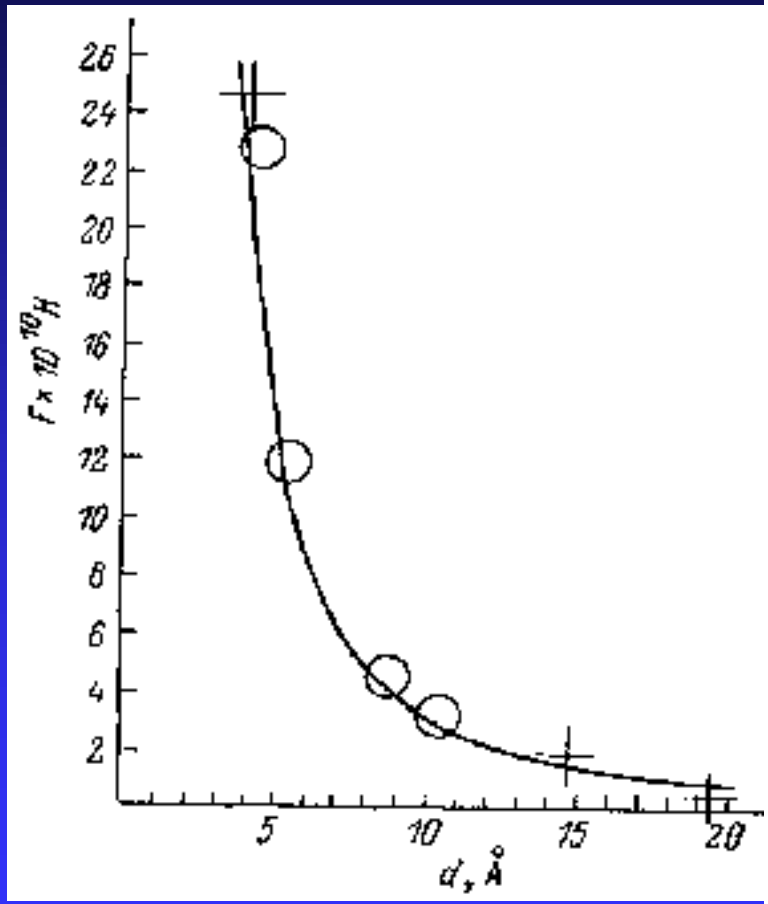
To clean windows is not so easy

Strongly trained professional has to use special equipment

Atomic Force Microscopy

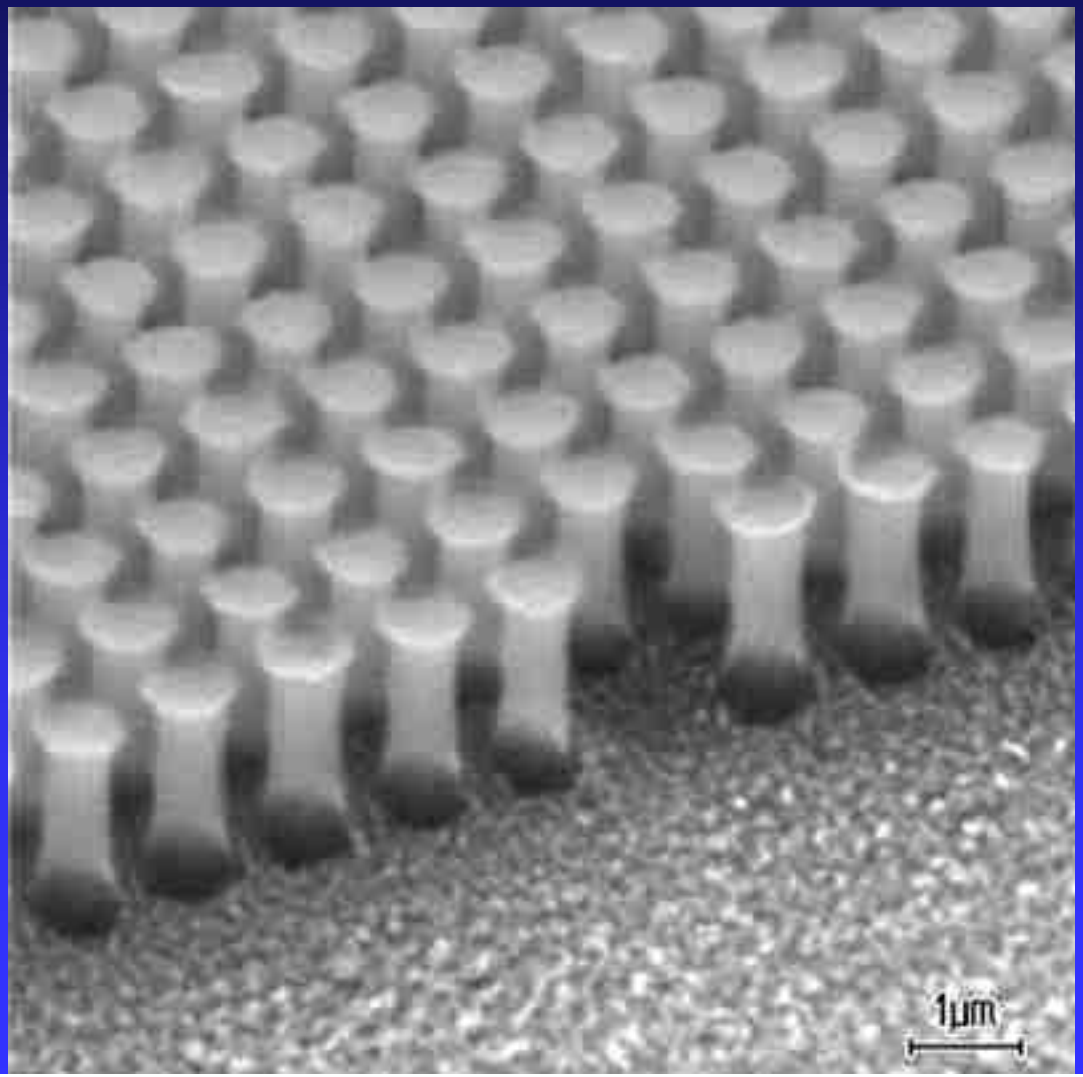


Due to Van der Waals and/or capillary interaction

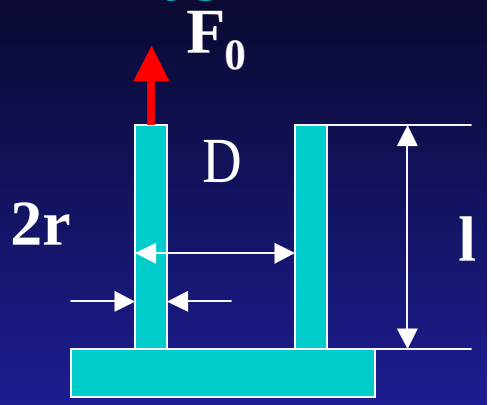


Millions of hairs acting together can create a formidable adhesion of ~ 10 N cm^{-2}

Physical limit - ?



