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MATERIALS SCIENCE

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Anisotropic, lightweight, strong, and super thermally insulating nanowood with naturally aligned nanocellulose

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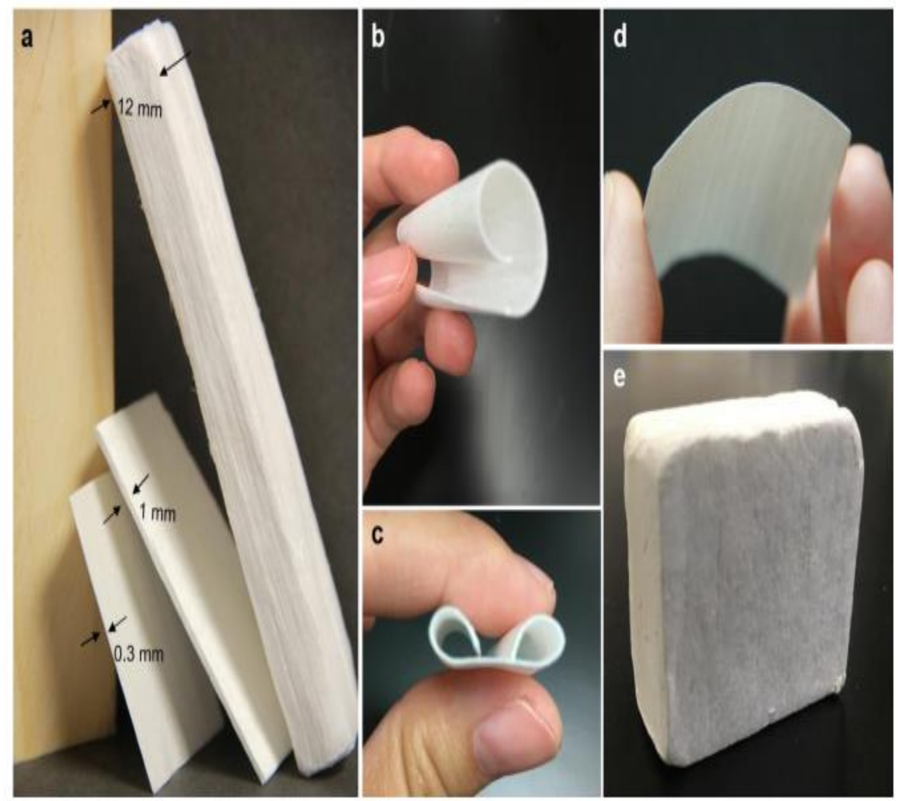


Paper Presentation

- Sritama Mukherjee (16.06.2018)

Background

- Good thermal insulation is highly desirable for many electrical, optical, and space applications in which heat transfer needs to be tightly regulated.
- The redirection of thermal energy in anisotropic thermal insulators can help (i) prevent heat localization and (ii) reduce heat flow in the direction of lower thermal conductivity, therefore resulting in improved thermal insulation that could not be achieved by isotropic materials.
- However, these types of anisotropic materials usually require complex designs and energy-consuming manufacturing processes

Anisotropic thermal diffusivity of aligned multiwall carbon nanotube arrays

T. Borca-Tasciuc, S. Vafaei, D.-A. Borca-Tasciuc, B. Q. Wei, R. Vajtai, and P. M. Ajayan

Citation: Journal of Applied Physics **98**, 054309 (2005); doi: 10.1063/1.2034079

nature nanotechnology ARTICLES

PUBLISHED ONLINE: 2 NOVEMBER 2014 | DOI: 10.1038/NNANO.2014.248

Thermally insulating and fire-retardant lightweight anisotropic foams based on nanocellulose and graphene oxide

Bernd Wicklein[1], Andraž Kocjan[2], German Salazar-Alvarez[1,3], Federico Carosio[4], Giovanni C
Markus Antonietti[5] and Lennart Bergström[1]*

Anisotropic thermal transport in highly ordered TiO_2 nanotube arrays

Liying Guo, Jun Wang, Zhiqun Lin, Sobieslaw Gacek, and Xinwei Wang

Citation: Journal of Applied Physics **106**, 123526 (2009); doi: 10.1063/1.3273361

