GECKO MIMICKING SURFACES

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Abstract: Adhesive capabilities of a gecko lizard have been the subject of many studies and an inspiration for many artificial imitations and inventions. This work proposes a design of synthetic gecko mimicking structures in a form of micro-pillars, that would have similar adhesion capabilities as gecko setae. Structures made of Parylene C have been created using photolithography and silicon etching methods. Following focus will be on various surface modifications and characterisation of these structures to determine the adhesion forces present.

Keywords: gecko adhesion, adhesive setae, adhesion forces, biomimetics, deep reactive ion etching, Bosch process, XeF_2 etching, Parylene C, scanning electron microscopy, atomic force microscopy

1 INTRODUCTION

There have been many studies in the past few decades, in which scientists try to unravel the phenomenon of climbing gecko lizards. With improved methods of surface and material characterization, e.g. scanning electron microscopy (SEM), they were able to spot microscopic hair-like structures which geometry and material properties makes them a very efficient dry adhesive. Geckos grow these hair-like structures called setae on their toepads and use them to climb vertical and even inverted surfaces. However, the actual adhesion is caused by inter-molecular forces that occur at very close distances when these setae conform to the roughness of climbing surface. [1] Researchers still try to come to an agreement about what form of inter-molecular forces is dominant. The proposing work focuses on mimicking these structures to some extent and their characterisation using a variety of methods and instruments.

2 THEORY

As has been stated, the extraordinary ability of Gecko lizards to stick to most surfaces is thanks to uniform microarrays of setae formed from β-keratin. They are arranged in uniform arrays and on the tip, they have a nanoarrays of spatula structures (see Figure 1). [1] These can bend in a way that can conform to microscopic ridges and gaps of a surface and consequently stick to it.

A single seta is approximately 110 μm in length and 4.2 μm in diameter, they are also uniformly distributed on lamellae. Setae branch several times at the tips into 100–1000 terminal structures known as spatulae. These are approximately 0.2 μm long with a similar width at the tip. It was estimated, that two front feet of Gecko can withstand ~20 N of force parallel to the surface across 227 mm^2 of toe-pad area. [1]

It's not clear which of the few forces that contribute to adhesion is more dominant. There are three main forces, that are believed to have some level of impact on the overall adhesion:

- Van der Waals forces – weak intermolecular chemical forces, that occur at small distances;
- capillary forces – the adhesion is dependent on relative humidity of air;
- electrostatic forces – they are created through an effect called contact electrification.

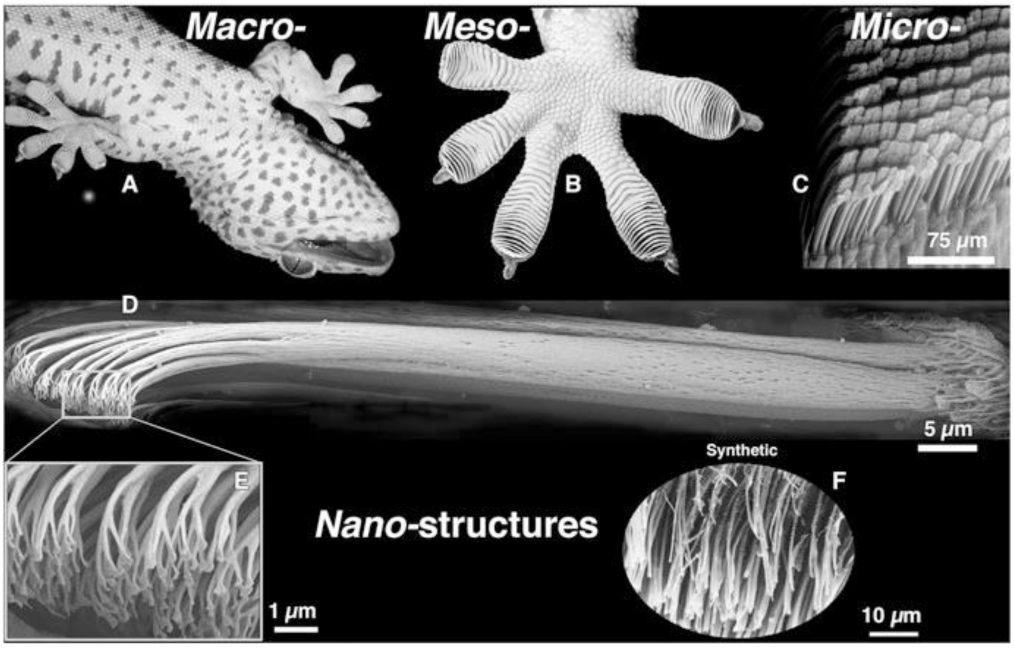

Figure 1 - Gecko adhesive system structural hierarchy: (A) Gecko lizard on a vertical surface, (B) foot with adhesive lamellae, (C) microscopic setae, (D) individual gecko seta, (E) nanoscale array of hundreds of spatula tips, (F) example of a synthetic spatulae from polyimide. [1]

