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Gecko Foot Mimetic Carbon Nanotube Patterned Adhesive Surfaces

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Extended Abstract

The supreme controllable adhesive ability (strong attachment and easy detachment) of Geckos has inspired scientists' interests for over two millennia. It has been widely accepted that the natural optimized fine hierarchical structure of gecko foot hairs contributes to its excellent adhesion/release and even self-cleaning abilities. On each toe-pad of gecko foot, there are nearly ten millimetre-sized grid-like lamellae, consisting of millions of high aspect ratio micrometre-sized setae which further splits into hundreds of nanometre-sized spatula tips (Figure 1). This incredible structure enables intimate contact adhesion and facile release through the van der waals (vdW) forces collectively. The hierarchical fibrillar system of geckos, from macroscopic pad, toe and lamella to microscopic seta and nano-spatula, effectively cooperate as a controller for its climbing movement. Researchers have pay lots of attention on mimicking the smart structure of geckos in order to design and manufacture a fibrillar adhesive, which shows a great application potential in various fields. Polymer pillar was chosen to fabricate gecko-inspired dry adhesive in the earlier research. Geim et al. (2003) were the first to micro-fabricate a gecko-like material out of a soft polymer. And recently, Kejia et al. (2013) developed a general approach to easily incorporate a desired tilt angle into gecko-like fibrillar structures, which show anisotropic adhesion and friction properties even in the absence of tilt in the structures.

Carbon nanotube array with great mechanical properties and nanometre diameter is becoming a popular candidate for dry adhesive. Ge et al. (2007) have fabricated a CNT-based gecko tape which can achieve shear strength ($36 Ncm^{-2}$) nearly four times higher than gecko foot and stick to various surfaces. Qu et al. (2008) have manufactured that VA-CNT array with a curly entangled top layer could support a macroscopic adhesive force of ~100 Ncm^{-2}, nearly 10 times than that of a gecko foot. Li et al. (2013) have developed CNT dry adhesive transferred on different soft materials and systematically measured its adhesive strength on normal and shear direction. Recently, Rong et al. (2013) have fabricate a biomimetic hierarchical nanostructures based on polymer micro-pillar arrays topped with densely packed, vertically aligned carbon nanotubes (CNTs), which closely resemble gecko toe-pads.

However, most of the gecko-inspired adhesives with different geometry just focused on the material and the hierarchy of micro-seta to nano-spatula. The lamella and supporting scansor were seldom

considered during the design of mimetic adhesive. Tian et al. (2013) shows that the lamella skin and its properties (i.e., stiffness) significantly contribute to the efficient and controlled attachment and detachment of the arrays and they fabricate a hybrid, three-legged, clamp-mimicking gecko lamella structure to achieve a lifting ability.

From the SEM analysis of gecko foot hair (Figure 1), we noticed that setae with branched spatula densely packed on patterned lamellae, which are incurved at an angle near 140°, and the soft ventral surface of gecko scansor supporting the lamella arranged on it. It is interesting to bio-mimic the lamella's curved shape with soft toe pads backing. Here we design a completely new gecko foot mimetic carbon nanotube patterned adhesive surface, where the carbon nanotube grown like a curved lamella. According to the geometric parameters analysis of geckos' lamellae in our lab, we combined photolithography, electron beam catalyst deposition and thermal chemical vapour deposition technologies to get this newly designed bio-mimetic structure(Figure 2A). Then we transfer this patterned CNT dry adhesive to soft polymer backing which can be bent to some extend like a gecko toe scansor (Figure 2B). We also systematically measured the normal and shear adhesion and friction, and we found that the curved shape could affect the shear friction and the anisotropic force distribution. We offer an excellent design option as a carbon nanotube dry adhesive although further optimization of the structural parameters still need to be considered.

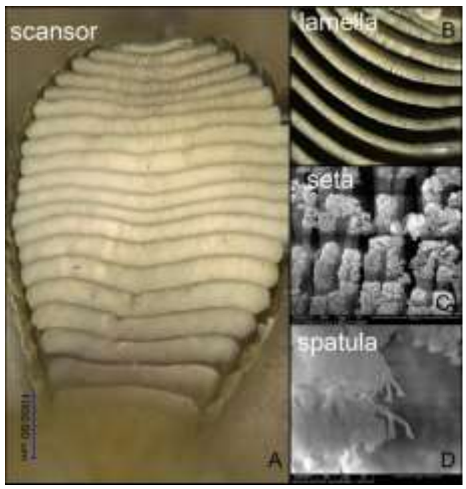

Fig.1. Hierarchical structure of Gecko foot pad: A. Scansor B. Lamella C. Seta D. Spatula

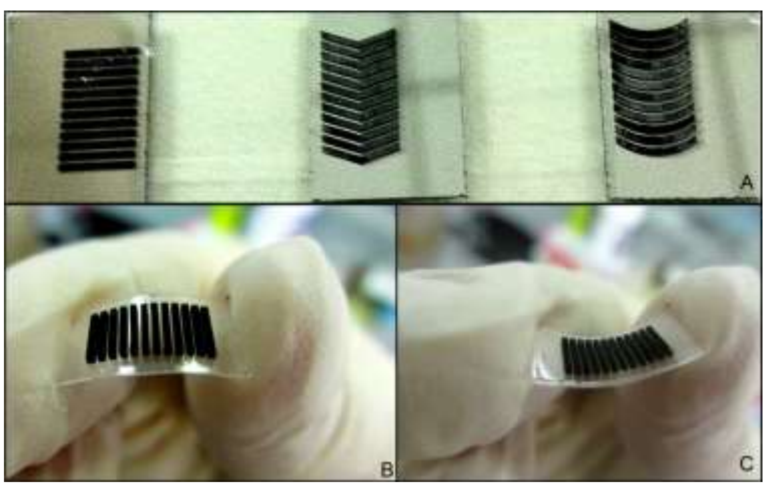

Fig. 2. Gecko foot mimetic carbon nanotube patterned adhesive surfaces:
A. Thermal CVD (chemical vapour deposition) CNT dry adhesive with different curved shape. (From left to right: linear, sawtooth and circular) B. Transferred CNT dry adhesive on soft polymer backing.

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