RESEARCH in Progress

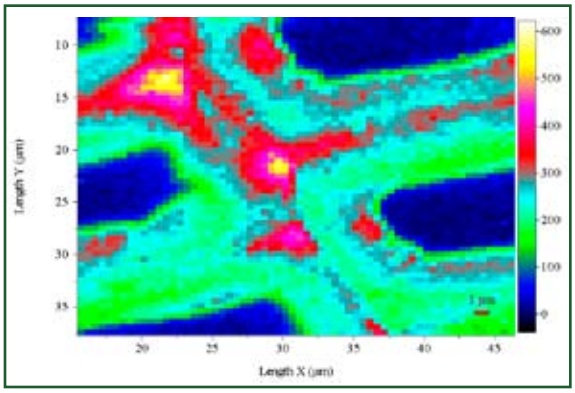
Forest Products Laboratory

Understanding the Ultrastructure of Wood Cell Walls by Confocal Raman Mapping

Utilizing wood to produce bioenergy, cellulose nanocrystals, and a range of bio-based products has become an important area of research. Fundamentally important to making progress in these topic areas is information on wood composition and structure. Such information is also needed to comprehend how growth and development factors influence wood cell wall formation.

Background

The wood cell wall is a heterogeneous natural nanocomposite of cellulose, lignin, and hemicelluloses. The wall also contains small amounts of pectin and protein in some areas. The wall is organized in several layers. The primary wall (P), secondary wall (S1, S2, and S3), and middle lamella (mL) have different structures. Likewise, within the secondary wall, S1, S2, and S3 differ with respect to the orientation of cellulose nanofibrils. The middle lamella surrounds the cell and holds the neighboring cells together. Although several models describe the ultrastructure, more research is required to better explain the cell wall. A complete understanding of cell wall architecture is important for both research and technological purposes. A better structural understanding of wood fiber will lead to progress in a number of areas, from wood-based materials to cellulosic ethanol. Raman microscopy is a high-spatial-resolution nondestructive technique that provides information on cellulose and lignin in the cell wall.



Raman image of lignin distribution in a black spruce wood cross section. Intensity scale is shown to the right. Higher intensity corresponds to more lignin.

Objective

The objective of this study is to characterize, noninvasively, plant cell walls in a number of tissue types at the molecular level using Raman microscopy. Of the various cell wall components, organization and distribution of cellulose and lignin will be studied with respect to cell wall morphology.

Approach

A number of traditional methods require isolation of morphologically distinct tissue or sectioning of tissue by embedding the samples. Such methods are enormously disruptive to native-state structures. Moreover, methods such as optical and electron microscopy describe only cell wall morphology and do not provide information on molecular structure. Additionally, for lignin analysis using electron microscopy–energy dispersive X-ray analysis (EM–EDXA), chemical treatment by Br_2 or Hg is indicated. None of these limitations exists in Raman mapping because sampling is done directly, and both lignin and cellulose can be mapped simultaneously by selecting Raman bands that are specific to these cell wall components. A 633-nm laser-based Raman microprobe spectrometer, LabRam HR 800, will be used in the present study. Where

U. S. Department of Agriculture
Forest Service • Forest Products Laboratory
www.fpl.fs.fed.us

appropriate, Raman mapping results will be analyzed using multivariate analysis tools.

Expected Outcomes

Results are expected to provide information related to several topics:

- Organization and distribution of cellulose and lignin in various cell wall morphological regions
- Microfibril angle in S1 and S2
- Cell wall composition and cellulose crystallinity in reaction wood tissues
- Chemical reactivity difference of S2- and mL-lignins
- Effect of drying and chemical/biochemical processing on cell wall ultrastructure
- Structure-property relationships of the tissue

Timeline

This study will continue for approximately 3 years, during which both softwood and hardwood species will be studied.

Contact Information

Umesh P. Agarwal, Research Chemist
U.S. Forest Service
Forest Products Laboratory
Madison, WI 53726
(608) 231-9441; uagarwal@fs.fed.us