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# Transparent Sodium Silicate Encapsulated Cellulose Nanospheres

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**_Abstract_**

*Transparent cellulose is a research hotspot in current science. Transparent nanocellulose finds applications in energy, environment, defense, catalysis, and medicine. Sodium silicate-modified cellulose fibers were reported to be transparent. There have been various other strategies, like generating sulfate groups on nanocellulose surfaces for inducing transparency in cellulose-based materials. However, the synthesis of transparent nanospheres of cellulose with encapsulated sodium silicate has never been reported in the literature. Here in, for the first time, it is surmised that the cellulose nanospheres encapsulating sodium silicate will outperform any other known morphologies of nanocellulose, for instance nanofibers, leading to efffective light management, especially in the perovskite-based solar cells. Sonochemistry-based approaches to synthesize cellulose nanospheres with average diameters around 50 nanometers have been demonstrated earlier. These nanospheres of cellulose encapsulated with aqueous or non-aqueous substances were used as effective nanocarriers for biomedical applications. In particular, sodium silicate-encapsulated nanospheres of cellulose (SSNSC) were assumed to be a new strategic material that could act as a promising support for nanoyeast buds for accelerating the carbohydrate fermentation process via effective management of the sun's light and heat. It is hypothesized that SSNSC, with their unique spherical morphology, will aid in the solar energy-based fermentation process by acting as an effective light management layer due to enhanced reflections within.*

**Keywords:** cellulose nanospheres, transparent cellulose, light harvesting, solar cells, solar fermentation

## INTRODUCTION

A web of science search with the keywords, namely, transparent and cellulose, yields 3586 results. The results shrink down by an order of magnitude to 818 (as on 24$^{th}$ September 2024) by changing cellulose to nanocellulose, implying that the field of nanocellulose is in its infancy. The growth of the field of transparent cellulose during the past decade (2013–2024) is shown in Figure 1. Though the applications of the transparent cellulose are enormous, in energy and environment and materials science and space exploration, especially for effective solar light harvesting and management, the material is not yet explored to its fullest, as evident from the slow but steady growth of the field (Figure 1) [1–50]. Apart from various other methods, the use of sodium silicate for inducing transparency in cellulose nanomaterials has been particularly appealing [51, 52].

In general, cellulose is believed to be a plant material; nevertheless, it is also produced by certain microorganisms. Cellulose is the most abundant organic, natural polymer on the planet. The polysaccharide in question is a non-toxic, renewable, biocompatible, and biodegradable substance. It is composed of rigid, long linear chains that are attached to D-glucose in a manner that repeats itself from one to four times. Cellulose is insoluble in water and in most organic solvents due to the strong hydrogen bonds that exist between the chains of

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cellulose. This lack of solubility is one of the most significant challenges that the field of cellulose science must overcome. In recent decades, there has been a resurgence in the interest in novel cellulosic materials and composites that are formed from a wide range of cellulosic components. This interest has been fuelled by the pursuit of sustainability and green chemistry. When it comes to the manufacturing of nanoparticles that are suited for nanomedical applications, particularly in targeted drug delivery systems or contrasting agents in imaging techniques, cellulose is the material of choice. Recently, there has been an increase in the use of cellulose in medical devices. Mild acid hydrolysis of cellulose is effective in preparing cellulose nanospheres from discarded textile materials.

