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Review

A Comparative Analysis of Standard and Nano-Structured Glass for Enhancing Heat Transfer and Reducing Energy Consumption Using Metal and Oxide Nanoparticles: A Review

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Abstract: The thrust to find new technology and materials has been greatly increasing due to environmental and technological challenges in the progressive world. Among new standard materials and advanced nano-materials that possess a huge potential and superior thermal, mechanical, optical, and magnetic properties, which have made them excellent and suitable components for mechanical engineering applications. The current review paper deals with recent enhancements and advances in the properties of nano-structured glasses and composites in terms of thermal and mechanical properties. A fabrication method of nano-structured glass has briefly been discussed and the phase change material (PCM) method outlined. The comprehensive review of thermal and optical properties confirms that nano-fabricated glasses show both direct and indirect running of band gaps depending on selective nano-structuring samples. The electrical and magnetic properties also show enhancement in electrical conductivity on nano-structured glasses compared to their standard counterparts. The realistic changes in thermal and mechanical properties of nano-structured glasses and composites are commonly attributed to many micro- and nano-structural distribution features like grain size, shape, pores, other flaws and defects, surface condition, impurity level, stress, duration of temperature effect on the selective samples. Literature reports that nano-structuring materials lead to enhanced phonon boundary scattering which reduces thermal conductivity and energy consumption.

Keywords: glass; nano-structured; phase change material (PMC); graphene oxide (GO); carbon nanotubes (CNTs); nanoparticles (NPs); thermal, mechanical, temperature and energy

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1. Introduction

Due to the high demand for energy as a result of the rapidly growing economy, conservation of energy is becoming increasingly important, particularly in the building sector, which uses a lot of energy to perform certain activities and maintain the interior atmosphere [1,2]. Because the building envelope consumes the majority of energy in the area of architecture, glazing units, as an integral aspect of the building envelope, are considered to be important determinant of improving energy efficiency [3]. Buildings are regarded as a large energy-consuming sector, using enormous amounts of energy for room heaters and air conditioners to provide a suitable interior atmosphere [4]. Buildings account for 30–40% of global energy use. Visual comfort and thermal comfort of the building is entirely based on windows. Windows were considered as significant contributor of visible light. Thermal transmittance of building were modeled based on the selection and design of windows and proper design of windows lowers the overall energy consumption of building [5]. The passage of infrared rays and absorption of sunlight is mainly done through windows. The overheating of buildings and other industrial spaces is mainly due to transparent surface in the buildings [6]. The continuous impact of global climate change will only lead to an increase in the usage of artificial heating and cooling systems. Thus, thermal comfort is critical in buildings, demanding proper selection and design of windows from a variety of perspectives, including aesthetic comfort and energy use [7]. In order to improve building energy efficiency, the usage of new building construction materials is growing in popularity in both the industrial and residential sectors [8,9]. The development of technology to improve building energy efficiency is now given a lot of attention. By using the building's energy-efficient systems into use, peak power may be reduced or shifted to off-peak hours [10]. Researchers have developed a keen interest in the use of phase change materials (PCMs), a novel technology that may be incorporated into buildings to lower their heating and cooling loads [11–13]. Universally used construction materials include sand, wood, bricks, cement and aggregates store heat energy in the form of tangible energy. These construction materials have very low volumetric energy storage density. In order to address these problems, it is possible to increase human comfort and save energy by incorporating phase-changing materials with a high volumetric energy storage density into building materials like concrete and bricks [14]. Heat waves created due to high temperatures and solar radiation during summer daytime permeate the heat waves into the buildings. The delay in the release of heat into the buildings is done by incorporating phase change materials integrated with the building envelopes [15]. Phase change materials absorb the heat and lower the heat wave during daytime in the building structure. Due to this temperature remains less inside the buildings and makes the humans comfort during the daytime, therefore it requires very minimal energy for the cooling system [16–18]. The heat energy stored in the phase-changing material during day time releases heat when there is a drop in temperature (night). Comfortable room temperature was achieved due to the release of heat energy and completes the cycle process [18].