Gecko hair array design limits



It was shown by M.Sitti, R.Fearing (J. of Adhesion Sic.&Technol, 2003) that

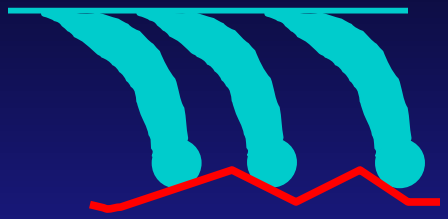
Minimum spacing

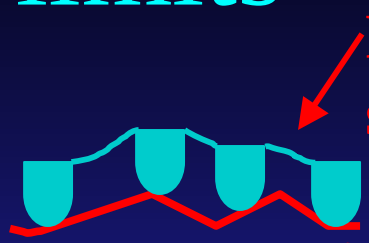
$$\Delta \geq \frac{8F_0 l^3}{3p\, r^4 E_P}$$

Adhesion pressure

$$P_{adh} = \frac{F_0}{\Delta^2} = \frac{9p^2 E_P^2}{64F_0}\left(\frac{r^8}{l^6}\right)$$

Gecko hair design limits





Last equations offer several interesting observations:

1. Smaller F_0 gives higher pressure (with lower F_0 hairs can be smaller radius and closer)
2. Stiffer stalks allow greater packing density.
3. Short, fat hairs give higher adhesion pressure (However, short fat hairs placed on non flexible substrate are not desirable for adhering to rough surfaces)
4. **Gecko hair array should be formed on flexible substrate**

Technology

- wet cleaning of the silicon wafer;
- deposition of 5 μm thick polyimide film (pyromellitic dianhydride-oxydianiline polyimide, baked at 250° C) on a silicon wafer;
- deposition of the electron resist;
- electron-beam lithography;
- 150 nm thick Al film deposition by aluminum thermal evaporation, lift-off, polyimide etching by electron cyclotron resonance (ECR) plasma discharge in the Ar/O_2 mixture.

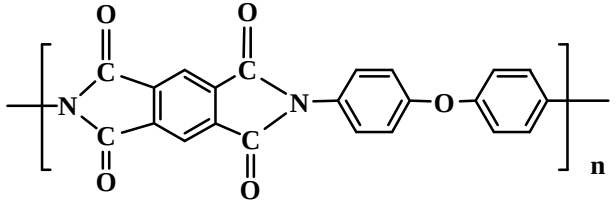
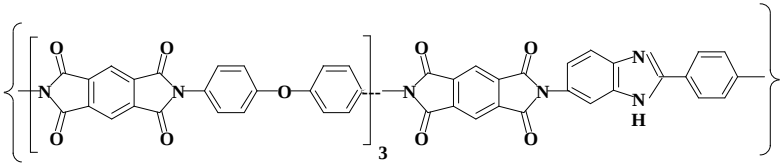
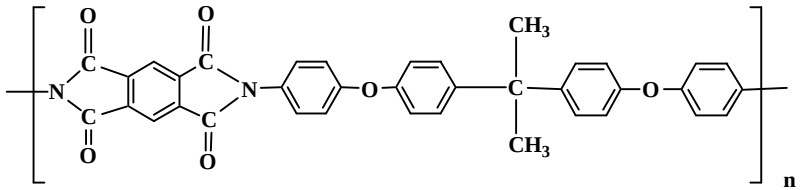
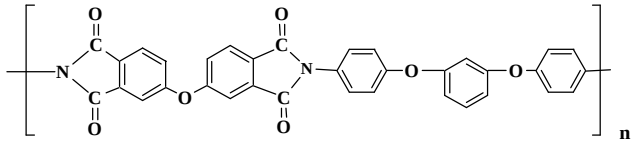
ECR-plasma precision etching

ECR etching allows us to control a hair profile angle and aspect ratio. The pillar aspect ratio is varied by applying 13.5 MHz RF to the etcher wafer chuck forming a negative DC self-bias on the substrate due to the different mobility of electrons and ions.