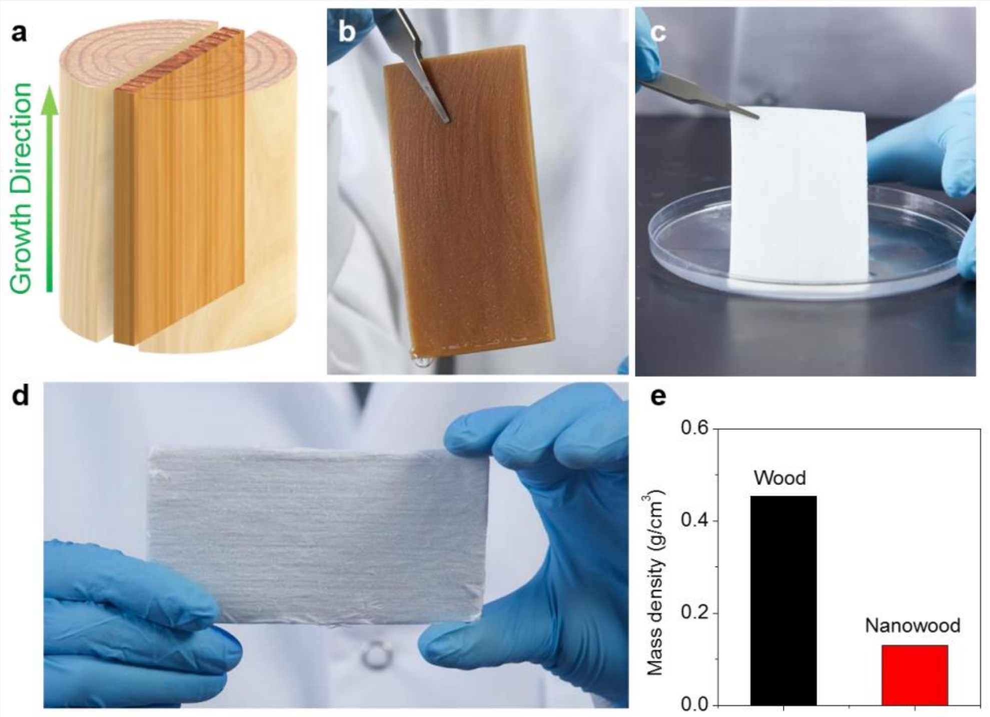
Relevance

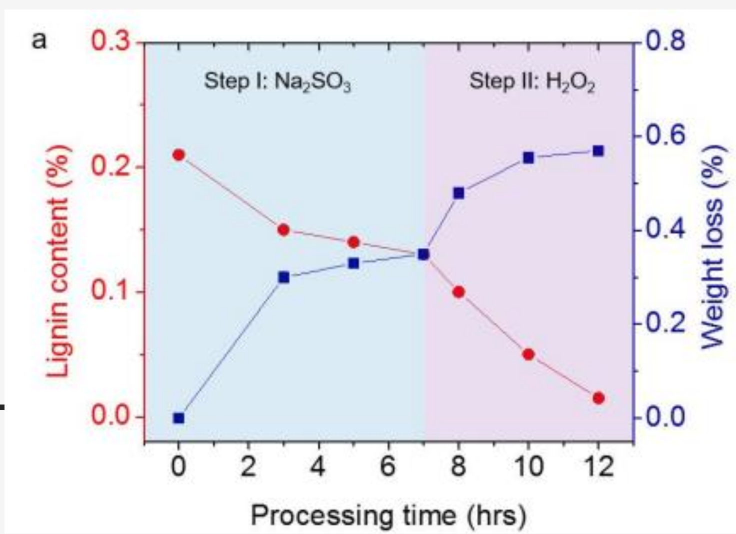
In our group, we are making different kind of anisotropic materials with cellulose or other polymers, this paper gives an insight about how anisotropy is an important factor for high performance in applications like thermal insulation and high reflectance.