NPs has widespread use in the construction industry. The incorporation of NPs as a building material improves the properties of concrete. Integration of NPs with PCM improves the thermal comfort of buildings and it reduces the artificial heating and cooling loads [19,20]. Glass technology reached its heights owing to its application in various fields. In specific, the cutting-edge efficient glass plays a crucial role in the modern construction field. Among the several developments, flat panel glass technology revolutionized the entire electronic field [21,22]. Discovery of the flat panel created a huge bloom in electronic displays. In follow up of the above, new glass materials are discovered to make it more comfortable for the consumers and user friendly. In recent days, folded displays, curved displays and other glass displays gained ample interest [23]. In addition to above it is mandated to design glass materials with high safety requirements. Laminated glass provided more resistance to the breakage owing to its sandwich construction. Smart glasses possess a great advantage for the energy sector. Due to their transparency and reflective ability, they are massively used in interactive surfaces [24].

The three popular categories of glass are standard, ceramic and nano-structured glasses. Standard glass is made of silica-based materials. The usually used on windows, lenses, and optical fibers due to its transparency [25]. Ceramic glasses are made of metal oxide which indeed has high strength, hardness and thermal stability [26]. Nowadays they are effectively used on ceramic knives, furnaces and other refractory materials. Nano-structured is an advanced glass technology. It is made of unique nanoscale properties. These nano glasses have a huge scope in the biomedical and optical field applications. Based on the required application nowdays the glass materials are re-engineered [27,28].

Nanotechnology's role in the glass industry is immense. Based on the requirement, the glass materials can be manufactured. The role of nanomaterials in glass technology is high. For instance, to enhance the thermal property of the glass with high mechanical strength SiO_2 has been used [29,30]. For ceramic-based glass, Al_2O_3 NPs have been used to improve thermal stability with superior mechanical strength and hardness [31]. In addition to the above, SnO_2 and ZnO metal oxides are also used to improve the property of the glasses. Use of the metal oxides in the glass material improves both the electrical and thermal conductivity of the glass [32–34]. These glasses are highly used in the electronic and energy applications. On the other hand, in recent days there was extensive research made on the non-metallic NPs such as carbon nanotubes, graphene, . . . etc. (see Figure 1). Carbon nanotubes are the tiny atoms used to improve the mechanical properties of the reinforced glass [35]. Graphene used to enhance the transparent conductive coating [36]. From the above, it is clear that nanomaterials plays a huge role in altering the properties of glass materials with the help of, transparent conductive coatings, thermal insulating coating, smart windows, and energy-generating windows [31].

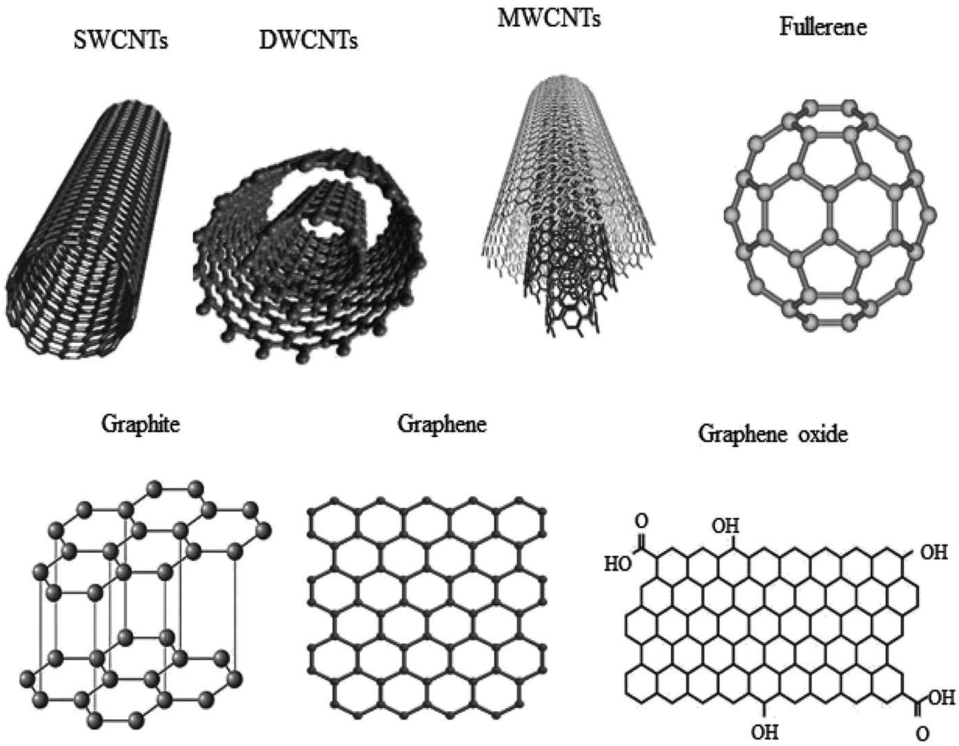

Figure 1. Schematic-representation of single-walled carbon nanotubes (SWCNTs), double-walled carbon nanotubes (DWCNTs), multi-walled carbon nanotubes (MWCNTs), fullerene, graphite, graphene, graphene oxide.

