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GECKO ELECTROSTATICS BY SPATULAE

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Abstract: Prior gecko electrostatics was based on the premise that dust nanoparticles (NPs) are ubiquitous and attach to all surfaces. NP detachment by spatula was shown to produce electromagnetic (EM) radiation that by the photoelectric effect produced charge, thereby allowing the gecko to walk on walls and ceilings by electrostatic attraction. About 45 million <100 nm dust NPs were shown necessary to support the gecko weight. However, surface concentrations of dust NPs surfaces inferred from typical volumetric air concentrations suggest the necessary number of NPs may not be available to support the gecko. But dust NPs are not necessary because the more than 600 million spatulae need only contact the surface to induce electrostatic attraction. Unlike the dust NPs, the EM confinement of thermal kT energy of spatulae atoms occurs because the spatulae is surrounded by media of lower refractive index (RI). For the spatulae idealized by a thin disk centrally supported on the setae stalk, air surrounds the spatulae except for the stalk. Because the mass density of the spatulae is 3 orders of magnitude higher than the stalk, the stalk has a lower RI making the spatulae interface act like a mirror to provide the EM confinement of the kT energy of spatulae atoms. Thermal kT energy is recovered at the instant the spatulae contact the room surface while detachment induces the emission of VUV radiation that charges the spatulae. Repetitive attachment and detachment induces an electric field that attracts the spatulae (and the gecko) to the surface. Otherwise gecko electrostatics by spatulae follows that for dust NPs.

Keywords: Geckos, biotribology, electrostatics.

1. INTRODUCTION

Prior gecko electrostatics [1] showed about 45 million dust NPs were required to produce the electrostatic force necessary to support the gecko weight. However, surface NP concentrations are simply not available for confirmation. Volumetric concentrations of NPs in air [2] are available, but the extension [3] to surface concentrations depends on a host of factors including turbulence and deposition rates that are simply not known.

However, the gecko has 600 million to 6 billion spatulae to supplement the dust NP induced electrostatic attraction. Spatulae may be idealized by thin disks 150 to 200 nm in diameter supported by the 85 nm diameter stalk. But the spatulae evolve [4] from and are a physical extension of the setae stalk. Unlike the dust NPs, the EM confinement of thermal kT energy from spatulae atoms cannot occur by physically separating the spatulae from the setae stalk.

But spatulae located at the tip of the setae stalk provide EM confinement of thermal kT energy if the RI of the spatulae is greater than that of the surroundings, thereby finding origin in John Tyndall's demonstration of total internal reflection (TIR) in the 1870s. Tyndall's principle of EM confinement relies on the properties of a dielectric (non-conducting) medium surrounded by another dielectric material of lower RI.

Indeed, the spatulae is a dielectric surrounded by air except at the interface with the stalk. Although the RI of the spatulae and stalk are not known, both are composed [4] of β -keratin having RI ~ 1.52 . But the spatulae having mass density 3 orders of magnitude [5] higher than the stalk suggests [6] the RI of the stalk should be <1.52 , say that of water having RI = 1.33. Since air has unity RI, the EM confinement of the thermal kT energy of spatulae atoms is thereby assured even though the spatulae is intact with the stalk. Unlike NP induced EM confinement by detaching NPs from the surface, the spatulae need not be detached from the stalk.

Gecko spatulae electrostatics consists of Phases 1 and 2 illustrated in Fig. 1.

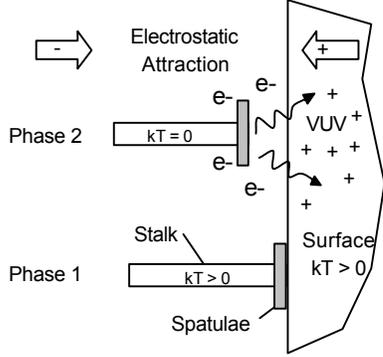


Figure 1. Gecko Spatulae Mechanism

Electrostatic force is produced in Phases 1 and 2. Phase 1 recovers kT energy of spatulae atoms following VUV emission. Upon surface contact, the spatula momentarily are part of the surface that by QM is allowed to have $kT > 0$. Contact occurs over the full disk surface and thermal response is prompt because of the nanoscale thickness. In Phase 2, the gecko detaches its foot from surface. Since the EM confinement requires the kT energy to vanish, conservation proceeds by the spatulae emitting VUV radiation. By the photoelectric effect, the VUV induces the surface to lose electrons and charge positive with the electrons charging the spatulae negative. The gecko is therefore held to the room surfaces by electrostatic force induced from the combination of dust NPs and spatula.

2. THEORY AND ANALYSIS

Gecko spatulae provide the function of acting as a nano-brush to detach the NPs from surfaces to induce the electrostatic attraction. But spatulae also induce electrostatic attraction without dust NPs as depicted in Fig. 2.

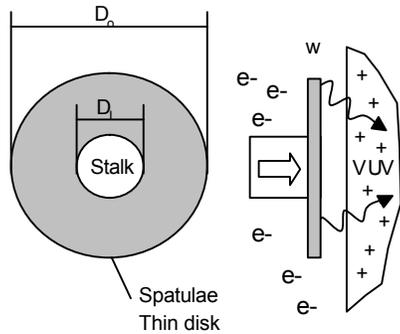


Figure 2 Gecko Spatulae Mechanism

2.1 QM Restrictions and Specific Heat

QM restrictions on the spatulae atoms through vanishing specific heat follow that [1] of the dust NPs.