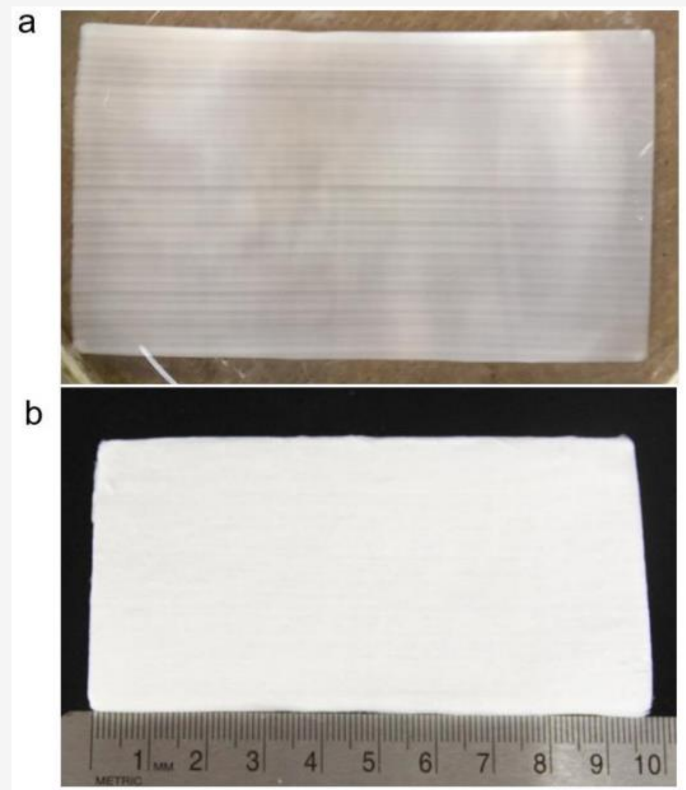
In this paper..

- Nanowood = delignified basswood
- Removal of hemicellulose also
- Top down approach
- Aligned cellulose nanofibrils
- Anisotropy

$$\text{Wood} \xrightarrow[\triangle \quad H_2O_2]{NaOH+Na_2SO_3} \text{Nanowood}$$







The wood microstructure and the hierarchal alignment are well-preserved during this process, and the sample is subsequently freeze-dried to preserve the nanoporous structure of the delignified wood.

aspect ratios (a diameter of ~30 nm and a length of approximately >1 um)

the porosity of the nanowood increases to ~91% [density of nanowood = 0.13 g/cm3, and of dry cell wall of basswood is 1.491 g/cm3], which is much larger than that of the original basswood (around 60%)

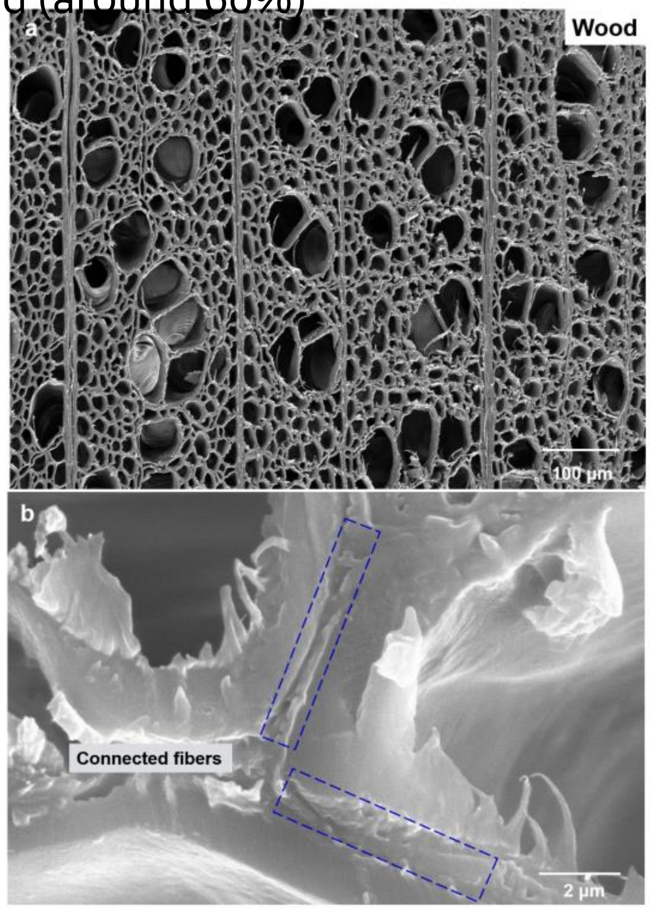


fig. S4. SEM images of natural wood. The wood exhibits aligned fibrils inside the wood structure. The SEM shows a top view of the open and aligned fibrils with hollow lumens. Inset: The lumens adjacent to each other are connected through an intricate pore system.