2. The Critical Role of Nanotechnology in Enhancing the Efficacy of Thermal and Mechanical Properties of Glass Materials

Nanotechnology or nanoscale science, as it is commonly known, has been considered a fundamental component of glass technology since its discovery. Modern technological applications of glass in diverse fields such as engineering, medicine, energy, communication and medicine, and communications are crucially dependent on our appreciation and awareness of the intrinsic connections between glass and nanotechnology [37–41]. Understanding the realistic mechanism of glass fabrication at the nanoscale size has recently been proved and a huge number of nano-materials applications have widely been studied and investigated, especially in mechanical engineering, i.e., the thermal and optical distinct properties of glass treated at the nanoscale size [42–48]. This has led literally to insight into the thermal and optical properties of the glass structure, band and micro-crack theories, surface modification, and controlled crystallization [49–56]. We review the fundamental theories and aspects to draw primal attention and their role in connecting both contemporary and future engineering glass devices. Despite not even intentionally noticing this fact, the most interesting behaviors and useful techniques of glass have been born at the nanoscale sizes.

2.1. Standard Glass

Standard glass is called as the soda lime glass [57]. Over the year's research and development in the standard glass material, nanotechnology plays a huge role in the fabrication of standard glass. Using nanotechnology in the standard glass modifies the properties and performance of the glass. One of the key innovations in the history of the standard glass is the use of sodium carbonate along with the glass materials [58,59]. Followed by them, calcium oxide has been to increase the strength and durability of the glass materials. By exploring the coating methods and materials the standard application in the various sectors has been widen massively [25,60]. In recent days, government policies are very strict regarding the degradability of glasses and recycling of glass materials. By using the sustainable technology, the glass materials can be more easily recycled. Although there are plenty of innovations available so far, still the research and development on novel glass materials was immensely required due to the massive usage of glass in several areas [61]. This is only possible by continuous innovations and development. By continuous innovation in the nanotechnology, the demerits of glass materials can be decreased [62]. Standard glass is widely used but it has its own limitations due the factors such as fragility, poor insulating properties, optical distortion, UV degradation, temperature tolerance and environmental impact. Standard glass is highly fragile, hence handling and storage of the glass is very difficult. Further, use of the fragile glass material in real-time creates safety concerns. Besides, they are also poor in insulation hence they can be used in cold and hot conditions [63]. Due to the poor optical distortion, the use of the think glasses affects the transparency of the materials. All these effects can be addressed by the application of advanced nanomaterials in the standard glass materials fabrication [64]. Genaro Correa and Rafael Almanza et al. [65] investigated the different window materials in order to improve thermal comfort and energy savings. Three different layers were incorporated into soda lime glass to enhance the thermal performance of buildings including Cu_2O, CuS + Cu_2O, and Cu + Cu_2O. The heat transmission through the second and third glass material is reduced and showed a significant control on infrared irradiance. These windows reduce the thermal load within the building by allowing the transfer of around 50% of heat under hot weather conditions. During the winter season, 50% of the heat loss was cut down using the same windows, minimizing heat loss and enhancing the comfort. Planar magnetrons were used in the sputtering process to create the thin layers [65]. Haoyu Wang and Chengwang Lei et al. [66] investigated the combined water wall and solar chimney for thermal comfort and building ventilation using numerical analysis. The water wall assembly was made up of soda lime glass, the standard glass used commonly in all building windows. CFD simulations are used to evaluate the effects of key design factors such as water column thickness, air gap width and glass panel thickness. The findings indicate that the combined system can maintain a room's daily average temperature of 4.8 degrees above ambient while delivering 4.1 air changes per hour on average daily ventilation. By incorporating solar control tinting to the water wall assembly or reducing the thickness of the glass panels the combined system's overall performance may be further enhanced. As a result, improvements in the ventilation rate and average room temperature of up to 7.3% and 5.2%, respectively were achieved. A 0.1 m increase in water column thickness results in a 4.9% or greater improvement in ventilation. The ventilation rate is improved by 13.9% when the air gap width is increased from 0.1 m to 0.2 m, with little to no change in the average room temperature. Further widening the air gap has a negligible effect on ventilation rate [66].

