Scanning electron diffraction reveals the molecular ordering of polysaccharides at the nanoscale

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Background
Cellulose is the most abundant biopolymer. Nature links glucan units to form polysaccharide chains which are organized in an intricate network of hydrogen bonds into crystalline cellulose fibers. These fibers are assembled into hierarchical structures that constitute the secondary cell wall of plants, forming the basis for their mechanical properties. The macroscopic attributes of these materials are determined by chemical interactions and mesoscopic organization spanning from the atomic scale to the macroscopic level. Understanding these assemblies is vital for grasping the properties of biological materials and for exploring ways to incorporate these naturally occurring components into hybrid materials.

Biopolymers are fundamentally challenging to study using electron microscopy due to their delicate and electron beam sensitive nature. Using scanning electron diffraction we can obtain unique nanoscale information about the molecular ordering of the polysaccharide chains, which can be used to understand e.g. their superior mechanical properties.

Methods
The strong interaction between an electron probe and matter enables the acquisition of scattering data from nanometer-sized volumes even from weakly scattering elements. Electron diffraction has proven to be an invaluable tool for the structural examination of a diverse range of nanomaterials. Scanning electron diffraction (SED) offers detailed maps that reveal the crystalline ordering at the nanometer scale, shedding light on the arrangement of polysaccharide chains within individual nanofibers and also their hierarchical assemblies in composite materials.

In this study, we are using a quasi-parallel electron beam, with a convergence angle of 0.1 mrad. The beam is scanned across the specimen to obtain a map containing information about the molecular scale ordering of the biomaterial. The high speed and sensitivity of hybrid detectors enable the acquisition of electron diffraction data from single cellulose nanofibers.

Results
Cellulose nanofibers (CNFs) can be extracted from various origins and stand out as a promising, sustainable building block with remarkable mechanical properties. Using SED data, the crystalline nanostructure within individual CNFs can be analyzed, offering insights into how the crystalline ordering persists. Data was obtained from twisted sections of the nanofibers and reveals that despite the strain this twisting introduces the crystalline structure remains intact.[1] Furthermore, SED data can be employed to investigate the hierarchical organization of cellulose fibrils within the plant cell walls as well as hybrid materials based on wood. One prominent example of this a composite mateial made from delignified and polymer-impregnated wood, the so-called transparent wood. SED data obtained from this material revealed the organization of cellulose fibrils into hierarchical helical structures across the various cell wall layers.[2] In most of the cell wall the cellulose fibers were organized along the extended dimension of the cells and towards the outermost part of the wall the fiber orientation gradually changed to a tangential orientation.

Conclusion
Using scanning electron diffraction we can for the first time reveal the molecular ordering of cellulose chains in twisting cellulose nanofibers as well as shed light on the mesoscale hierarchical ordering of cellulose fibers in hybrid materials and cell structures with nanometer resolution.

Keywords:

Scanning electron diffraction, biopolymer, cellulose,

Reference:

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