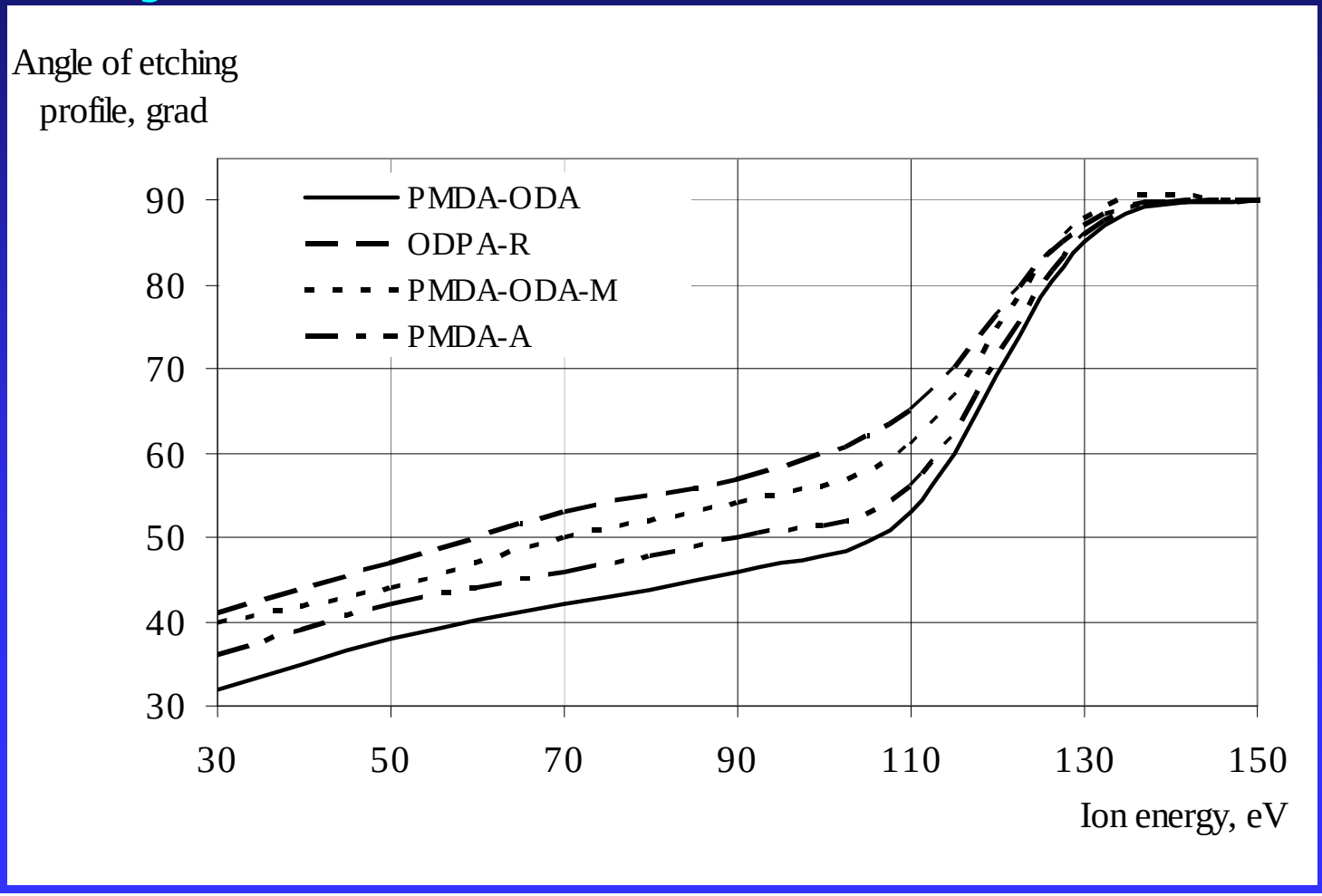
High ion density: $10^{12} – 10^{13}$ cm^{-3}

Low operating pressure: up to 0.2 mTorr

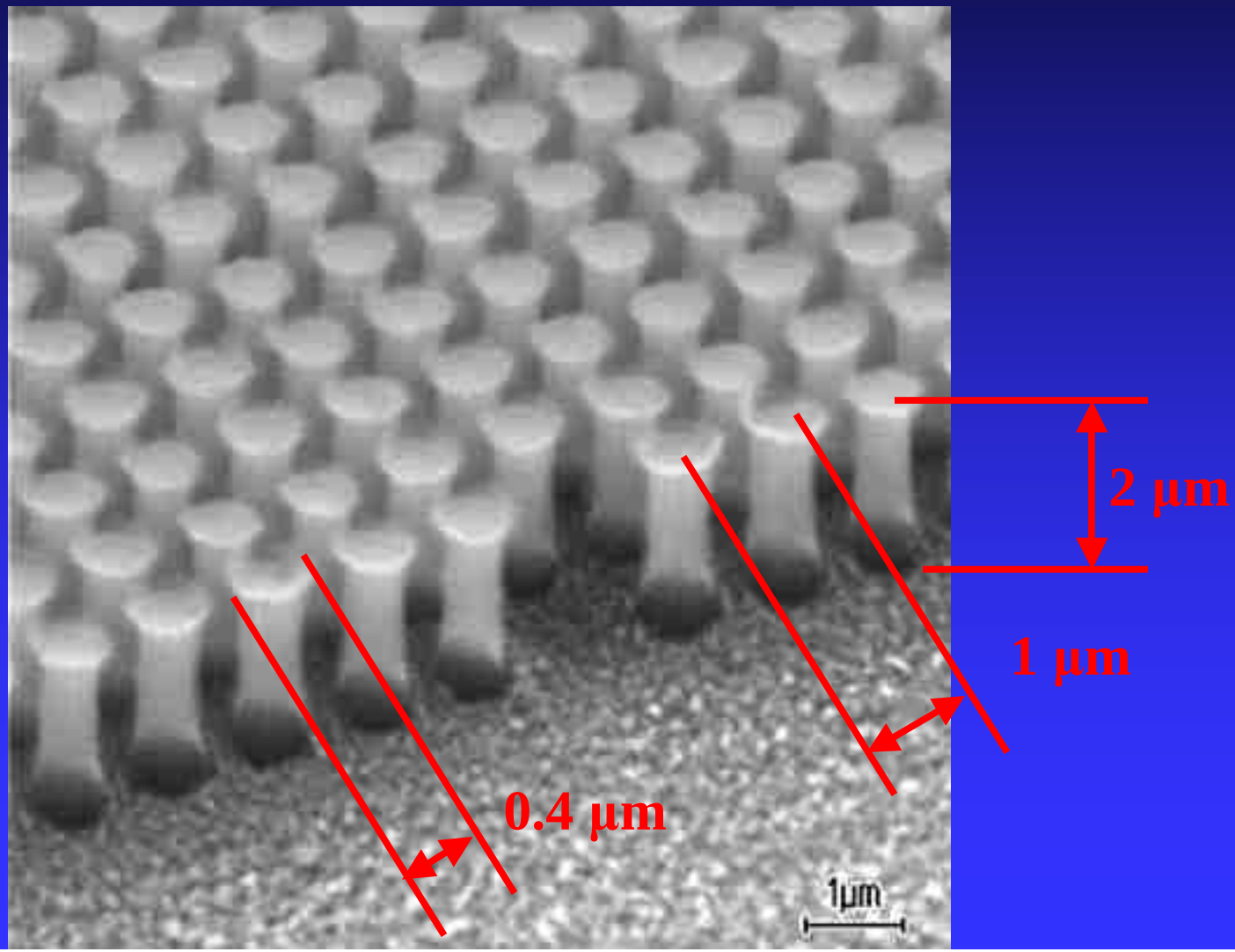
Example of Different Modifications of Polyimide Used

Polyimide	Monomers
	Pyromellitic dianhidride (PMDA)-4,4’-oxydianaline (ODA)
	PMDA-ODA-2(p-aminophenil)-6-aminobenzimideazole (M)
	PMDA-Diaminophenil ether of bisphenol A (A)
	Oxydiphenil 3,3’4,4’-tetracarboxilic acid dianhydride (ODPA)-Diaminodiphenyl ether of resorcinol (DR)

