New Innovations in the Sustainable, Eco-friendly Fabrication of Patternable Transparent Wood

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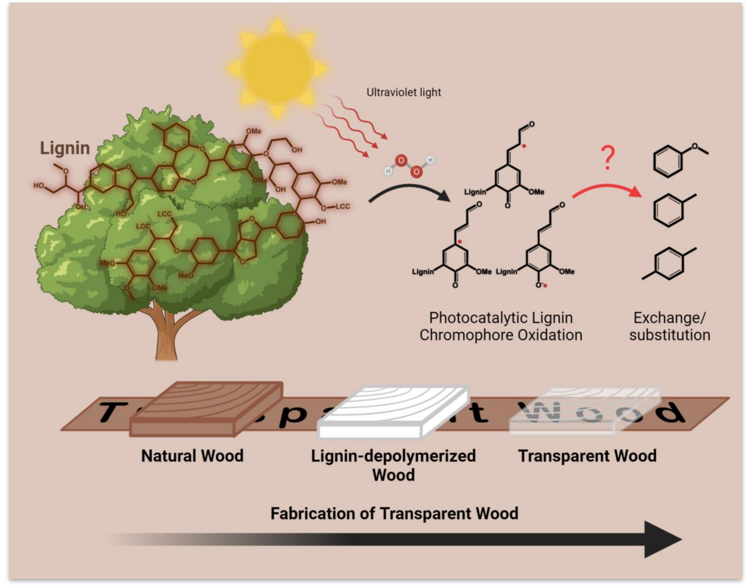
INTRODUCTION



Research highlights:

- Chromophore substitution can be achieved with various aromatic compounds undergoing oxidation.
- Laser Engrave-assisted Patterned Transparent Wood (LEAP-TW) selectively substitutes lignin chromophores on regions of the wood.
- The cell wall and porous structure of TW and LEAP-TW are preserved as observed in natural wood.

The movement toward energy efficiency, biodegradability, and environmental conservation in materials manufacturing necessitates the investigation of sustainable alternatives to petrochemical-based polymers and high-cost materials like plastics and glass. Transparent wood (TW)—a low-cost, lightweight, renewable material—offers a sustainable advantage over traditional materials. Over the past decade, various methods for producing TW have been developed, each contributing to waste reduction, sustainability, or novel functionalities. In our study, we employed a patternable technique involving chemical oxidation and resin infiltration of various wood veneers. This method uses the photocatalytic depolymerization of lignin chromophores and washings with clear, aromatic solvents. The lignin chromophores, which comprise conjugated systems within the cell wall, depolymerize under an oxidizing agent, effectively bleaching the wood. After solvent washing, a stabilizing resin is infiltrated into the wood to fabricate TW. Although the technique has become significantly waste-reducing and environmentally nonhazardous, the use of more user-friendly solvents with varying optical properties and new patternable techniques remains unexplored. Here, we identified several modalities involving different patterning techniques and chemical solvents in the fabrication of TW. We report a novel laser engrave-assisted patterned TW (LEAP-TW) that maintains the structure of the wood. Our findings indicate that through various lignin-modifying and solvent exchange processes combined with new patterning techniques, the hierarchical, porous structure of the wood is preserved. These results open promising avenues for novel TW fabrication methods in green materials manufacturing.

BACKGROUND

- Wood as an abundant, biodegradable material has become a promising template for the development of multi-functional, ecofriendly biocomposites (Akpan et al, 2021).
- Transparent wood (TW) is a novel, sustainable alternative to high-cost material manufacturing (Chutturi et al, 2023).
- Advances in the fabrication of TW use delignification, the complete extraction of lignin, to achieve TW, but ultimately reduces the anisotropic strength and integrity of the material (Zhu et al, 2016; Xia et al, 2021).
- A sustainable lignin-modifying process involving photocatalytic H2O2/NaOH oxidation of conjugated chromophores in lignin removes the natural color of the wood and can be designed to pattern TW (Xia etal, 2021).
- The new patternable, lignin-modifying method of TW fabrication incorporates toluene exchange and imprecise patterning techniques, which are not feasibly implemented into the craft of woodworking (Dalheim, 2021).
- The present study investigates novel innovations in the fabrication of TW.