Shazim Ali Memon et al. [67] investigated the effects of waste glass powder on heat storage purposes in buildings. Waste soda lime glass powder was impregnated by n-octadecane and the maximum retained n-octadecane on glass powder was found to be 8%. The composite material was prepared using waste glass powder and PCM and assessed for thermal performance. The freezing and melting temperatures of PCM and waste glass powder composite were found to be 25.030 °C and 26.930 °C respectively. The composite material is reliable and thermally stable which was confirmed using thermal cycling and

TGA analysis. The indoor temperature was found to be 3 °C lower when cement paste with waste glass and PCM was used in the buildings [67]. Chiara Molinari et al., assessed the thermal performance of soda lime glass scraps and PCM-impregnated tiles. In the range of 0.6 to about 1.2 g/cm^3, the specimens before impregnation possessed higher thermal conductivity and that after impregnation possessed lower thermal conductivity; and in the range of about 1.2 to 1.4 g/cm^3, the specimens before impregnation possessed lower TC and that after impregnation possessed higher thermal conductivity [68]. Hyun Koo et al. [69] investigated the effects of buffer layers on thermochromic properties of soda lime glass. By taking into account the buffer layer material having structural similarities with VO_2, it is possible to build VO_2 films on soda lime glass at low temperatures with outstanding thermochromic characteristics. ZnO can be one of the most efficient buffer layer materials since the degree of crystallization of the buffer layer is also connected to that of the VO_2 film [69].

Previous literature releveled that use of nanotechnology helps to improve the optical and mechanical properties of glass. For instance, the inclusion of the TiO_2 improves the ultraviolet ray's resistance [59,60]. Furthermore, the thermal stability of the glass has been massively improved with use of nanotechnology. Similar to the above, SiO_2 NPs widely used in the standard glass to improvise the scratch resistance and transparency. Furthermore, optical, mechanical, and self-cleaning properties are the key parameters that help the standard glass to capture the market in the energy sectors [57]. With introduction of the nanotechnology in standard glass, properties such as optical, mechanical, and self-cleaning properties are massively improved and which helps them to act as self-cleaning and smart windows materials [32].

2.2. Ceramic Glass

Ceramic is another popular glass made of both ceramic and standard glass materials. These glasses are potentially used for the high-temperature applications [70]. Furthermore, they also used in applications where the requirement of durability and strength is higher such as thermal shock applications [71]. Owing to it high-temperature tolerance, they are used extensively. Ideally, standard glass is highly brittle and can break at high temperatures. By mixing the ceramic materials with the standard glass materials, the working temperature of the materials increased to more than 1400 °C. Hence these ceramic glasses are widely used in kitchen appliances. Ceramic glasses are made of ceramic, silica, lime and soda. Ceramic glass has been fabricated by melting the raw materials around 1500 °C to form the homogenous mixture [72,73]. After melting they were poured into the mold and allowed to solidify and cooled steadily. After the annealing process, the molded glass cut and shaped as per the requirement. Before transporting they undergo etching, polishing and other treatments to enhance their durability and performance [74]. Enríquez et al. [75] investigated the use of glass ceramics on lower thermal diffusivity and high albedo to achieve energy savings and the effect of urban heat island. Glass ceramic was developed using one step ceramic process. To decrease thermal conductivity, enhance the sun-reflecting characteristics, and boost specific heat, a tile laminated with a novel glass-ceramic substance has been developed in this study. To get low thermal diffusivity materials for effective cool roof applications, these three factors are essential. A high reflectivity in the NIR band, which is extremely beneficial for colored materials, is added to the improvement of solar reflectivity. Together with enhancing the albedo, these combined qualities also helped to increase the structures' internal thermal comfort. As a result, a significant energy reduction of over 20% is calculated in contrast to traditional ceramic tiles [75].

Compared to the standard, ceramic glasses are several times stronger hence they are highly resistant to the impacts which these glasses are also used in building skyscrapers. Another added advantage of the ceramic is, it blocks the UV radiation [76]. Owing to all these extensive properties they become one of the essential materials in the industrial, commercial and residential sectors. Although ceramic glasses have numerous applications, still they need huge advancements and innovation to make them as sustainable [77].

Ceramic glass is high cost compared to standard glass. Hence the economic viability of the ceramic glass is still a concern. Added to the above, they are heavier and less transparent than regular glass. Despite the high strength and durability, fragility is still existing [78]. During transportation the breakage of such glass is highly viable. Overall, ceramic glass offers many benefits, but its high cost and fragility remain challenges that need to be addressed in order to make it a more sustainable material [79].