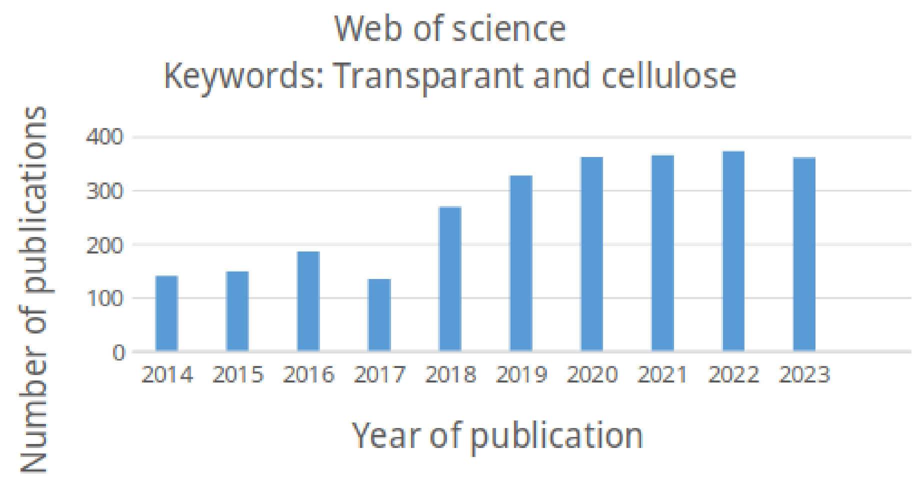


**Figure 1.** Advances in the research and development of transparent cellulose during the past decade (2014–2023).

## METHODOLOGY OF SYNTHESIZING SODIUM SILICATE ENCAPSULATED CELLULOSE NANOSPHERES

Gedaneken et al. reported for the first time the sonochemical synthesis of nanospheres of cellulose under aqueous and non-aqueous conditions for encapsulating organic molecules and demonstrated their utility for the selective conversion of cellulose to glucose. The spherical nanocellulose containers (SCC) prepared from the microcrystalline cellulose shown in Figure 2 were of size ~50 nm and served as an ideal precursor for the selective production of glucose (30 wt.% yield; 70 wt.% conversion of biocatalytic SCC [53]. A good agreement between the particle size measurements from DLS and SEM analysis was observed. A typical sonochemical process for the synthesis of SCC comprises two steps. In the first step, 1 wt.% MCC in water is sonicated for 90 minutes to obtain an aqueous suspension of the nanocellulose. In the second step, 30 mL of the 1 wt.% suspension of nanocellulose is added to organic solvent (20 mL of dodecane shown as a representative example). The contents were sonicated for 3 minutes by placing the sonication tip at the interface of the aqueous and organic layers, resulting in the formation of the nanospherical cellulose containers. The procedure is applicable for encapsulating water-soluble as well as materials soluble in organic solvents in the nanospheres of cellulose. It is surmised that sonication of aqueous nanospherical cellulose suspensions (of concentration < 1 wt.%) in the presence of sodium silicate will successfully entrap a significant amount of sodium silicate to yield transparent nanosperical cellulose containers of sodium silicate with remarkable application in light harvesting.

Such small nanospheres of cellulose, owing to their high specific surface area, lead to enhanced interaction of the substrate surface with the catalyst active site of the solid acid catalyst (for instance, heteropoly acids), and so yield high catalytic activity and product selectivity. Conversion of cellulose to bioethanol is a much-wanted industrial catalytic process for sustainability in the realms of energy [54–65].

 

The shell and the core of the dodecane containing spherical nanocellulose containers (SCC-D) prepared in the presence of either Nile Red or Rhodamine 6G were clearly examined using the fluorescence images shown in Figure 3 using various filters.

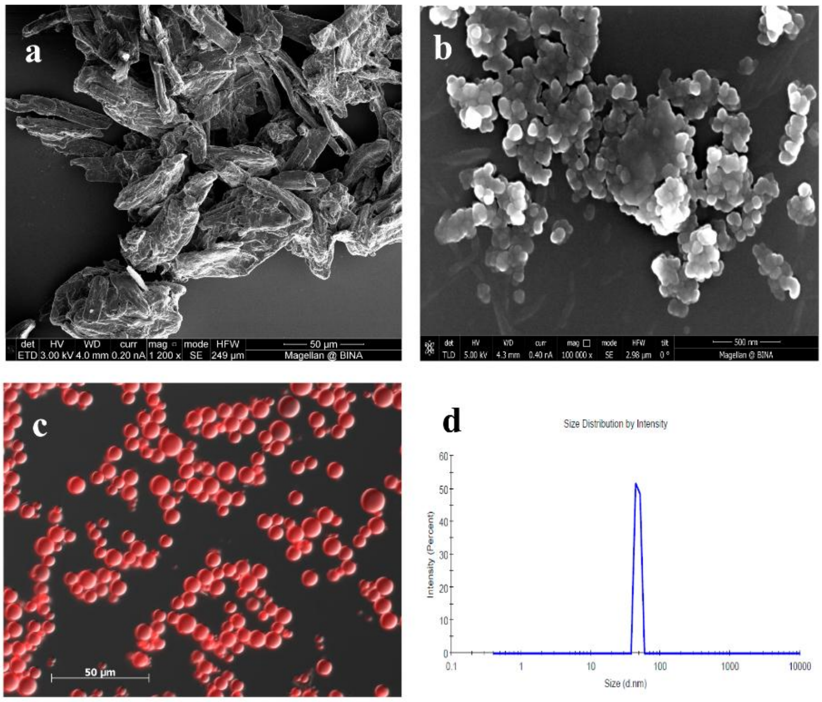


**Figure 2.** (a) High resolution scanning electron microscope (HRSEM) image of microcrystalline cellulose (MCC); (b) HRSEM image of spherical nanocellulose containers (SCC); (c) combined image of white light mode and fluorescence images of spherical nano cellulose container with dodecane (SCC-D) synthesized in the presence of nile red (red signal); (d) Dynamic light scattering (DLS) graph depicting the size distribution of the sonicated SCC-D.