2.2 EM Confinement Frequencies

The EM confinement of thermal kT energy of spatulae atoms follows the QM analogy of creating

photons of wavelength λ by supplying EM energy to a QM box with walls separated by $\lambda/2$.

For spatulae idealized as disks having outer D_o and inner D_i diameters, and thickness w , the EM confinement wavelength λ is,

$$\lambda = 2n_r w \quad (1)$$

where, n_r is the RI. The QED induced photon stands across the spatulae thickness. The frequency f and Planck energy E_p are,

$$f = \frac{c}{\lambda} \quad \text{and} \quad E_p = \frac{hc}{\lambda} = \frac{hc}{2n_r w} \quad (2)$$

2.3 Spatulae Force

Upon contact with room surfaces, atoms in nanoscale spatulae promptly acquire the full kT energy of atoms in macroscopic structures. The total kT energy U is,

$$U = \frac{3p}{4D^3} D_o^2 w kT \quad (3)$$

where, D is the cubic spacing between spatulae atoms at solid density, $D \sim 0.3$ nm. Lacking specific heat, the spatulae conserve [1] the energy U in a burst of VUV radiation that by Einstein's photoelectric effect electrifies the surroundings. The charge q is,

$$q = N_p Y e = \frac{U}{E_p} Y e = \frac{3p}{2D^3} w^2 kT D_o^2 \frac{n_r}{hc} Y e \quad (4)$$

where, N_p is the number of QED photons induced in the spatulae at Planck energy E_p . Numerically, the average spatulae thickness $w = 25$ nm. For the RI of spatulae $n = 1.52$, the Planck energy $E_p \sim 16$ eV where most materials [7] have yields $Y = 0.1$ electrons/VUV.

The charge q produces an electric field F between the spatulae as a whole and the surface. The spatulae force F_{spat} is,

$$F_{spat} = qF < qF_{BD} \quad (5)$$

where, F_{BD} is the breakdown field in air, $F_{BD} \sim 3 \times 10^6$ V/m. The upper bound spatulae force F_{spat} is shown with the charge q in terms of spatulae diameter D_o in Fig. 3. For $D_o = 200$ nm, the force $F_{spat} \sim 6.7$ nN that corresponds to charge $q = 2.2$ fC at field F_{BD} . In comparison, the 15 nN force [1] for dust NPs is about 2x higher than for the spatulae because the 100 nm sphere provides more efficient packing of kT energy than the thin disk.

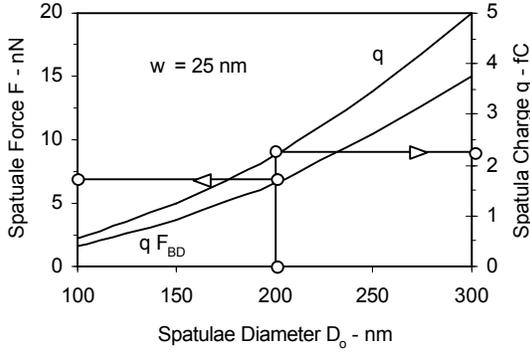


Figure 3 Upper Bound Electrostatic Spatulae Force

The total electrostatic force F_{ES} from number N_{spat} of spatulae is,

$$F_{ES} < N_{spat} q F_{BD} \quad (6)$$

For a gecko weighing 70 g, the necessary force F_{ES} is about 0.68 N. In combination with the dust NPs, the attraction from $N_{spat} = 600$ million spatulae is more than sufficient to support the gecko, i.e., for $q F_{BD} = 6.7$ nN gives $F_{ES} = 4$ N > 0.68 N.

3. DISCUSSION

The spatulae tipped setae function both as a nano-brush to detach dust NPs from room surfaces and to carry gecko weight, both of which are induced by QED induced EM radiation to produce the VUV radiation that provides the electrostatic attractive force to hold the gecko to the wall.

3.1 Self-Adhesion

Paradoxically, gecko setae that readily attach to walls and ceilings [8] do not stick to each other. Indeed, pushing setae spatulae together does not cause them to stick. Certainly, the vdW attraction should provide adhesion under such conditions, but the contrary finding only proves the vdW attraction cannot be the mechanism which holds the gecko to room surfaces.

By QED induced EM radiation, the spatulae are not expected to stick to each other. The kT energy lost by VUV emission is promptly recovered upon contact with the macroscopic room surface that by QM is allowed to have $kT > 0$. However, spatulae are submicron having $kT \sim 0$, and therefore pushing the spatulae together cannot recover $kT > 0$ to allow subsequent emission of VUV radiation and the electrostatic attraction of spatulae to each other consistent with observation.

3.2 Self-Cleaning

Electrostatic attraction from dust NPs and the spatulae is caused by an electric field F . The larger micron particles (MPs) that are > 1 micron are cannot produce VUV, but rather only infrared radiation. On this basis, the 2.5 micron MPs found [8] attached to a glass surface shows the act of self-cleaning is caused by the electric field that accompanies dust NP and spatulae charging. The vdW mechanism does not produce an electrical field, and therefore cannot explain the self-cleaning action of MPs observed for geckos.

4. CONCLUSIONS

Geckos walk on walls and ceilings by electrostatic attraction from charges produced by detaching NPs from room surfaces and by spatulae contact with those surfaces.

Gecko toe-hairs do not carry load in charging by detaching dust NPs because the induced electrical field is distributed over the toes. However, the spatula upon surface contact do carry load through the gecko hairs that significantly supplements that induced by the detachment of dust NPs.

Gecko walking on walls and ceilings by vdW attraction is not only unlikely because contact at the nanoscale cannot be assured but also because of observations of self-adhesion and cleaning.

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