2.3. Oxide Glasses/Oxide Coatings

Oxide glass is a typical type of standard glass made of metal oxides. As discussed above, standard glass has numerous disadvantages to overcome this, metal oxides are added to the glass mixture [80]. Using the metal oxides in the glass materials enhances the physical and chemical properties of the glass. Among various oxides, aluminum, iron, silica and boron are the widely used oxides in the fabrication of the glass material. Oxides glasses are fabricated by melting, casting, fusing and sol-gel methods [81]. These glasses are widely applied in optical fibers, solar, flat displays and optical lenses due to their high refractive index, transparency and low thermal expansion. Oxides glasses distinguish themselves compared to ceramic due to the following reasons such as lower thermal expansion, high chemical stability, cheaper, high transparency and superior electrical conductivity [82]. Furthermore, oxides glasses can be easily molded into different shapes. However, there are not relatively cheaper than standard glass. During the fabrication of the oxide glasses, depending on the purity of the metal oxides the cost of fabrication increases. Since the oxides are difficult to process at high temperature, the fabrication needs specialized equipment. Oxides glasses are highly sensitive to temperature, humidity and they can break under mechanical stress [83,84].

Another major concern in the oxide glass was environmental impact. Since metal oxides are prone to the environment, there is a limitation in the production and recycling of the waste is tedious. The impact of metal oxides used in the fabrication is high. Disposal of the oxide glass leads to environmental pollution due to the presence of slag and other by products. Oxides like boron are highly toxic to plants and animals. Hence it is mandatory to recycle them before dumping them in the waste yard. Oxide glass also generates greenhouse gas emissions during their production. Despite these cons, the future of oxide glass is bright in the optics, photonics, energy and environment, display technology and biomedical [85]. In summary, oxide glass is a type of standard glass that has been modified with the addition of metal oxides to improve its physical and chemical properties. This glass is widely used in various fields due to its high refractive index, transparency, low thermal expansion, and superior electrical conductivity. Although oxide glass has some disadvantages its future is optimistic. Overall, oxide glass is a versatile material with a bright future ahead [86]. Anurag Roy et al. [87] assessed the building thermal comfort discernment using graphene oxide coating. In their study, flexible graphene oxide coatings were developed to act as a thermal absorber in buildings. Graphene oxide coatings were applied on aluminium-based substrate and exposed to direct sunlight. Graphene oxide coatings were used to maintain the stable temperature inside the buildings when the outside temperature is very less. At 1 SUN 1.5 AM condition, it was found that the temperature inside the buildings always remains higher than the outside temperature due to the application of graphene oxide coatings. During the light exposure time, outside and inside temperature difference were significantly higher, whereas the temperature difference is very low during nighttime. Investigation of different factors includes moisture, temperature, water resistivity and flexibility in using graphene oxide coatings were studied in this research [87]. Hung-Tao Chou et al. [88] assessed the energy efficiency of hydro-gel and graphene oxide-based smart glass. In this research, smart glass with the ability to automatically modify transparency was built to save energy use by blocking sunlight from entering a structure.

The photothermal conversion material graphene oxide (GO) combined with hydrogel, can efficiently convert solar energy's photo energy into thermal energy, causing the smart glass to become opaque due to the hydrogel's increased temperature. This lowers the ambient temperature and incident solar energy intensity. Moreover, the colored organic solvent is absorbed by the GO contained within the thermotropic hydrogel, giving the smart glass variable color [88]. F. Stazi et al. [89] investigated the durability applications of different glass coatings and their impact on thermal comfort and heat light transmission. Metal oxides-based glass coatings were incorporated in this study. Aging had a significant impact on the optical and energy characteristics of silver-based coatings, and on the solar control film with the greatest Ag percentage, an artificial saline treatment resulted in an unacceptably low daylighting factor. On the other hand, environmental effects and the examination of energy usage revealed that Ag-based coatings, even after aging, had the highest performance due to their extremely high solar selectivity qualities under the initial circumstances. The synergetic application of vanadium dioxide and PCM enhances the thermal performance of buildings more than solo ones [89]. Linshuang Long et al. [80] utilized PCM and vanadium dioxide to improve the thermal performance in transparent and non-transparent parts respectively. The energy saving index was used to assess the energy performance of the materials. It was found that, in cold locations, neither the solitary application of VO_2 nor the combined application of VO_2 and Phase changing material was a bad choice due to the negative ESI throughout the heating phase [90].