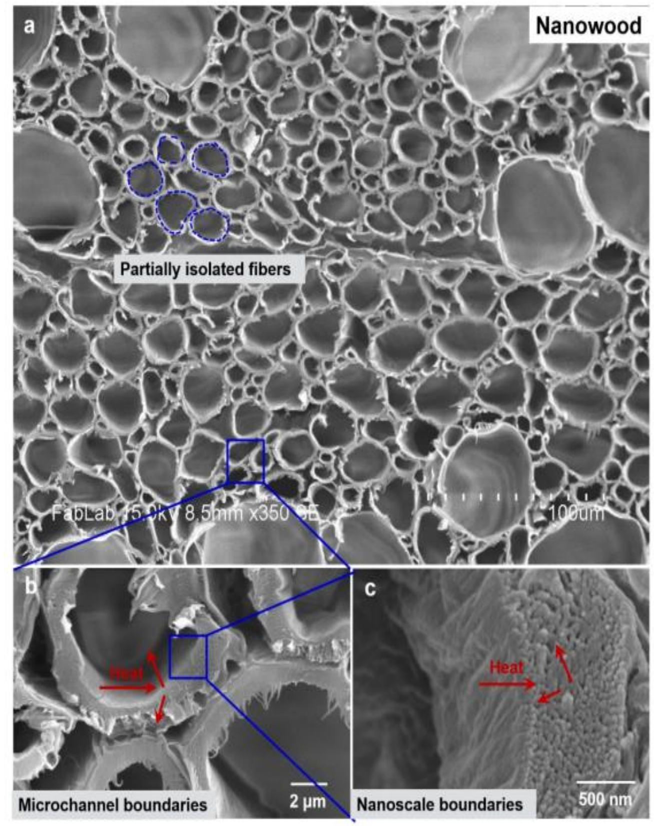
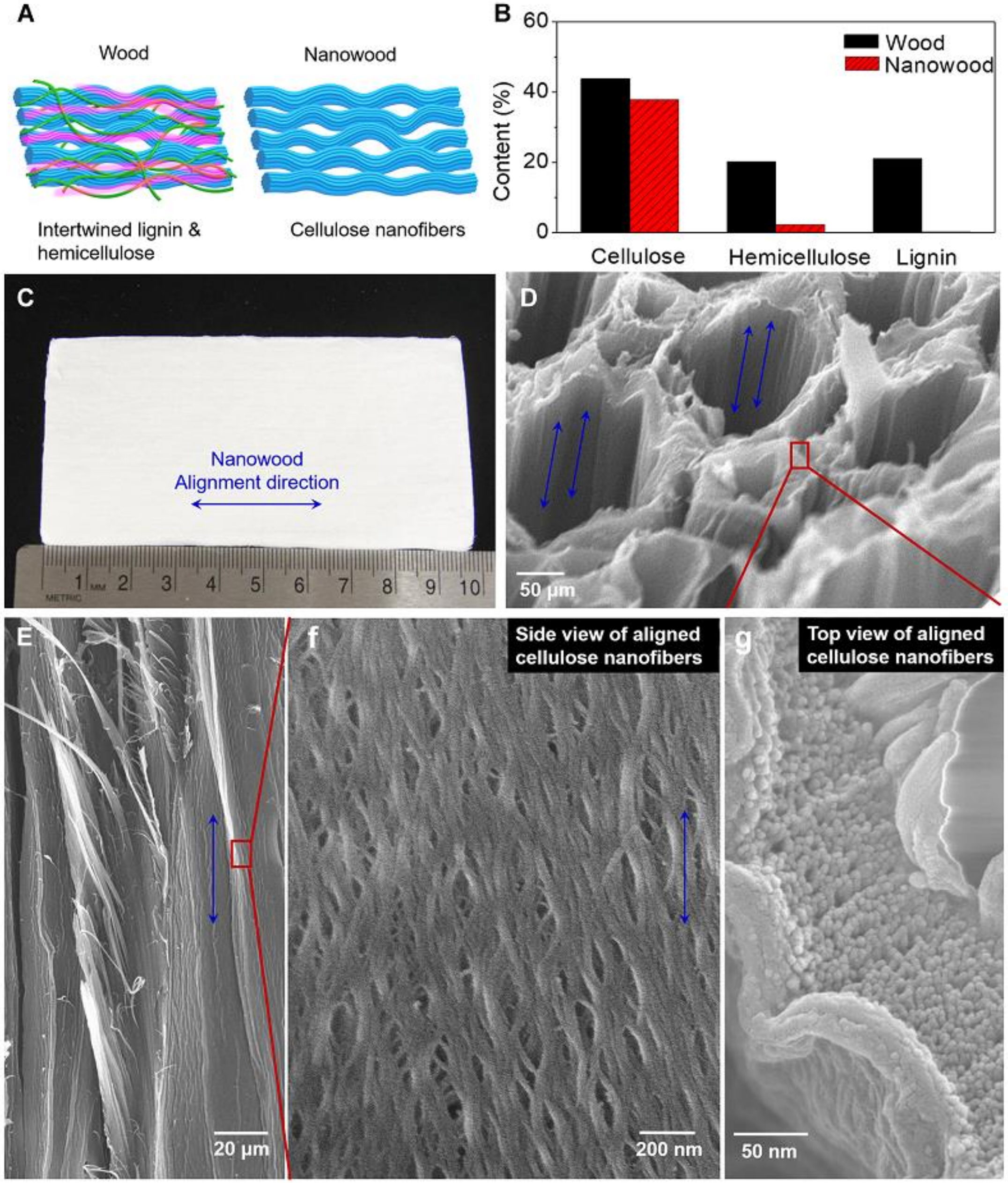


