"Gecko-Workshop 2010" – INM initiates new worldwide conference series

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In July 2010, scientists from all over the world gathered at INM to discuss gecko inspired adhesion at a workshop entitled „Bioinspired adhesion: from geckos to new products". The talks covered a range of current issues, including natural attachment systems, developments in artificial gecko-mimics, advances in mechanical models and possible products. This was the first dedicated workshop on this topic. The attendees unanimously agreed to create an international workshop series based on the INM example.

Researchers have pondered the principles of gecko-adhesion for nearly a century. Unlike many conventional adhesives that can only be used once on clean surfaces, foul and attach accidentally to inappropriate surfaces, natural so-called "dry adhesives" are reversible, durable, controllable and self-cleaning. The key strategy in dry adhesives is the formation of structures, i.e. fibrillar surfaces or complex subsurface patterns. Over the past decade, many research groups around the world became interested in dry adhesion and made great advances in understanding the principles and developing artificial mimics. At the workshop, this community of biologists, material scientists, physicists and engineers was brought together to discuss the status and future challenges.

Directionality

In the opening address, biologist *Walter Federle (Cambridge University, UK)* stressed the diversity in natural attachment systems using a variety of examples including ants, cockroaches and beetles. He documented the directionality in adhesion and showed how individual parts of adhesive setea have different functions (pulling vs. pushing) facilitating up and downward climbing. Several material scientists attempt to mimic directional adhesion by fabricating tilted or slanted fibrillar structures. Different approaches varying from heated rollers to photolithography and etching processes at well-defined angles were presented by different speakers to effectively produce anisotropic shear behavior. Mechanical engineer *Metin Sitti (Carnegie Mellon University, Pittsburgh, USA)* showed advanced tilted structures, but argued that, for many technological applications, isotropic adhesion behavior is required and directionality could lead to easy failure.

Reversibility

Biologist *Kellar Autumn (Lewis & Clark College, Oregon, USA)* gave an overview of the current understanding of gecko adhesion. He explained that one of the key features is the non-sticky default state of attachment pads that requires a proximal shear load to be switched to an adhesive state ("frictional adhesion"). To detach, the gecko releases the grip and peels the toes outward, returning the pads to the non-sticky state. Mechanical engineer *Huajian Gao (Brown University, Providence, USA)* presented a fundamental contribution to the current understanding by proposing a pre-stress model. Proximal shear generates a pre-stress in the spatulae that "turns on" adhesion. Moreover, above a critical angle the pre-stress dramatically decreases the peel-off force to nearly zero, thus enabling the gecko to detach effortlessly and independently of the applied force. The great challenge to mimic this specific mechanism of "on demand" strong adhesion and easy release is being explored by several research groups using topographical changes upon applying an external stimulus:

1) Mechanical engineer *Kimberly Turner (University of California at Santa Barbara, USA)* presented microfab-

ricated actuated adhesives based on magnetic, thermal and piezoelectric switching using cantilever and latches.

2) Materials scientist *Eduard Arzt of INM* presented shape memory polymer and elastomer based microfibrillar arrays that were shown to actuate upon temperature and pressure changes, respectively.

3) Materials scientist *Kaph-Yang Suh (Seoul National University, S-Korea) s*howed adhesion actuation using stretching of fibrillar arrays on a wrinkled backing layer.

4) Materials scientist *Anand Jagota (Lehigh University, Bethelem, USA)* showed that self-adherence of subsurface structures can switch the system from being in compression to tension which alters the adhesion dramatically.

Roughness

Although geckos can adhere to almost any kind of surface most research groups still struggle to make surface structures that adhere strongly to rough surfaces. In conventional pressure sensitive adhesives the viscoelastic properties enable large contact areas even for very rough surfaces. Roughness may even enhance adhesion to viscoelastic material systems by dissipation of energy through crack arrest which was shown by physicist *Anke Linder (ESPCI, Paris, France).* Following similar reasoning, physicist *Christophe Poulard (Paris University, France) p*resented how surface patterning can enhance the peel strength of pressure sensitive adhesives and elastomers. Many scientists agree that for patterned dry-adhesives with minimal viscoelastic properties to adhere strongly to rough substrates, hierarchical designs will be required. Promising developments were presented by mechanical engineer *Ronald Fearing (University of California at Berkeley, USA), Kaph-Yang Suh* and *Metin Sitti. Physicist Bo Persson (IFF Research Institute, Jülich, Germany) s*tressed the importance of roughness in a variety of applications and presented his contact mechanics theory for friction on rough surfaces. In a different context it was shown by mechanical engineer *Paolo Decuzzi (University of Texas, Austin, USA)* that the effect of roughness on cell adhesion can be modeled by balancing contributions from specific and nonspecific binding and strain energies.