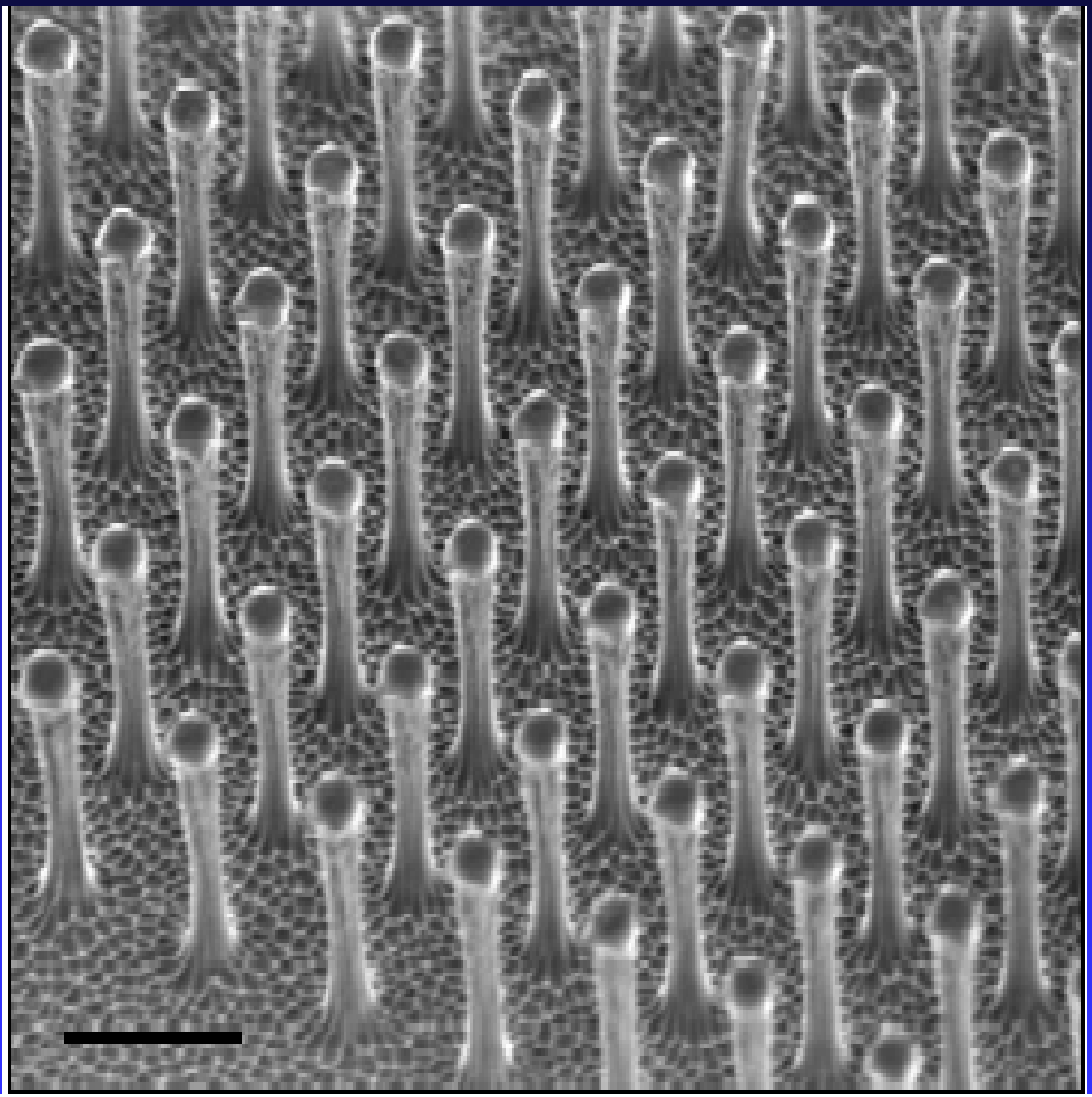
Dependence of the Etching Angle on DC Self-Bias as a Function of Polyimide