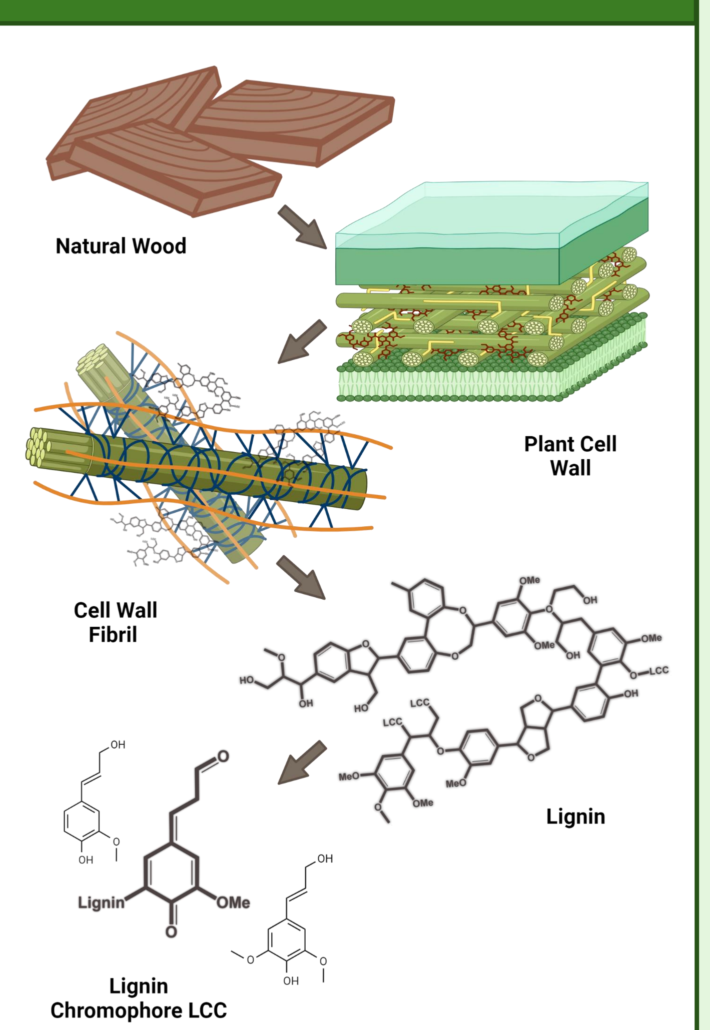


Figure 1: *Wood Structural Layers.* Lignin comprises plant cell walls within the wood.

