

Biomining for Mother Nature's Superlenses

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Conventional optical microscopes are restricted by a predetermined limit beyond which it is impossible to resolve distinct points in the objective field. The origin of this limited resolution is associated to the optical diffraction and the loss of evanescent waves in the far field. As a result, objects below this diffraction limit, such as subcellular structures in biology and nanochips in semiconductors, cannot be seen. To overcome this problem, many solutions have been introduced over the past decades, comprising of super-oscillatory lens, Pendry negative index superlens, plus many more including our own all-dielectric superlenses which achieved a record resolution of 50nm in 2011 [1], and have since accomplished 45nm with mSIL in 2016 [2]. A problem accompanying many of today's superlenses is the requirement for complex manufacturing processes, with chemical synthesis and photolithography. Subsequently, superlenses become inaccessible to non-professionals.

In 2016, we began the process of biomining (searching nature for suitable materials and models) for superlenses to resolve the issue of inaccessibility. This led to the pioneering of the first biological superlens provided by nature: the minor ampullate spider silk spun from the *Nephila edulis* spider [3]. This natural biosuperlens can noticeably resolve 100nm features under a conventional white-light microscope with a peak wavelength of 600nm (fig. 1a), conquering the classical diffraction limit with a result resolution of $\lambda/6$. This work unlocked a new door to developing biology-based optical systems. The surrounding physics behind this novel superlens is 'photonic nanojet' focusing by the cylindrical spider silk and near-field evanescent-to-propagating wave conversion.

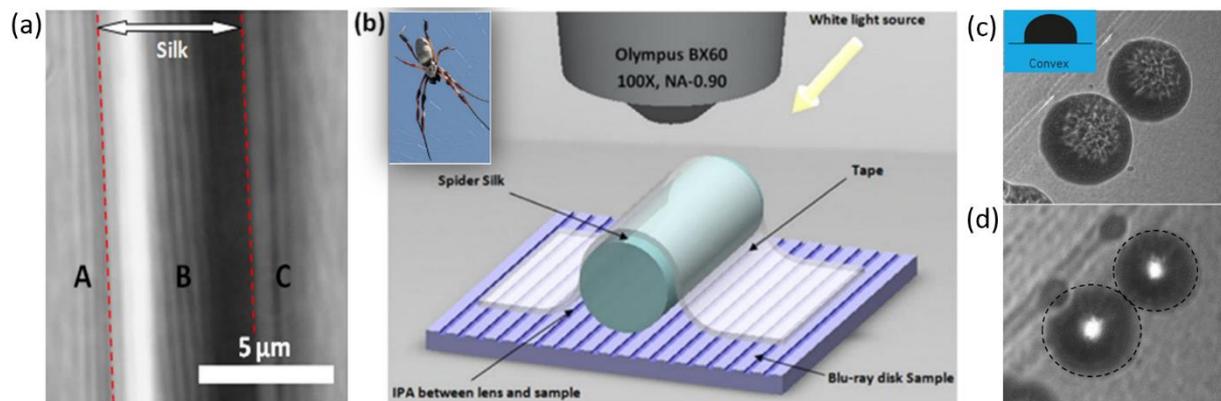


Fig. 1 (a) Typical imaging example of Blu-ray nano pattern via silk superlens (b) Schematic drawing of reflection mode silk biosuperlens imaging, with *Nephila edulis* insert. (c) Cyanobacteria half-ball aggregation. (d) Lensing effect produced by Cyanobacteria half-ball aggregation.

Furthermore, Cyanobacteria has shown to be a promising addition to biological superlenses. Research conducted into Cyanobacteria's usage of micro-optics to sense light direction [4] gave rise to the micro-optics effects for spherical bacteria. The study demonstrated the presence of photonic nanojet in single bacteria, an importance aspect for super-resolution imaging. However, the size of this strain of cyanobacteria, *Synechocystis*, is individually too small to resolve an image beyond the diffraction limit as the viewing window is too narrow, with the bacteria sizing in the range of 2-3μm. To disable this sizing limitation, we are able to demonstrate a clear lensing effect through half-ball aggregation of the Cyanobacteria (fig. 1d), which created a convex morphology structure similar to that found in mSIL assembly technique.

Reference

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