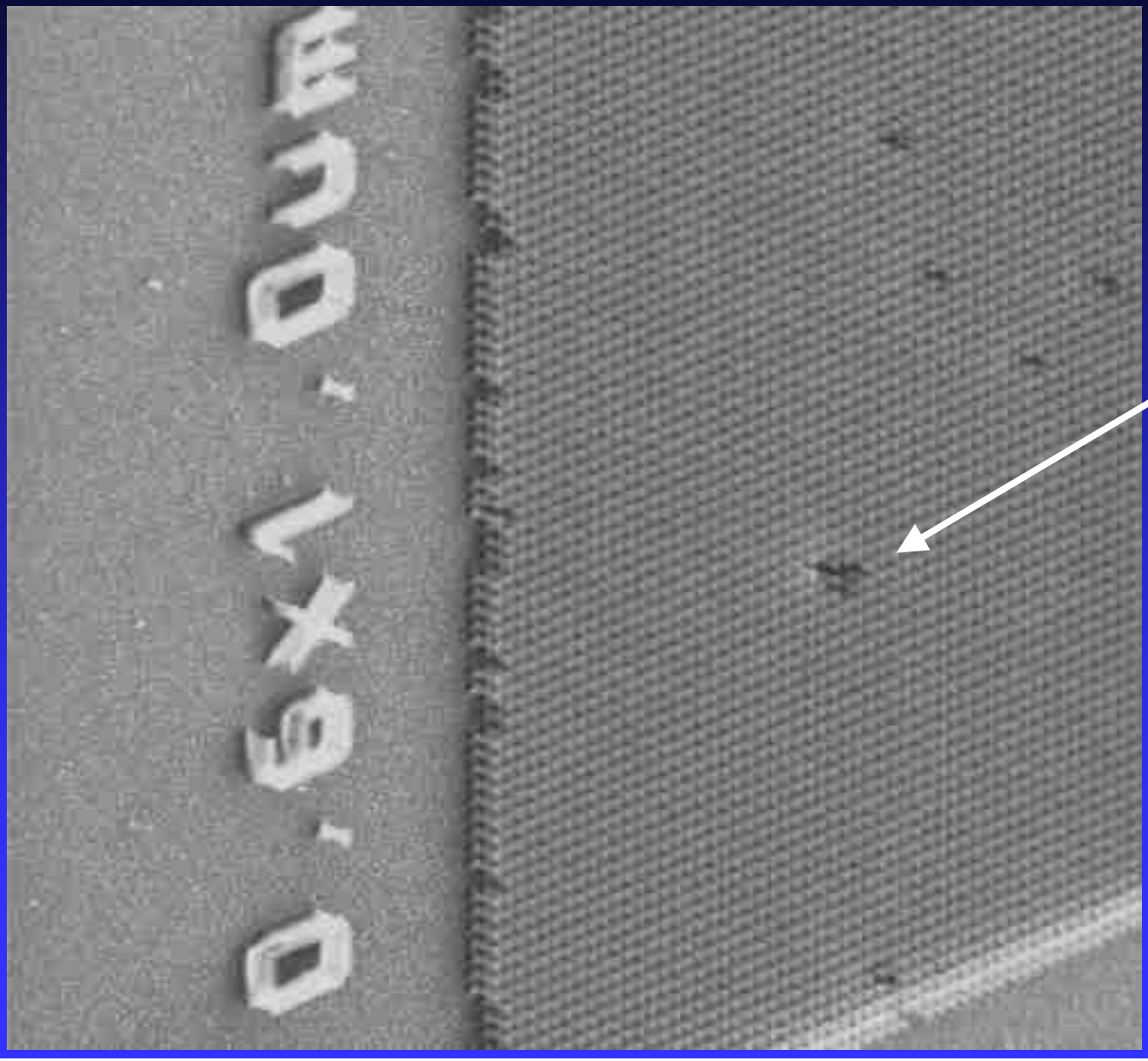
Optimal gecko hair array geometry



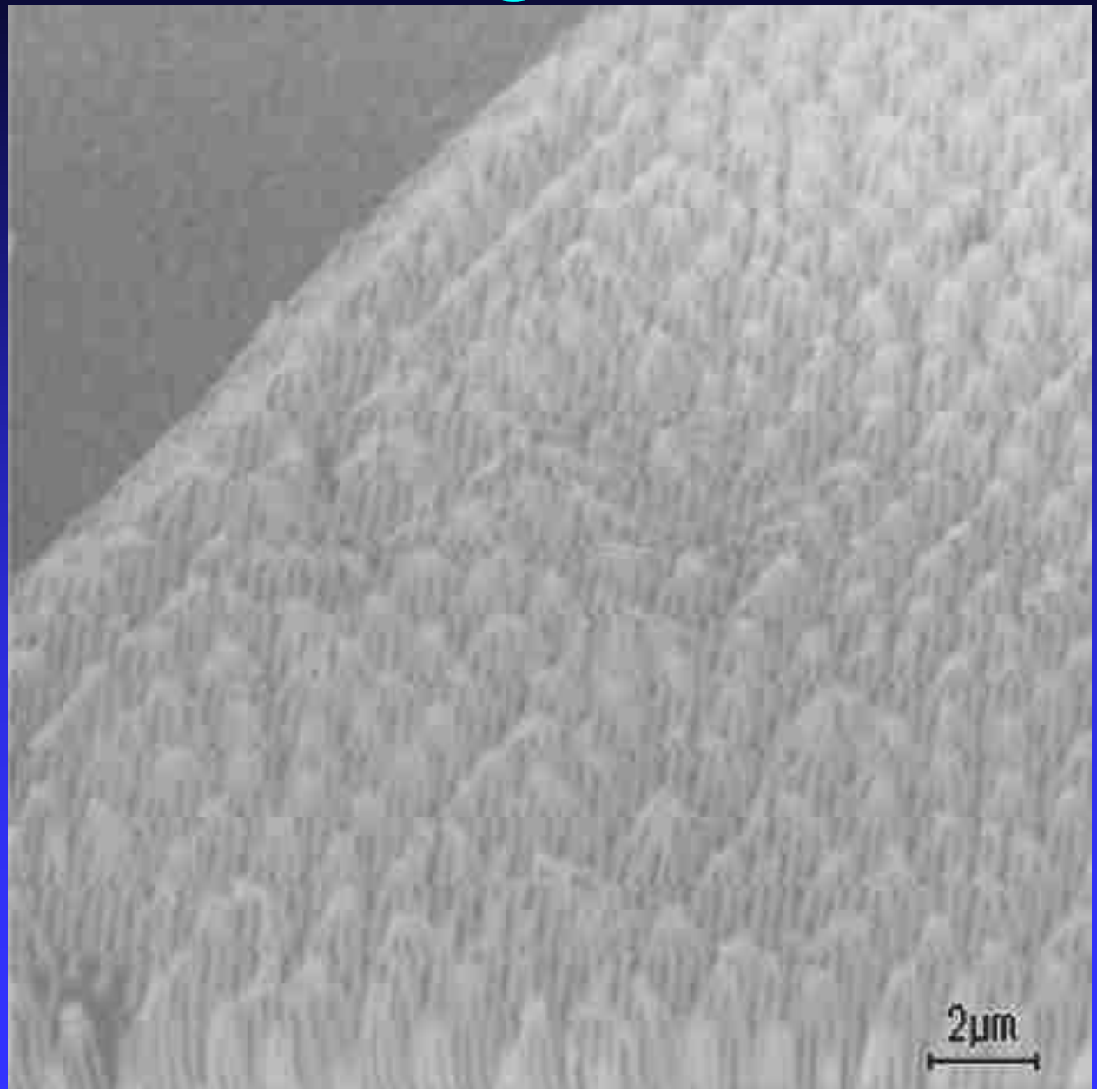
Gecko hairs with spherical cap



Large area gecko hair array



Thin and long hairs



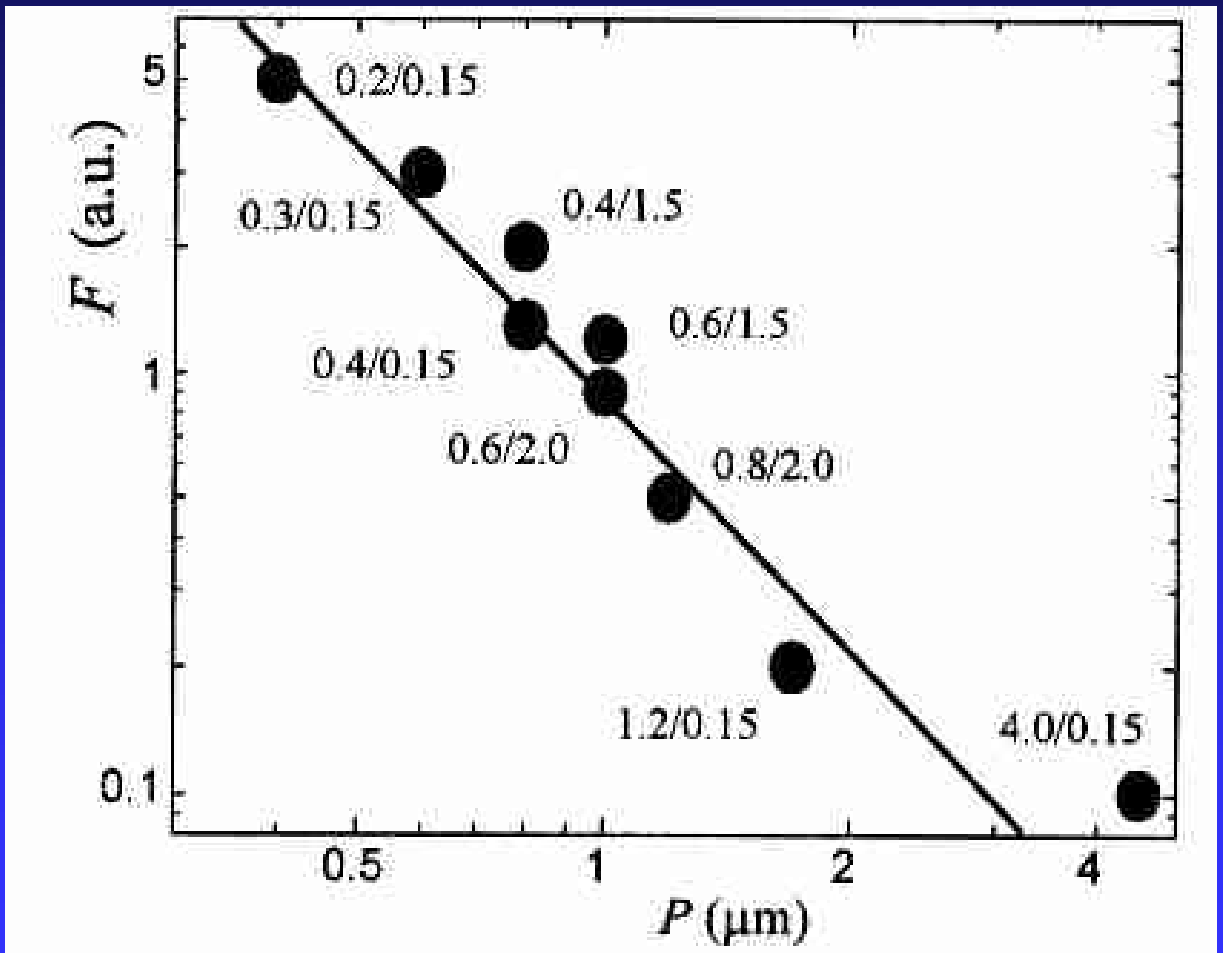
Gecko hairs after sixth contact

We have to develop "goose skin" technology

Parameters investigation

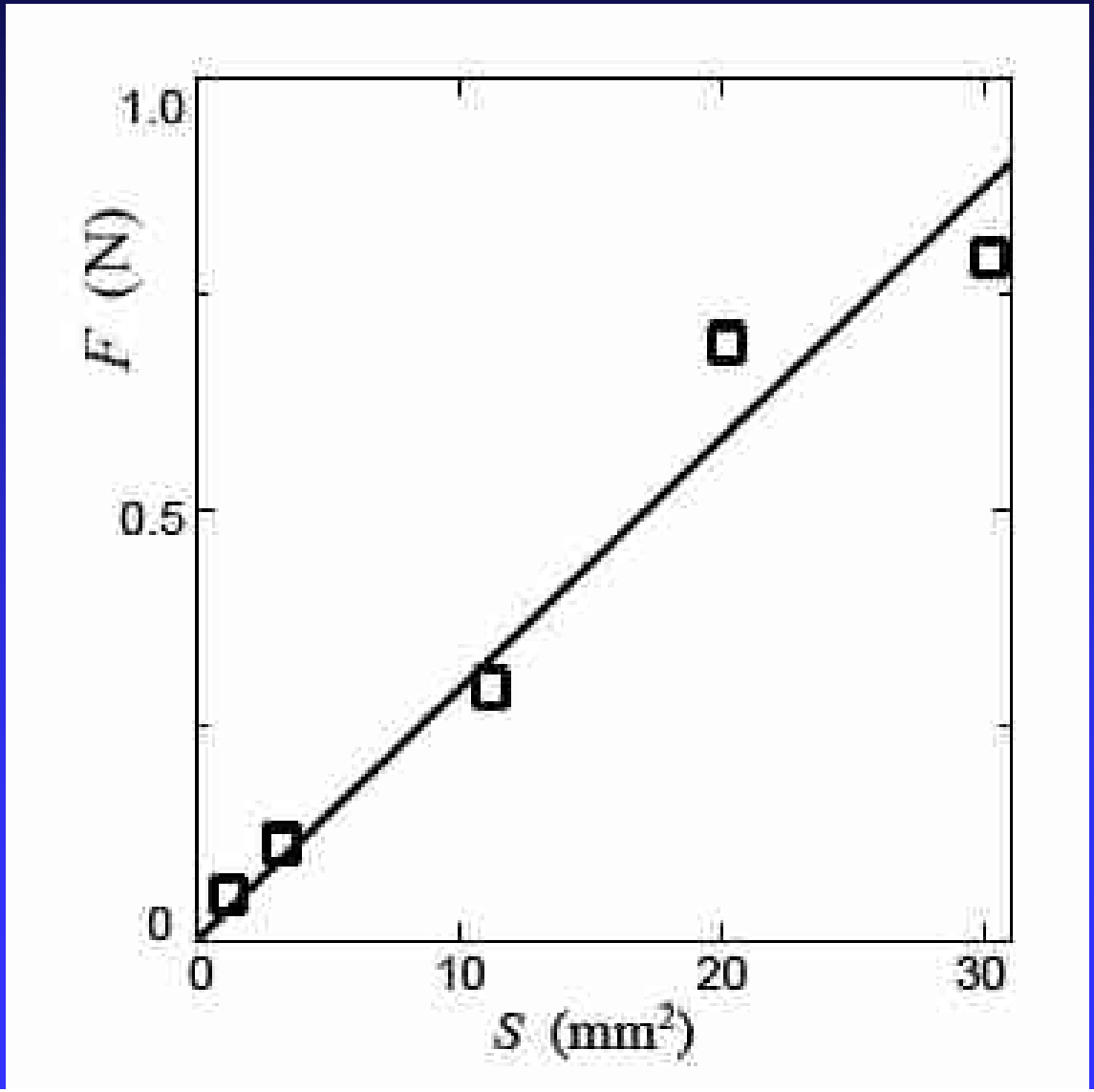
Then we measured the perpendicular force F required to detach the samples from SiO_2 surface (this work was carried out by the Manchester University group). This was done using an atomic force microscope (AFM) in the force mode. The adhesion between the samples and a flat tip (about 50 μm in size) was found to depend strongly on the initial preload. For all measurements we used the same preload of about 10 mg.