fig. S5. SEM images of nanowood. The alignment of the fibrils is maintained after delignification. However, owing to the purification of the cellulose content, the fibrils become separated and partially detached from each other. The nanofibrils in the fibril walls are more distinct as the intermixed lignin and hemicellulose in between cellulose are removed. The sample was cut before delignification.



Among the cell wall layers, the middle S2 layer in the secondary cell wall is the thickest and is composed of parallel cellulose nanofibril aggregates aligned in a small angle difference with the length axis. The fibril angle of the S2 layer varies
about 10° to 15° and can help define the alignment of the cell wall. After chemical purification, the cellulose nanofibril aggregates in the cell wall layer can be directly observed in the fibril cross section

Fig. 2. Structural characterization of nanowood. (**A**) Schematics of the aligned cellulose nanofibrils in the nanowood before and after which the intermixed amorphous lignin and hemicellulose have been removed. (**B**) Concentration of lignin, hemicellulose, and cellulose in the natural wood and nanowood. (**C**) Photograph of a nanowood specimen that exhibits pure bight color and an aligned texture. (**D**) Nanowood exhibits a large porosity, a hierarchical structural alignment of fibril aggregates, and a maintained alignment of the fibril aggregates. (**E**) Side-view SEM image of the microsized porous and aligned channels inside the nanowood. (**F**) SEM image of the porous channel walls that composed of aligned nanofibrils. (**G**) Top-view SEM image of the nanowood channels with separated nanofibrils ends.

Anisotropic thermal conduction of the nanowood

Thermal conductivity in the radial direction: **0 . 0 3 2 ± 0.002 W/m·K** and **0.056 ± 0.004 W/m·K** at 24.3°C in the axial direction.

In comparison, the natural American basswood exhibits **0.107 ± 0.011 W/m·K** in the radial direction and **0.347 ± 0.035 W/m·K** in the axial direction.

The partially isolated fibrils help further reduce the transverse thermal conductivity.

Reasons?