There are some noticeable traits of Gecko toe-pads that could be utilized and even replace some traditional tools or aids, such as wet adhesives (wide popularity of Hook-and-loop fasteners is a prime example for mimicking bur found in nature [2]). The traits are:

- rough surface compatibility – even with increasing surface roughness, the adhesion capabilities of gecko pads don't dramatically decrease;
- self-cleaning properties – the morphology of gecko pad is less contaminated with small particles, because the adhesion of these particles is grater to the surface, on which the gecko crawls (paradoxically, on a macroscopic scale, the pads are hydrophobic, thus acting in a similar way as lotus leaves);
- effortless and controllable detachment – by just slightly curling their toes, geckos are capable to generate large detachment forces and can do it in short periods of time, therefore are able to run even on vertical surfaces;
- maximised adhesion – it has been confirmed, that despite the smaller contact area, gecko pads may maximize adhesion. [3]

3 EXPERIMENTS

Measurements of adhesive forces required designing a biomimetic structure – structure mimicking properties of a studied natural object to some extent. Therefore, a simple design has been proposed. This design consists of an array of short and thin pillars created from a material similar to gecko setae by its mechanical strength and similar adhesion properties. A polymeric material known by its commercial name Parylene C was used as a supporting structure (actual shape of the pillars)

Figure 2 shows a shortened manufacturing process of gecko biomimetic structures. A single silicon wafer is used as a substrate with a thin (200 nm) layer of SiO_2 that has been machined by several techniques known for their use in micro-electro-mechanical systems manufacturing processes. During photolithography, the design – an array of dots 1 μm in diameter, was projected onto a polymeric photoresist (PR) using a glass carried chromium mask. After PR development, the holes were etched using the Bosch etching technique with deep reactive ion etching and filled with Parylene C. The samples are then flipped, and all the remaining silicon is etched away in XeF_2 gas.