KEY FINDINGS

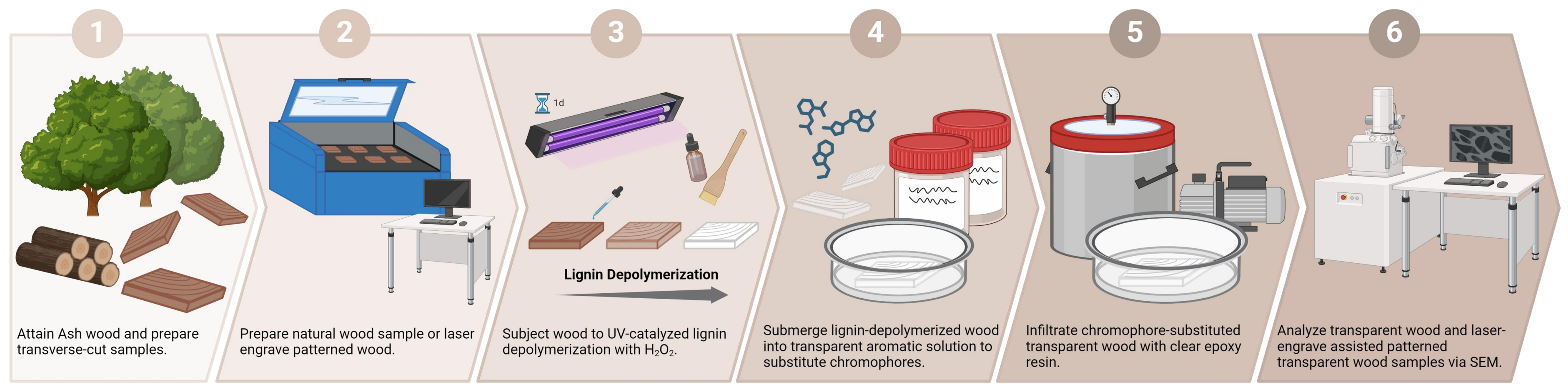


Figure 2: *Experimental Approach*. Wood samples transverse-cut on table saw (1) and prepared with or without a pattern on the laser engraver (2). Samples were brushed with a bleaching solution under UVA light for 24h (3). Lignin-modified wood was submerged into transparent aromatic solvent (4) and vacuum infiltrated with an epoxy resin (5). All wood samples were imaged by Scanning Electron Microscopy (6).

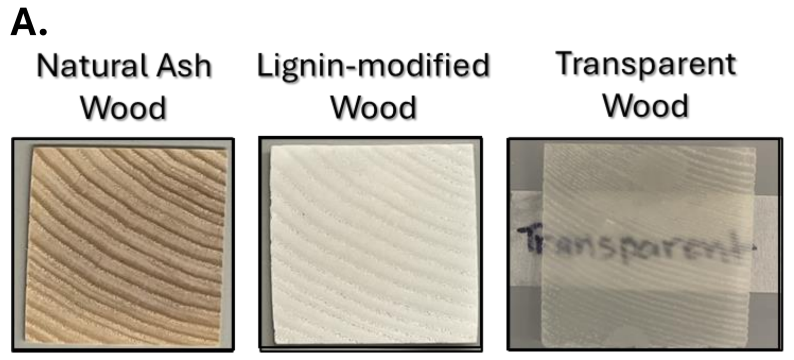
A.

B.

Wood Species	Wood Density (lb/ft³)	Janka Hardness (lbs)	Modulus of Rupture (ksi)	Modulus of Elasticity (ksi)
Am. Cherry *Prunus serotina*	34	995	11.31	1486
Am. White Oak *Quercus alba*	56.2	2544	20.99	2213
White Ash *Fraxinus americana*	46.8	1320	15	1740
Balsa *Ochroma pyramidale*	7	67	2.84	538

Figure 3: *Bleaching Different Wood Species*. Ash, Am. Cherry, and Am. Oak woods were bleached for 24h showing different levels of depolymerization (A); the physical properties of wood indicate no correlation to wood bleaching duration (B).

A.



B.

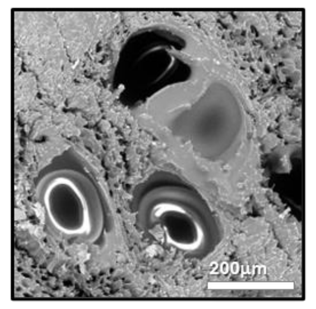


Figure 4: *Transverse Transparent Wood.* Transverse-cut, White Ash wood was prepared into transparent wood (A) and pore infiltration was analyzed via SEM (B).

A.

B.

C.

Figure 5: *Laser engrave-assisted patternable TW (LEAP-TW).* A laser engraving of the Berea College Student Craft logo was printed on the wood in different powers and orientation (A). LEAP-TW of the logo (B) and the mini-movie of the process of LEAP-TW were created (C).