2.4. Nanofabricated and Nanostructured Glasses

Nanofabricated and nanostructured glasses are the class materials which is widely popular due to their unique optical, mechanical and thermal properties. These materials' properties are altered by changing their structure at nanoscale [91]. These glasses can be made using sol-gel, vapor deposition and electrospinning methods. By changing its structure, their properties can be improvised. This glass has high transparency, optical and thermal properties compared to conventional glasses [92,93]. These glasses have potential applications in optics and photonics applications. In addition, there are widely used in the energy environmental application in the production of photovoltaic cell. The production of solar energy depends on the nature of the photovoltaic cell, these nanostructured glass increases thermal stability and which helps the photovoltaic cell to convert sunlight into chemical energy. In the field of electronics these glasses are widely popular [94,95]. Used in the application of high-performance electronic devices including diodes and transistors. Due to its unique properties, these glasses are highly fragile and impact resistance is poor. Hence the usage is limited.

Furthermore, the fabrication of these glasses required specialized equipment. Apart from the above, these glasses have issues related to the cost of production. Fabrication of the nanostructured glasses is highly expensive and special instruments are required to manufacture them [96]. In addition, the production of glass is limited due to the lack of innovations and scalability issues. During the production cycle, hazardous chemicals are used and proper disposal is needed to avoid the environmental effects. Due to its small size reliability, compatibility and stability are the major concerns. These are the major barrier to be addressed in future research [97]. Extensive further research is needed to address these barriers and exploit the full potential of nanostructured glasses. Serious of research works are needed on the nanostructured glass making owing to its wide range of applications. Nanostructured glasses possess improved mechanical strength than other conventional glasses [43]. They made of small size complex structure which enables them to increase their strength and toughness with enhanced optical properties. High refractive index and optical dispersion help them for superior optical properties. Due to their size and enhanced surface are they can be used as the catalysis for energy application to increases the functionality of any application [45]. Hanna kim et al. [98] utilizes polymer nanofiber technology to improve the radiative passive cooling. The proper size and shape nanomaterial improves the solar reflectance ability. In this study transmission and scattering characteristics of polyacrylonitrile nanofibers were investigated. The efficient solar scattering was achieved on nanofibers with ellipsoidal beats. Despite PAN's inherent IR absorption, this advantageous scattering reduces the quantity of material required to achieve above 95% solar reflectance, enabling high infrared transmission. By coating a reference blackbody surface with beaded nano-polyacrylonitrile, this study further illustrates how nano-polyacrylonitrile can enable surface cooling with comparatively low solar reflectance. This design may drop the black surface's temperature to as low as 3 °C below the surrounding air temperature during the peak hours [98]. Saeed Alqaed et al., compared the energy efficiency of PCM and nano PCM materials in buildings. $CSxWO_3$ was used as a nano PCM in different proportions ranging from 0.25 to 1.0% weight at an interval of 0.25. 0.5% weight of NPs incorporation in PCM enhances the thermal performance of buildings [99].

3. Nanotechnology of Self-Cleaning Glasses

Self-cleaning glasses are popular nowadays especially, in the Middle east countries owing to the presence of high particulate matter in the atmosphere. Self-cleaning glasses have the highest potential applications in solar panels and building facades. Due to the dirty air, the glass structures need heavy maintenance [100]. To maintain the cleanliness of the glasses huge resources were spent for highly polluted countries. Further, using the surfactants to clean the glasses ended up in the environment which obviously polluted the environment, hence the self-cleaning glass coating has the highest potential based on the wide range of applications. Self-cleaning glasses have ability to clean the dirt of their own and which require minimum maintenance [101]. By advancing the nanotechnology in the glasses with fine coating, the self-cleaning property of the glass can be introduced. Implementation of such glasses reduces the cleaning cost and saves tons of resources in the long run. Recently the study has concluded the TiO_2 nanoparticle role in the self-cleaning glass. TiO_2 is hyperbolic in nature, this ensures the photocatalytic property. In the self-cleaning glasses, the property of the hyperbolic is crucial [102]. Hydrophilic properties play an essential role in the production of glass with self-cleaning. In general, the coating is done on the glass surface via chemical vapor deposition method. Chemical vapor deposition method is a material processing technology where thin films are formed with the help of gas phase precursors [103,104]. In chemical vapor deposition method, the product self-assembles itself and coats the substrate. In general, there are three different parts of coating chemical vapor deposition method, chemical bath deposition, and electrochemical deposition [105]. The chemical vapor deposition method process uses an electric field to charge the liquid and the collected liquid particles are coated over the glass due to the combined effect of anode and cathode in the electric field. Electrochemical deposition is a cheap and simple process due to the absence of temperature and pressure. Further, this type of technology is cheaper. On a positive note, this method can be applied even to composite materials. The most popular method of this was the anodization method. Here, the anode is used as a coating element [106,107].