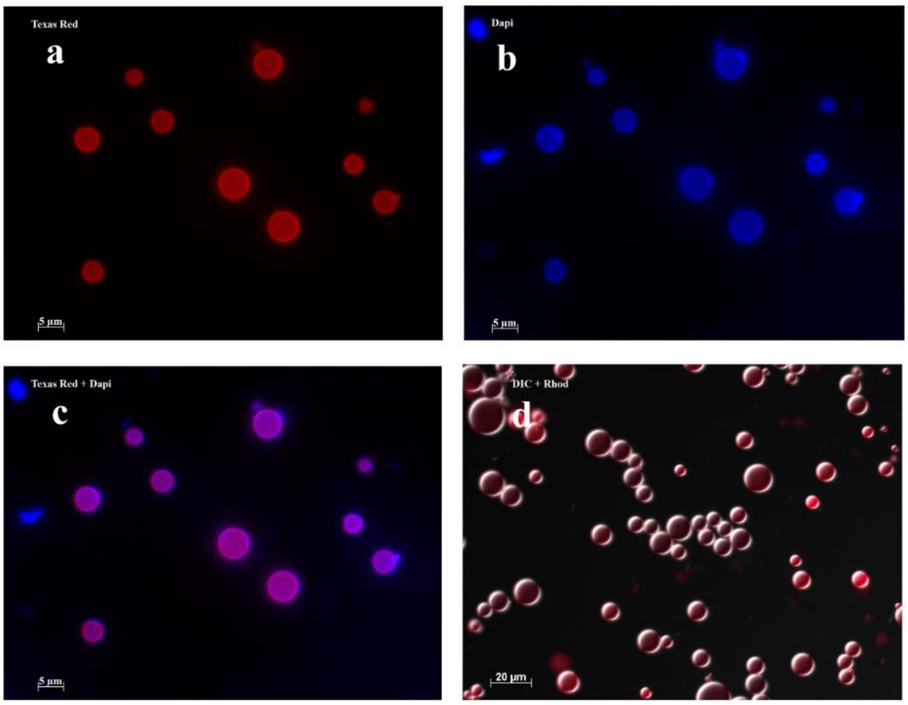


**Figure 3.** Fluorescence images of Spherical Nanocellulose Container with Dodecane SCC-D that were

synthesized in the presence of nile red and then colored with the blue fluorophore, calcofluor white (a−c). (a) Fluorescence image using texas red filter (red signal); (b) fluorescence image using dapi filter (blue signal); (c) combined image of images a and b; (d) combined white light mode image and fluorescence image using Rhod filter of SCC-D that were synthesized in the presence of Rhodamine 6G.

## APPLICATIONS OF SODIUM SILICATE ENCAPSULATED SPHERICAL NANOCELLULOSE (SSNSC)

SSNSC's can be used as a catalytic bed for the adsorption of yeast in a non-competitive manner for an efficient fermentation process. Besides baker's yeast, efficient expression systems, such as the *Pichia pastoris* yeast can be adsorbed to produce biopharmaceuticals, a potential revenue generator for companies, and to help the nation grow. Various kinds of microorganisms can also be supported on the SSNC catalytic system and push them to work and produce compounds of interest. SSNSC's coated with hydrophobic compounds can be used in solar cells, such as perovskites. Encapsulation of sodium silicate within cellulose nanospheres makes it transparent. The spherical morphology may contribute to more efficient light management and as a concentrator. Nanospheres would increase the total available surface area for the adsorption of orphaned yeast particles in a non-competitive manner, which would ultimately result in an efficient fermentation process. Dried Cellulose nanospheres obtained via sonochemical methods and encapsulated with sodium silicate are hypothesized to be stable due to the thermal stability of cellulose as well as sodium silicate. Agglomeration of nanospheres in the dried state is a possibility, but it can be overcome at the point of usage by the application of mechanical methods to separate them.

As it is possible to make cellulose nanospheres (50 nm) using the sonication process, advancing further, it is possible to fill it with sodium silicate and nano $TiO_2$ powder (average size 2 to 5 nm). A large transparent cylinder can be filled with this powder and bacteria- or virus-laden water. When passed through such a column, the solar light will pass through the spheres due to sodium silicate, and it will be interrupted at some points by $TiO_2$ nanoparticles. At those points, $H_2O_2$ will be produced in situ, and it can kill the microorganisms. This arrangement can be used repeatedly for a long time. If $H_2O_2$ is no longer required, it will breakdown and decompose. It is further assumed that in the realm of energy too, especially in the accelerated production of glucose from nanospheres of cellulose, the presence of sodium silicate will play a constructive role. Such ion effects, for instance, the Hofmeister ion series, are well known in protein chemistry.

## CONCLUSIONS

Sonochemical irradiation is a proven technique for the synthesis of nanomaterials, including those in the biological world, namely, nanoyeast and nanocellulose. Strategies for the synthesis of spherical nanocellulose containers for encapsulating exotic molecules like sodium silicate for light harvesting applications in the realms of energy and environment are demonstrated with specific case studies. Such exotic nanocellulose-based composites can be used as support for nanoyeast for solar energy-driven fermentation processes, apart from being used in solar cells.

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