



Colloquium

To Read the memories of a tree: Birefringent-colored optical profiling of wood presenting the 3D cellulose microfibril architecture

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Date: 2026/10/27 (Tue)

Venue: S4-625

Time: 14:00



Abstract :

Wood is a composition of slender, long, tube-like cells. The cell walls are composed of cellulose fibrils embedded in a lignin and hemicellulose matrix. The 3D fibril organization explains how wood achieves extraordinary tensile strength, structural integrity, flexibility, and energy-saving water transport. Therefore, the 3D structure of the fibrils in the cell wall has been of great interest in biophysics and biomimetics. Wood slices under a polarized optical microscope show a spectrum of interference colors, such as cyan, blue, magenta, yellow, and bluish gray because of the birefringent cellulose in the microfibrils. As xylem cell walls adapt to environmental physical stress, wood stores information as fibril structures, which can be deciphered using the birefringence colors. An optical model was established to simulate the birefringent-colored micrograph of wood. Five typical cell wall architectures, line, helix, ring, crossed helix, and twisted helix, were considered. With a retardation wave plate to distinguish fibrils of different orientations, each structure displayed its unique birefringent-colored texture, presenting its underlying 3D structure with the vivid colors. Cross sections of *Eucalyptus grandis* presented birefringent-colored profiles. Three identification methods were compared: visible fibril trends, birefringent-colored optical textures, and the simulated look-up library. The three methods gave consistent results, proving that the birefringent-color tags are efficient and accurate. The five architectures are like the five alphabets of the tree's language, and their distribution and network could be the diary of a tree's life. The natural cellulose composite can inspire polarization multiplexing and wavelength encoding to achieve high-density optical information storage. This approach enables statistical and spatial analysis of complex biomaterial compositions. Capable of profiling dozens of cells simultaneously, this high-throughput optical method provides a potentially fully automated analysis framework for plant science, biomechanics, and bioinspired cellulose materials.