Perpendicular force F required to detach various samples of polyimide hairs from a silicon surface. The experimental points are marked by D/H, indicating hairs diameter D and heights H respectively.



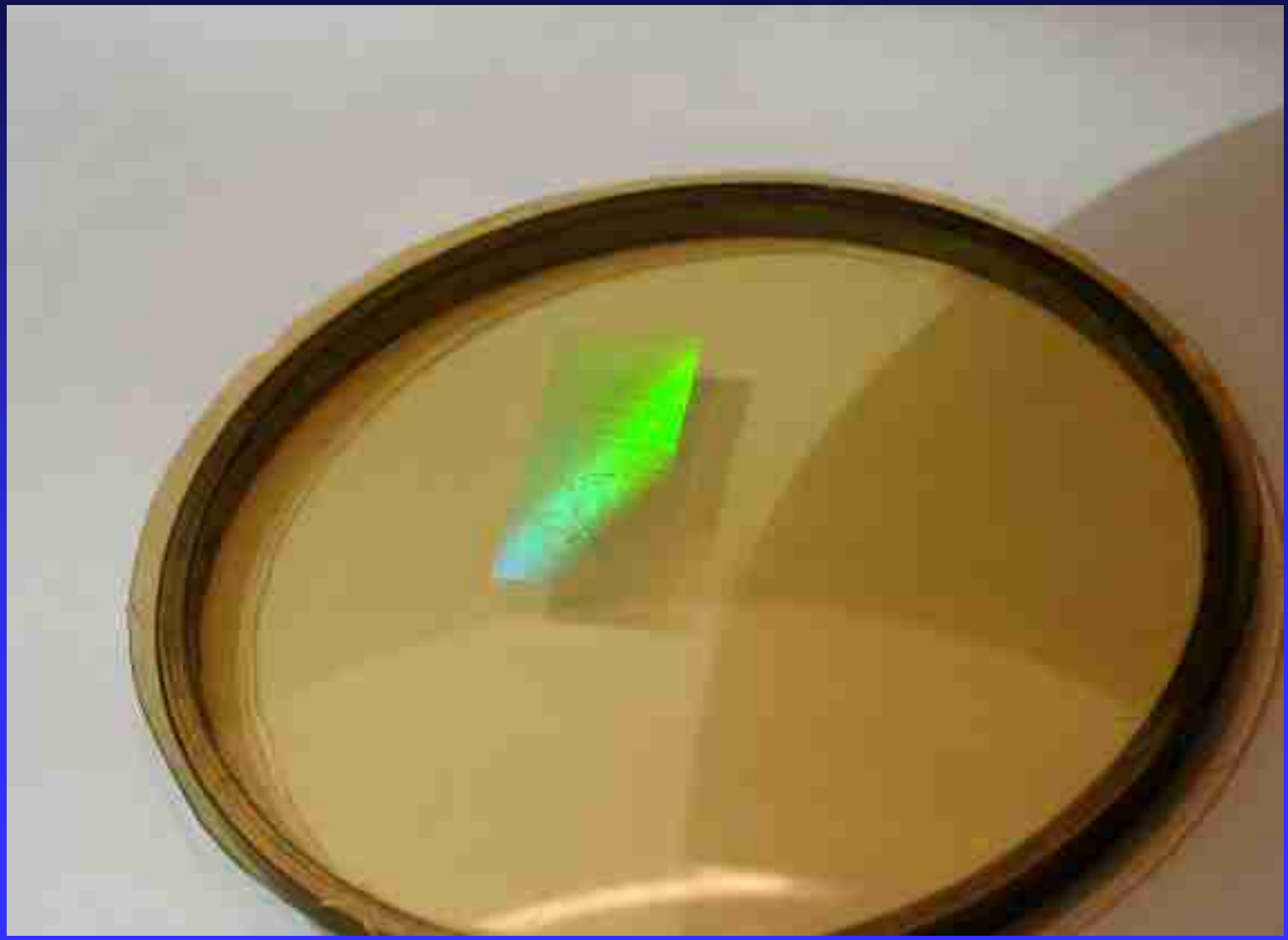
Period **P** is the main parameter (each pillar still has single point contact with surface)