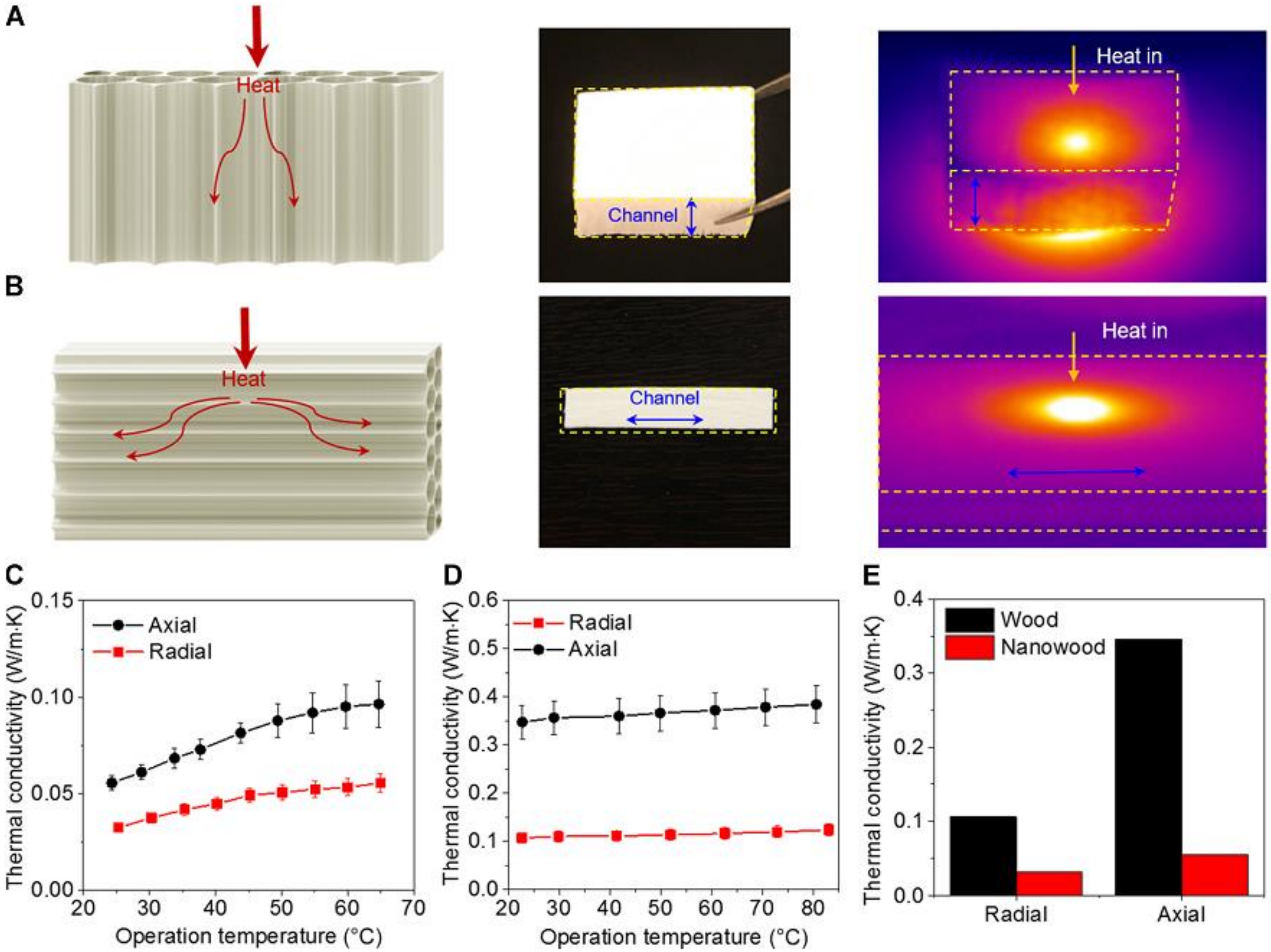


Fig. 3. Transverse and axial heat transport in nanowood. (**A**) Schematic representation of heat conduction along the wood cell walls as axial heat transfer, whereas (**B**) heat conduction across the cell walls and hollow channels (that is, the lumen and the nanosized pores inside the fibril walls) is referred to as transverse heat transfer. (**C**) Measured thermal conductivity of the nanowood from room temperature to 65°C. (**D**) Measured thermal conductivity of the original wood from room temperature to 80°C. (**E**) Comparison of the thermal conductivity of the natural wood and nanowood at room temperature.

