Transparent aerogels reduce energy loss through building windows

Glass panes have been used in windows since the times of ancient Rome, but they exhibit poor thermal insulation. Aerogels made from silanized cellulose nanofibres are better thermal insulators and more transparent than glass, offering an approach to developing window products to reduce the loss of building heating and cooling energy.

The problem

Commercial and residential buildings consume about 40% of all energy generated globally, most of which is used by heating, ventilation and air conditioning (HVAC) systems[1]. A large fraction of this energy is wasted owing to the poor thermal insulating properties of windows, enabling heat flow between the exterior and interior[1]. Although most windows are double-pane insulating glass units, often with low-emissivity coatings, energy-inefficient single-pane windows are still common[2,3]. To increase the energy efficiency of windows, new insulated window designs and retrofits are needed. Beyond saving energy, thermally insulating glass units and retrofits could also reduce water condensation on windows and improve the comfort of occupants[2]. However, the challenge is developing materials that combine very high optical transparency with a thermal insulation capability comparable to or better than that of still air. Moreover, transparent insulators need to be reliably fabricated at low cost on window-relevant scales.

The solution

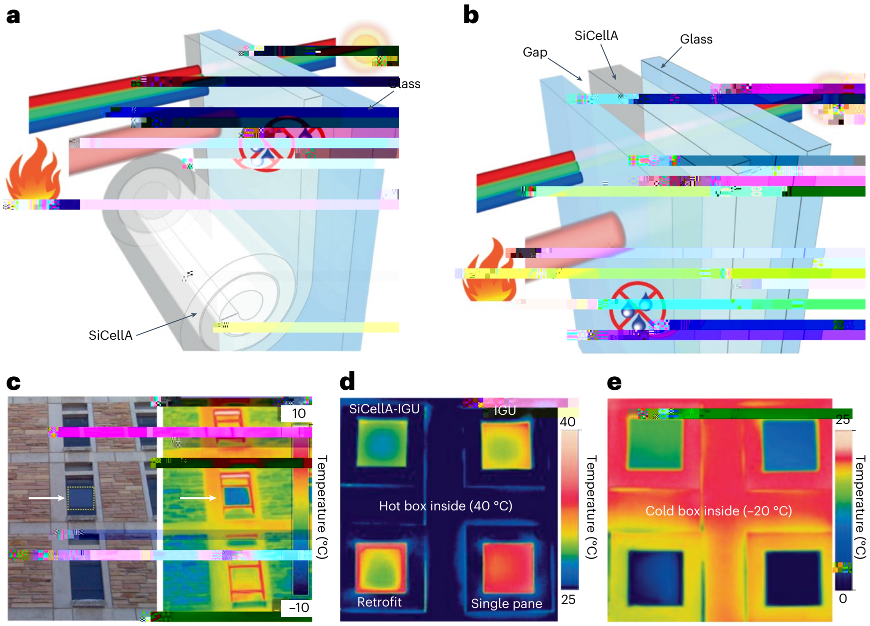
We focused on developing visibly transparent, thermally insulating, mechanically stable and flexible aerogel films to serve as transparent thermal barriers. To achieve this unusual combination of physical properties, we designed and fabricated porous nanostructured metamaterials that contain ~99% air by volume[3]. We then developed and applied window products based on these aerogels and performed physical property characterizations and durability tests.

The aerogels are made from cellulose nanofibres, 4–6 nm in diameter, which can be derived from wood or produced by bacteria in a process similar to one used in the food industry[4,5]. The fibres are then crosslinked in a water dispersion to form a hydrogel, before being converted into an aerogel by replacing the fluid medium around the fibres with air through a carefully optimized procedure involving solvent exchange and supercritical drying. The aerogel films can be adhered to plastic substrates and rolled.

To achieve materials with the desired physical properties, particularly a hydrophobic surface, for window applications, we chemically modified the amphiphilic cellulose nanofibres within the aerogel network. The resultant silanized cellulose aerogel (SiCellA) materials were used to laminate a single-pane window and inserted into the gap of a double-pane insulating glass unit (Fig. 1a,b). By assessing the ability of heat to transfer from the hot to cold sides, we demonstrated that the SiCellA materials improve the thermal barrier performance of windows (Fig. 1c–e).

Furthermore, free-standing slabs of SiCellA have a very high visible-range transmissivity of 97–99%, which is higher than that of clear glass (~92%), and, depending on the thickness, typically have a low coefficient of haze. These properties can be linked to the nanoscale morphology: the fibre diameters and pore dimensions are much smaller than the wavelength of visible-range light, which helps to minimize light scattering. Additionally, the SiCellA-based window products exhibit good stability in various tests and SiCellA increased the condensation resistance of the windows.

Overall, we have developed an aerogel that meets various technical targets for applications in building windows and gained broader understanding of how such trancn8 TJ T* [(alone ac)5(c)5(ounts for 7)25(0 millio
pre-designed transparent insulators,



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