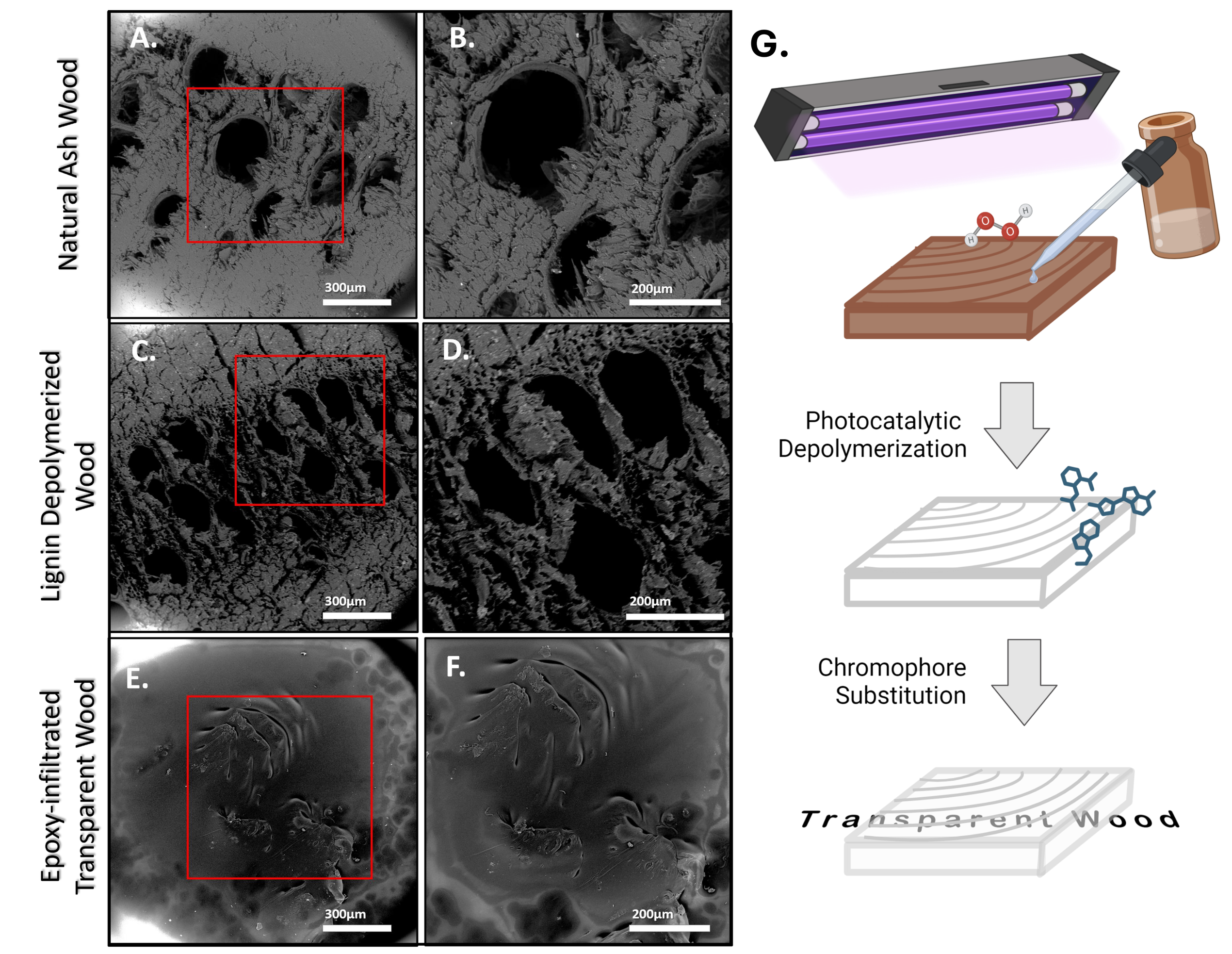


Figure 6: *Preservation of the Porous Structure.* The porous structure of transverse-cut natural wood (A-B) is preserved during lignin depolymerization (C-D) and infiltrated with a transparent resin (E-F) as shown with an SEM. The workflow of the fabrication of transparent wood depicts which stage of the process each micrograph was captured (G).

CONCLUSION

Our study demonstrates the potential of transparent wood (TW) as a novel alternative to traditional materials used in material manufacturing. By employing a novel laser engrave-assisted patterning technique (LEAP-TW) combined with chemical oxidation and resin infiltration, we have successfully preserved the hierarchical, porous structure of wood while selectively engendering transparency in the wood pattern. This method presents new, innovative opportunities for the application of LEAP-TW for novel designs in green materials manufacturing.

Limitations: The research was performed by a single undergraduate, the college did not have a transmittance instrument, and the lignin extraction process was not optimized in time.

FUTURE DIRECTIONS

Future research should explore the use of more user-friendly solvents and further refine patterning techniques to enhance the practicality and versatility of LEAP-TW. Additionally, the use of lignin extraction and characterization and transmittance measurements would allow for the comparison of lignin modification techniques used in the fabrication of TW.

The implementation of LEAP-TW into the novel, green design in the field of craft can be tested for the production of new materials and products.

References

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