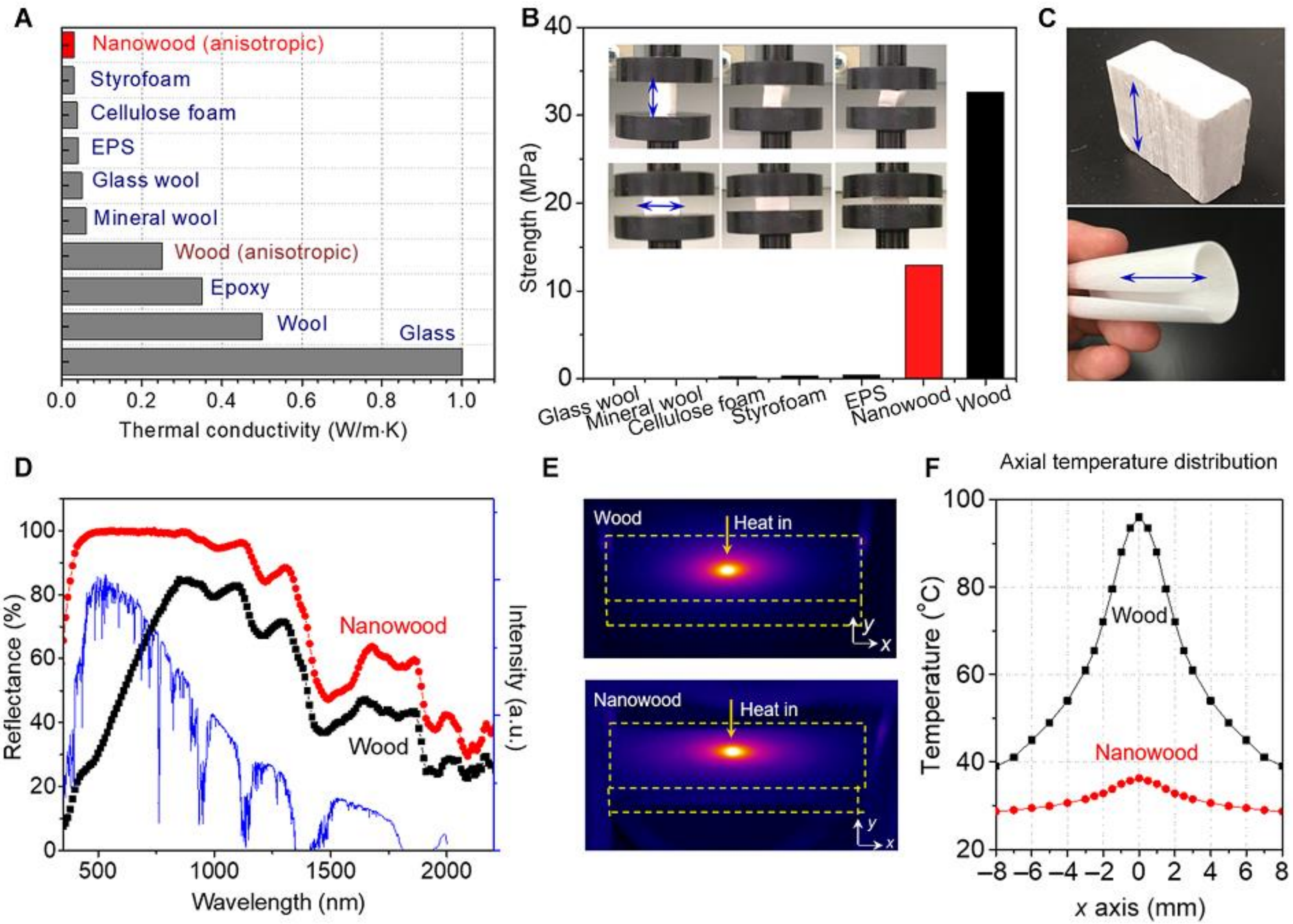


Fig. 4. Characterization of nanowood. (**A**) Thermal conductivity comparison among existing thermally insulating materials. The nanowood exhibits a very low transverse thermal conductivity along with high anisotropy. (**B**) Mechanical properties of the nanowood in comparison to other materials with a thermal conductivity smaller than 0.05 W/m·K, as well as natural basswood. (**C**) Photographs of a bulk piece of a nanowood and a thin and rollable nanowood. The arrows indicate the alignment direction. (**D**) Reflectance of the nanowood. The nanowood exhibits a larger reflectance covering the spectrum of solar radiation (that is, a low solar-weighted emissivity compared with wood). The blue curve is air mass 1.5 solar spectrum. a.u., arbitrary units. (**E**) Infrared image of the natural wood and nanowood when illuminated by a laser with a wavelength at 820 nm. (**F**) Temperature profile for the samples in (E).