Dependence of adhesive force on probe area is linear



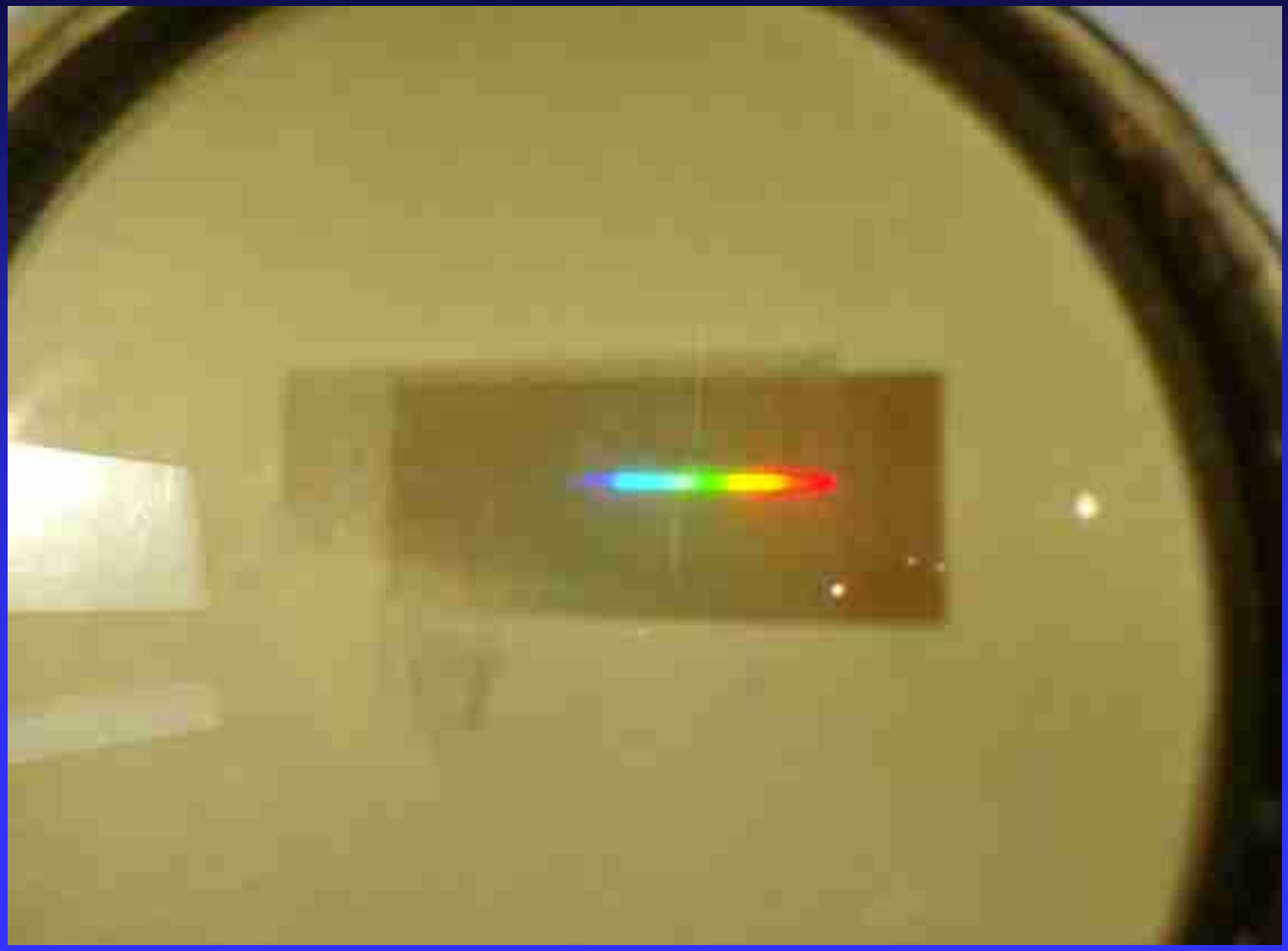
Gecko hair array on flexible transparent substrate

Lamp



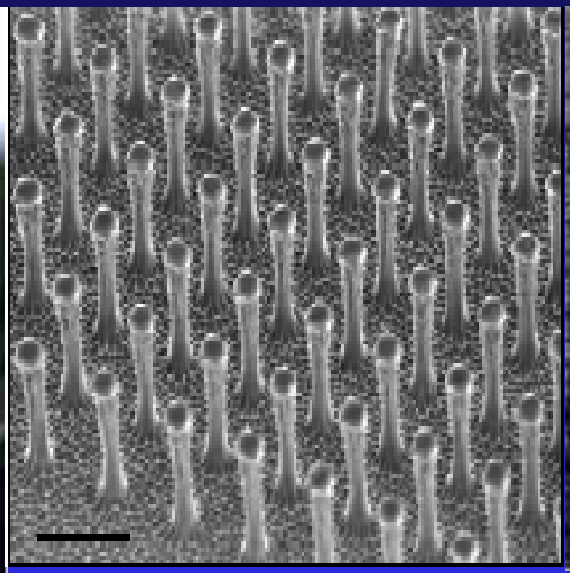
Gecko hair array on flexible transparent substrate

Sunlight

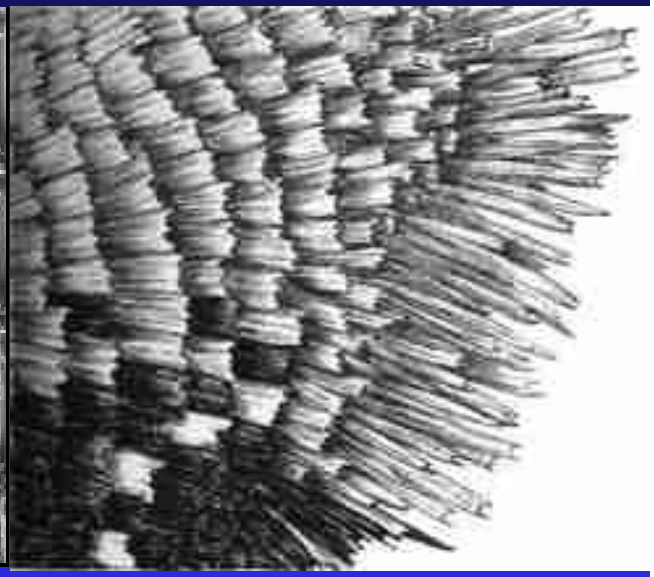


Butterfly colour

Apollo

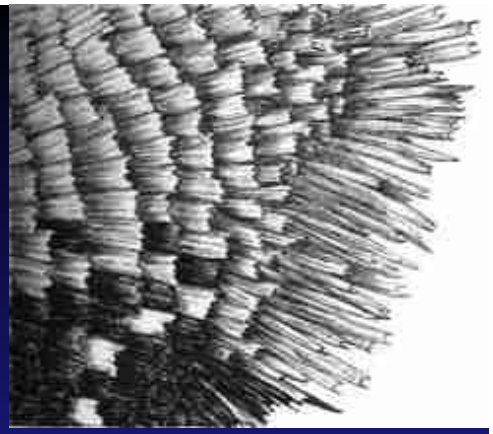


Gecko hair array – photonic crystal?



Structure of the butterfly pillars

Butterfly colour



Wings are the most important systematic characteristic of the branch of the butterfly: they are covered with squams whose structure and arrangement determine the fancifulness of color. Therefore, butterflies are called lepidopterous. Squams are transformed hairs. Good evidance for this is close examination of the squams cover of Parnassius appolo. Squams color depends on pigment granulas present in it; its external surface is ribbed. Apart from these pigment squams many butterflies, especially tropical whose wings display iridiscent metallic color, have squams of another kind, optical.

Blinking butterfly (passion vine butterfly)

Left Handed Material

Conclusions

Re-attachable dry adhesives based on the gecko principle can find many applications.

- Science
- Art (ballet,painting, …)
- Micromechanics
- Space equipment
- Clothes
- Household
- Toys
- Optics
- Others

Acknowledgements

The authors thanks our colleagues

Natalia Ushakova (EpiLab, IMT) for precision ECR-plasma etching of the gecko hair array,

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Mr. A Razbash (ORT TV channel) for movie about geckos

Thank you for attention