Unique optical and mechanical properties of the spider silk

The silk made by spiders is an ancient biopolymer that has naturally evolved for more than 350 million years. It possesses exceptional physical properties. It is a light-weight material and it has high tensile strength yet being elastic. This makes it five times stronger than steel, and it is one of the strongest known polymer on the Earth. Remarkably, the spiders have developed seven different highly specialized, task-specific silks using few simple molecular building blocks. Spiders use silks for capturing prey, withstanding strong winds and danger, for laying eggs and for migrating. In addition to the strength, it is biocompatible, biodegradable, green material and possesses great potential for diverse applications such as in bullet-proof jackets, biomedical suture, biological optical fiber etc. Due to these outstanding credentials, the spider silk has been a fascinating interdisciplinary research topic for biologists, chemists, biomedical engineers and physicists. Despite applications of diverse tools of modern science to understand and mimic this unique material its structure-function relationship is still not fully understood.

At IISER Mohali, Dr. K. P. Singh and his group ventured to unravel physical properties of the spider silk, primarily motivated by their curiosity and ubiquitous availability of the silk. At the early days of the institute, when they had no established laboratory and instrumentations, Dr. K. P. Singh and his PhD student B. Kumar started this original research direction and decided to focus on investigating strength of this material under large twisting. While the torsional response of biopolymers like DNA is fundamental to their structure and proper functioning inside the cell. However, to their surprise, the torsional response of the spider silk has remained much less studied. Dr. Singh and his team at IISER Mohali developed a low-cost, yet sensitive, setup (Fig. 1) to understand the limiting torsional stress the silk can withstand without breaking. They discovered that unlike metals, that typically fails after few twist cycles, a spider silk of about 1cm length and few micron diameter can absorb more than 10,000 turns. Moreover, this response was reversible in that the silk regained its original shape after many cycles of extreme twisting and untwisting, as they verified using electron microscope and optical diffraction. The observed torsional super-elasticity under extreme strain was attributed to the nanoscale compressibility in its diameter that was optically unveiled by laser diffraction. This work showed that the spider silk could be an ideal material for applications that require shock absorption at microscopic scale. The detailed molecular mechanism behind this remarkable super-elasticity is currently being investigated using micro Raman spectroscopy.

In another line of work, since the spider silk is stronger than steel yet being elastic, they learnt that it was difficult to precisely machine this polymer. They thought of new application of femtosecond laser pulses to demonstrate precision micro and nano processing spider silk. The femtosecond light pulses are the light bullets that instantly deposit energy on to the material in short time scale. This allows us to make fine cuts, holes etc. Using the state-of-the art facility at IISER Mohali, they obtained promising preliminary results and a manuscript is under preparation. Their work could have potential for several applications. For example, these new properties will serve as a bench mark for biomimetic polymers, and it might help to refine the atomistic models of silk that could offer a deeper understanding of its inner structure. The ability to do clean micro-machining of spider silk might pave the way for silk based nanoscale devices and novel biocompatible sensors. In fact, there are many more lessons still to be learnt from the nature’s wonderful material, the spider silk.

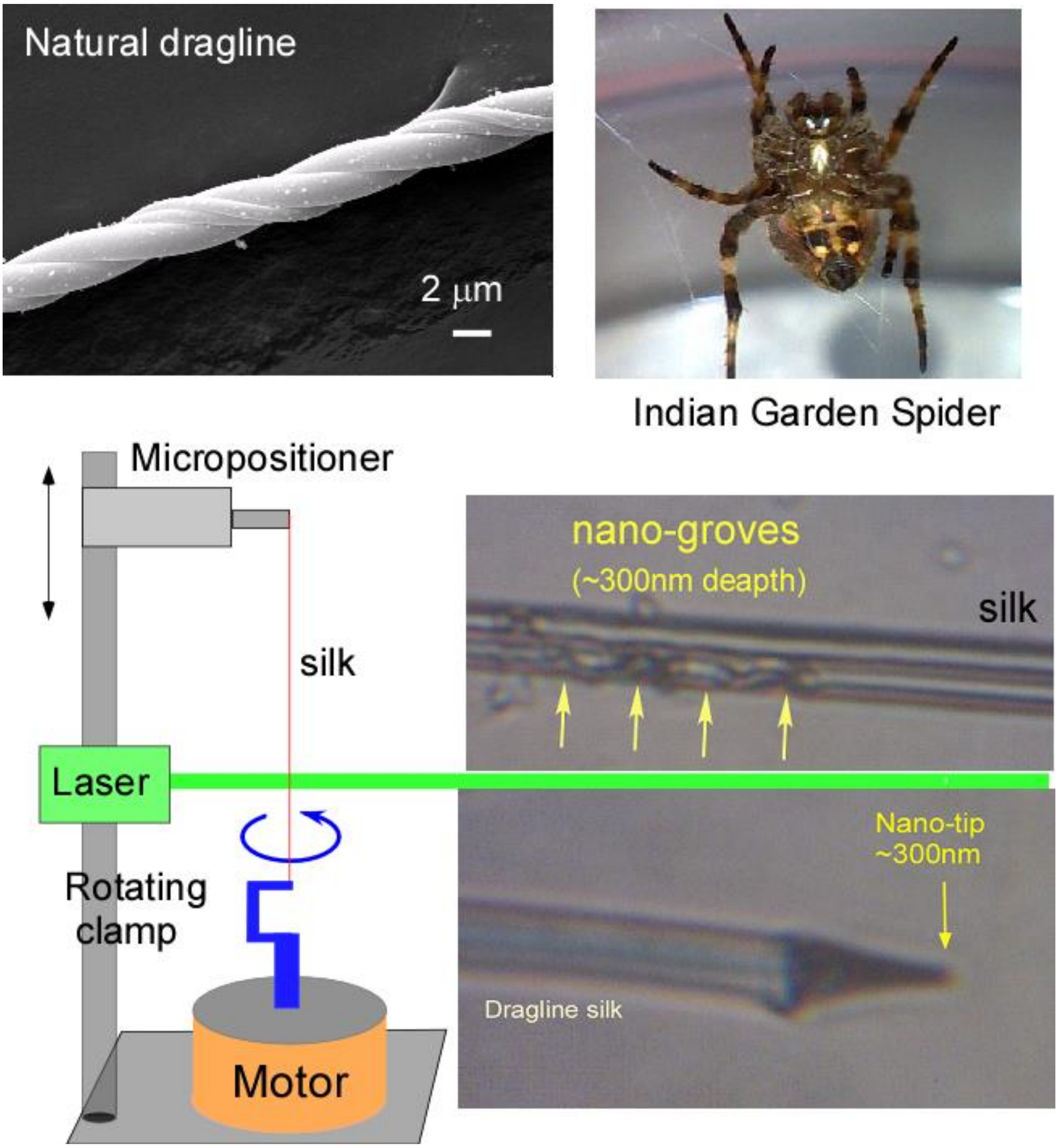

Figure 1: A picture of the spider and electron microscope image of its twisted silk. The experimental setup is schematically shown in the bottom left. Bottom right shows some nanoprocessed silk using femtosecond laser pulses.