Similar to TiO_2, another popular nanoparticle used in the self-cleaning glass coating was vanadium dioxide. University College of London (UCL) found this nanoparticle which can be used as the coating element for the self-cleaning material. UCL team determined that the building heating cost can be reduced by 40% by using these glasses. Vanadium proved to be high resistance to water particles owing to its morphology structure. Vanadium NPs are in the form of conical shape, which does not allow the water to stay on the glass surface. Further, during the rainfall the water collects the dust present in the glass without leaving any traces of dirt or markings [108]. On the other hand, vanadium also prevents sun radiation from penetrating inside the building. Due to the high penetration of the sunlight inside the building, the cooling effect of the air conditioners required more effort. By using the nanoparticle-coated glasses the sunlight infrared radiation can be minimized. Coating the vanadium in the window glasses ensures no thermal radiation escapes from the room [109]. During cold winters the temperature inside the room is maintained without any effect on the atmosphere. Similarly, during summer the penetration of the sunlight is also avoided.

Self-cleaning glass uses two processes to clean the presence of dirt on the surface by being photocatalytic and hydrophilic. In photocatalytic, the NPs act as a photocatalyst. During the summer, the sun's radiation hits the glass surface due to which the electrons are produced owing to the influence of the NPs coating. These electrons convert the water content from the atmosphere to the hydroxyl radicals. These produced radicals broke the carbon dirt into fine pieces hence they can be washed easily even in the rain without much effort. Another important process is hydrophilic, Due to the generation of the hydroxyl radical, the glass becomes hydrophilic. With the hydrophilic the dirt particles even with fine fragments were cleaned and wiped without leaving any traces or markings [110].

Pilkington is a commercial producer of self-cleaning glasses for both solar and energy buildings. They are divided into many categories based on the protection they provide. The coating works by the dual action method. The coating reacts to the sunlight and allows the dirt to break down into loose particles [111]. Which indeed leads to the removal of the dirt without any presence of impurities in the glasses. It also reduces the streaking. These glasses cut the window cleaning cost and also help in reducing the heating cost. These pilkinglton designed the glasses in such a way that, when rain hits the glass surface they roll over the surface and pick up the dirt and other particles present in the glass and wash them away. This characteristic behavior is viable due to the nanostructures profile of the coating. By coating the glasses, the marking of the dust particles can be also avoided. By using the coating of 5 to 10 nanometers, more energy cost-cutting is possible. In addition to cleaning, these glasses also provide anti-glare support. It minimizes the light reflection in the building, which indeed increases the physical comfort of the building occupants [112].

Another key coating method is colloidal sol-gel. Coating the glass surface with the colloidal sol gel provides the scratch resistance with dust reduction. These coatings are done by wet chemical methods such as spray, dip, and atomizing. The nanomaterials are coated above the surfaces, and it is allowed to cure for at least one day to form the ultra-thin coating above the surface, which indeed acts as a protective shield.

4. Polymer Glass Coating

In the polymer coating, the hyperbolic polymers are highly preferred. The main polymers used for the coating include polydimethylsiloxane (PDMS), polymethylmethacrylate (PMMA), and polytetrafluoroethylene (PTFE). Among the top three, PDMS is used widely owing to its low reflective index and transparency [113]. Further, PDMS also provides a very good view even at regions of high ultraviolet rays. The transparency of the glass depends on the materials coated on the surface. In addition, the process of the coating method also plays a crucial role. The dip coating method is widely used due to its high homogeneity and transparency [114]. Further, they also possess uniformity on glass substrates. PDMS coating via dip provides more than 90% of the transparency [115].

5. Superhydrophobic Coatings on a Glass Surface

Two types of methods used for the preparation of the glass surface for the super hydrophobic coatings, top-down strategy and bottom-up strategy. In the top-down strategy, acid etching, plasma etching, and laser etching. Besides on the bottom up, template transfer technology, sacrificial template method, electrospinning, magnetron sputtering, Chemical vapor deposition method and sol-gel method. In the top-down strategy etching methods and photolithography has been used mostly. Under the etching methods, acid, plasma and laser [114]. In the bottom-up strategy, the materials used are organic such as plant residues including leaves, and animal skin. This is applied for high superhydrophobicity and anti-reflection characteristics.