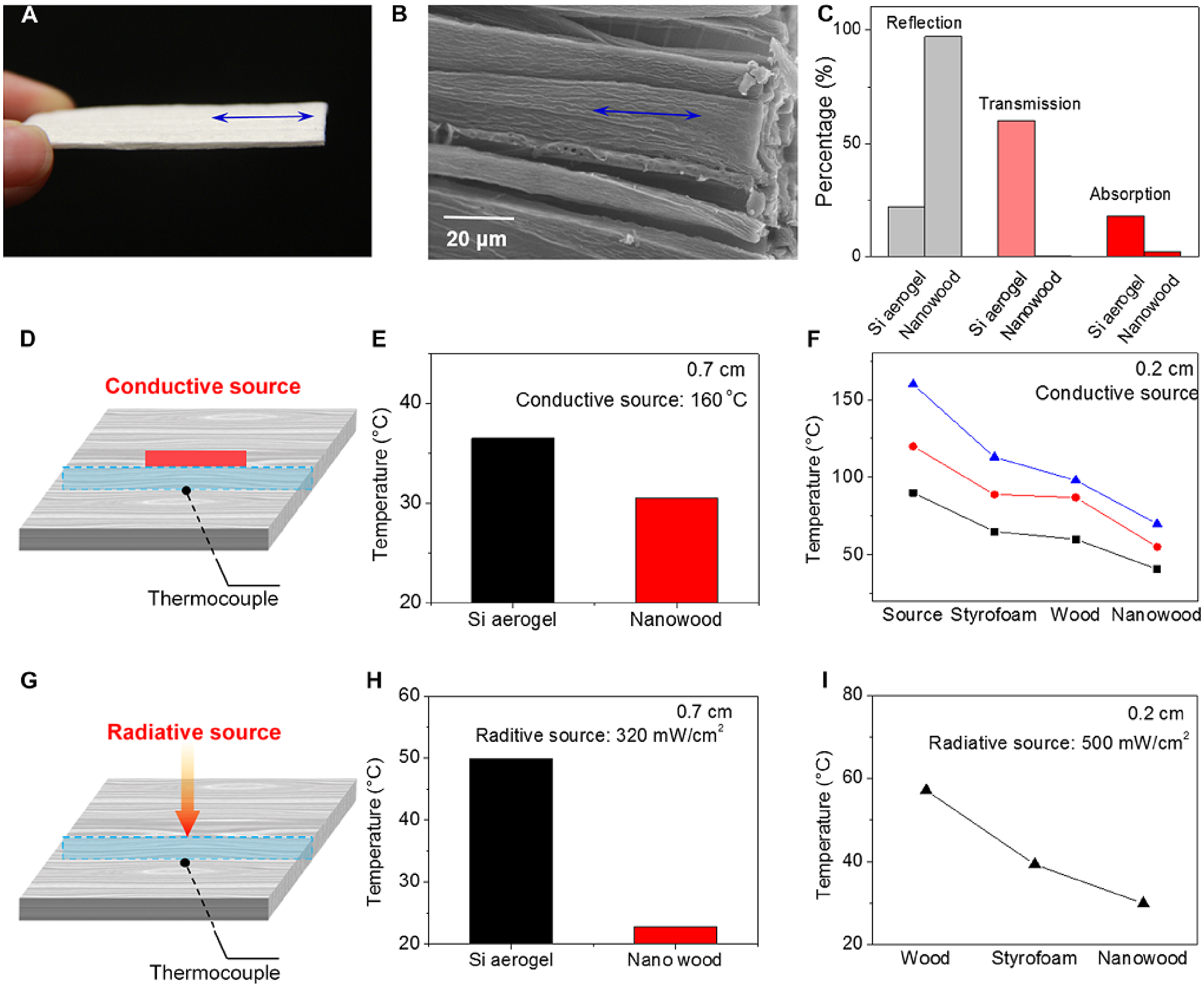


Fig. 5. Thermal insulation performance of nanowood in comparison with a silica aerogel, a Styrofoam, and a natural wood. (**A**) Photograph of a 1-mm-thick specimen of a nanowood. (**B**) SEM side view of the nanowood channels composed of aligned cellulose nanofibrils. (**C**) Optical reflection, transmission, and absorption of the silica aerogel and nanowood illuminated by the standard solar simulator. (**D**) Schematic description of the nanowood being illuminated transversely (perpendicular to the nanofibrils). (**E** and **F**) Summary of results showing the stabilized backside temperatures of the thermal insulators when the top surface is in direct contact with a conductive heat source via thermal paste. (**G**) Schematic description of the measurement setup using radiative heat sources (solar simulator). (**H** and **I**) Summary of the results showing the stabilized backside temperatures of each thermal insulator, with the top surface receiving radiative energy from the solar simulator.

Conclusions

The nanowood also has the following unique properties:

(i) exhibits unique anisotropic thermal properties with a low transverse thermal conductivity of 0.03 W/m·K and ~0.06 W/m·K axially.

(ii) a high mechanical strength of 13 MPa, owing to the crystalline ordering of the glucan chains of the cellulose fibrils, which is ~50 times higher than cellulose foam and >30 times higher than the commercially used strongest thermal insulation materials;

(iii) low mass density;

(iv) low emissivity from 400 to 1100 nm; and

(v) when the thickness is less than 1 mm, the nanowood slice can be rolled and folded, making it suitable for scenarios that require flexibility, such as pipelines in chemical factories and power plants.

(vi) materials cost analysis to fabricate the nanowood, including raw materials and processing chemicals which can be as low as $7.44/m^2.

Thanks