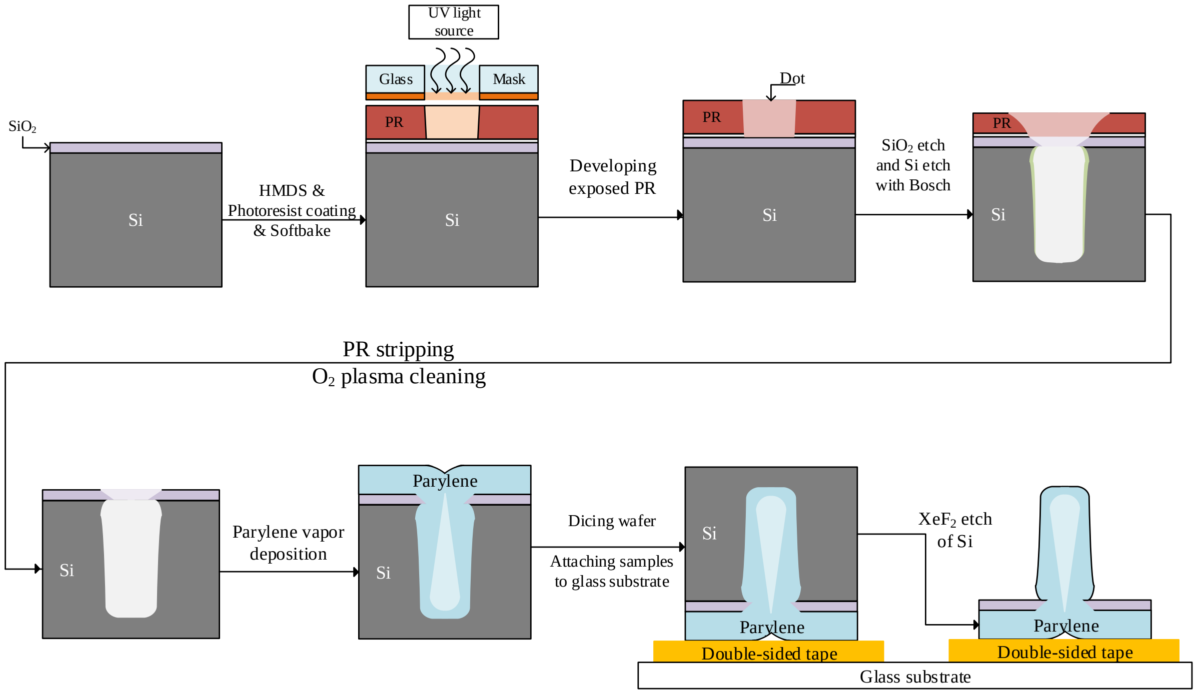

Figure 2 - Process chart showing the manufacturing steps using photolithography and Bosch etching and creating artificial gecko pillars made of commercially available Parylene C.

The resulting structures using SEM are shown on Figure 3.

Created structures could be later modified with organic layers supporting β-keratin that is found in the basic composition of gecko setae, thus, mimicking the surface of actual gecko lamellae. The mechanical properties of the pillars could be modified by adding a thin layer of SiO_2 and compared with the unmodified. A design option was also discussed, in which the pillars with larger pitch will have their tip enlarged, forming a bubble on top, that resembles the shape of gecko spatulae.

Modified and unmodified pillars will be analysed by atomic force microscopy (AFM) using a tip-less cantilever, and a cantilever mounted with a glass sphere to measure their response to applied force and adhesion properties. Furthermore, a contact angle measurement method can obtain wetting properties of each samples.

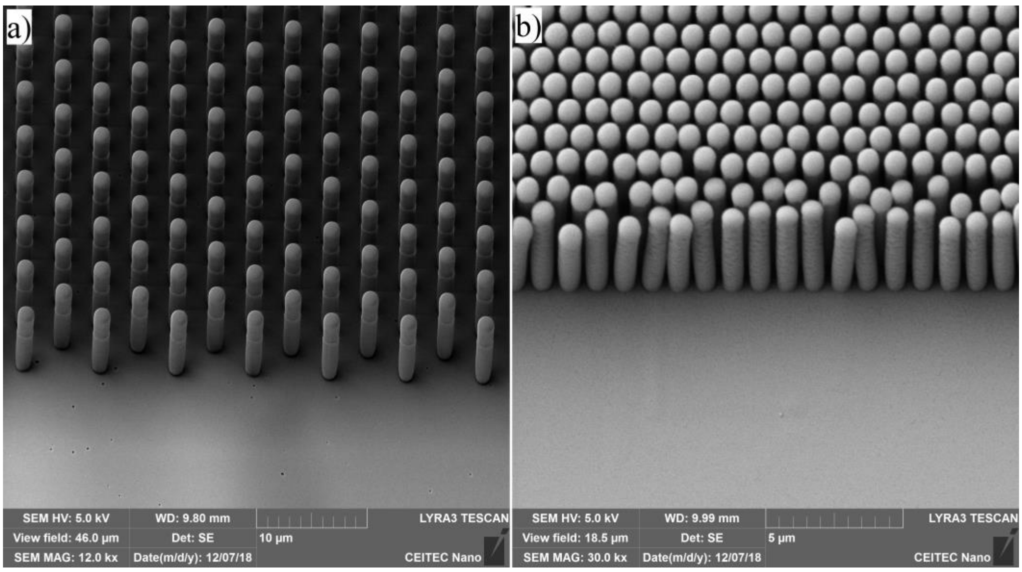

Figure 3 - Parylene C pillars with a (a) diameter of 1 µm and 4 µm pitch; (b) 0.5 µm diameter and 1 µm pitch (length is approximately 5:1 ratio of width).

4 CONCLUSIONS

Gecko toe-pads are a very interesting source of inspiration for biomimetics simulating their adhesive properties, that can even be used in a commercial area. But a lot of research has to be done to fully utilize the qualities of this natural adhesive. Overall, the aim is to understand and replicate its extraordinary behaviour and use it in special applications, that would benefit from such surface improvement, starting from simple adhesive tapes to wall climbing robots. Some successful attempts have already been made to mimic the structures of Gecko lizard's feet [4-8].

In this work, structures in the form of pillars have been prepared, which surface can be further enhanced using crosslinkers (FAS-17, APTES) to bind β-keratin, which is a fundamental building block of studied gecko setae, or by SiO_2, that can alter mechanical properties of these pillars. These qualities would be determined using AFM, and also using contact angle measurement methods.

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