Design rules

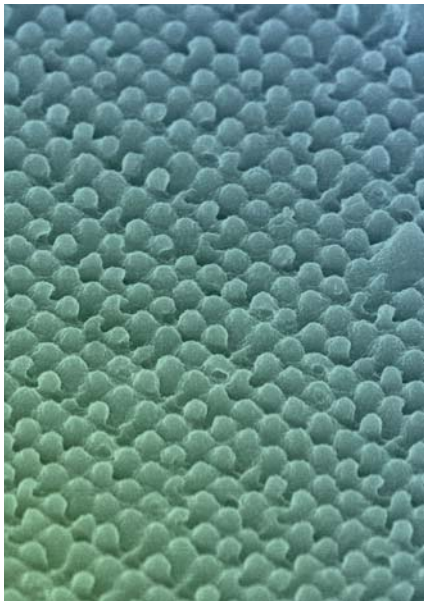
Most participants agreed that the ultimate aim is not to fabricate exact copies of natural examples but rather to extract underlying design principles. *Alfred Crosby (University of Massachusetts, Amherst, USA)* emphasized this by proposing scaling laws that guide dry adhesive design based on system geometry and material stiffness. He showed how complex hierarchical systems can be modeled by addition of separate elements using their compliances. Many researchers presented advanced artificial structured adhesives, but used different design criteria. *Yohei Maeno (Nikko Denko Corp., Japan)* and *Ronald Fearing* both stressed the importance of using materials with high bulk stiffness (polypropylene and carbon nanotubes, respectively) and low effective elastic modulus due to its specific surface structure. *Animangsu Ghatak (IIT Kanpur, India)* and *Anand Jagota* showed intelligent subsurface structure designs that enhance adhesion by interfacial crack trapping in dry and wet conditions. *Huajian Gao* emphasized that adding levels of hierarchy can enhance adhesion strength up to the point that the material itself becomes the weakest link. *Kaph-Yang Suh* also mentioned material limita-

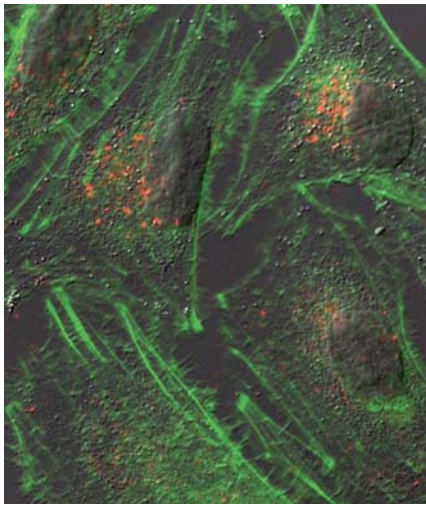
tions and emphasized that more efforts are required to develop materials systems that accommodate requirements other than adhesion. One of the highlights of the workshop was a recent theory presented by *Huajian Gao* on how humidity may affect the adhesion in geckos. He proposed that humidity in air changes the stiffness of gecko setae which in turn alters adhesion.

Test methodology

Convergence of testing methodology was one of the goals set for the workshop. Many agreed that it is hard to compare different designs because of the wide variety of tests used to evaluate the adhesion performance. In addition, new methodology specifically designed for dry adhesion may be required. *Eduard Arzt* presented the development of a cantilever based adhesion tester at INM and showed that only slight misalignments between micropatterned sample and flat probe result in major changes in the measured adhesion. Misalignment issues can be prevented using spherical probes and *Anand Jagota* reviewed their elegant model-independent method to extract adhesion energy from indentations with spherical probes.

After three days of high quality lectures one question remained: Has time come for a technological breakthrough of gecko-adhesives? We might be close, as evidenced by encouraging results in large scale patterning and proof-of-principle applications shown by *Mike North (North Design Labs)* and *Peter de Oliveira (INM)* and also indicated by the large number of participants from industry.





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