5.1. Dip Coating

In the dip coating the substrate is immersed into the coating materials. The thickness of the coating depends on the density, porosity, viscosity and dipping speed. Usually, the coating is done up to 50 um. Increasing the coating above 50 um deters the transparency of the glass. Three crucial factors in the dip coating are immersion compounds, dip time and removal. Figure 2 shows the process of dip coating. Dip coating is most popular owing to its simple construction. These methods are highly reliable. However, the unbalanced coverage of the substrate creates numerous problems in the glass surface quality. The above negative effects can be reduced by ensuring the effective coating practice [107]. During coating the substrate must be free from the dust particles. Further, the dip time needs to be followed based on the coating thickness. Most importantly the excess coating materials must be drained. Dip coating works based on the gravity and surface tension of the coating. In addition, the viscosity and inertia force also play a wider part in the dip coating. The major drawback of using dip coating is time. Dip coating consumes high time due to its slow curing process. However, they can be applied to complex parts. Using the silica NPs increases the anti-fogging properties of the glasses with the help of superhydrophilic [116].

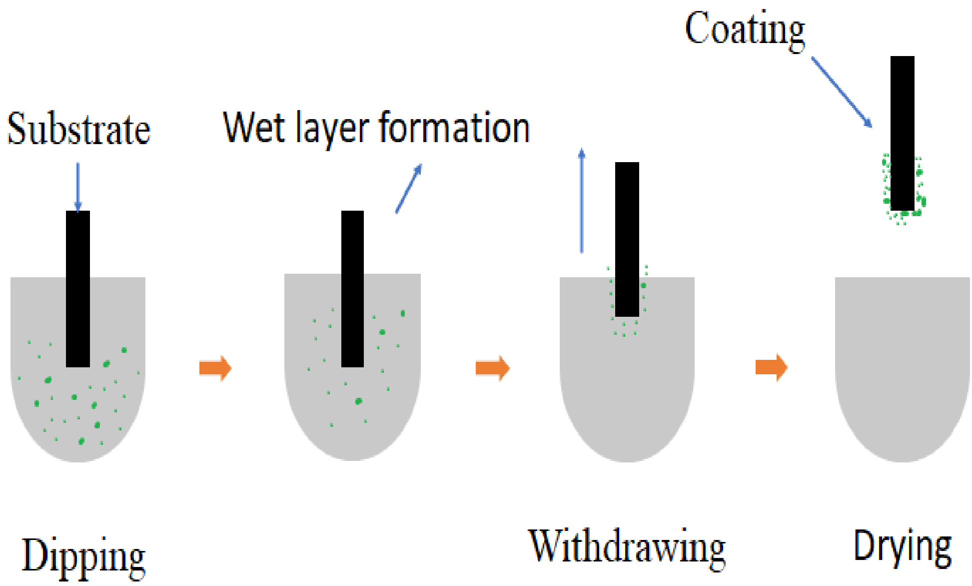

Figure 2. Dip coating process.

5.2. Spin Coating

Spin coating is the most common method used to coat the substrate as thin films. Figure 3 shows the process of spin coating. This process is divided into four different steps such as deposition, spin up, spin-off and evaporation. The coating is carried out with the aid of centripetal force and surface tension. The loaded solution was able to rotate at high speed and spray the substrate to the glass surfaces. The excess of the coating materials available in the glass surface evaporated. This type of method is only used when a thin film coating is required. Higher the spin speed thinner the coating layer [116]. Furthermore, due to the high-speed spinning, evaporation takes place throughout the entire process. Due to the evaporation, the presence of the volatile compounds in the surface will be removed easily. Although the process is simple, using them for large-scale applications is challenging. Both polymers and biomaterials prefer spin coating. The coating effectiveness depends on the environmental conditions, consumables, cleanliness of the substrate, and uncertainty of the equipment's. Most of spin coating uses the static dispense method to dispense the chemical on the substrate [117]. The chemical is purged into the substrate using the syringe until it covers 50% of the diameter of the substrate. After filling the substrate by 50%, the spreading takes place with the help of rotation. During rotation, the excess materials are cast off and ensured no excess materials enter the substrate. At the final stage, solvent evaporation and edge bead removal. In recent days, dynamic dispenses are highly preferred compared to static [118]. Dynamic dispenses are highly consistent and reduce time. Further, the wastage of the chemical is lower.

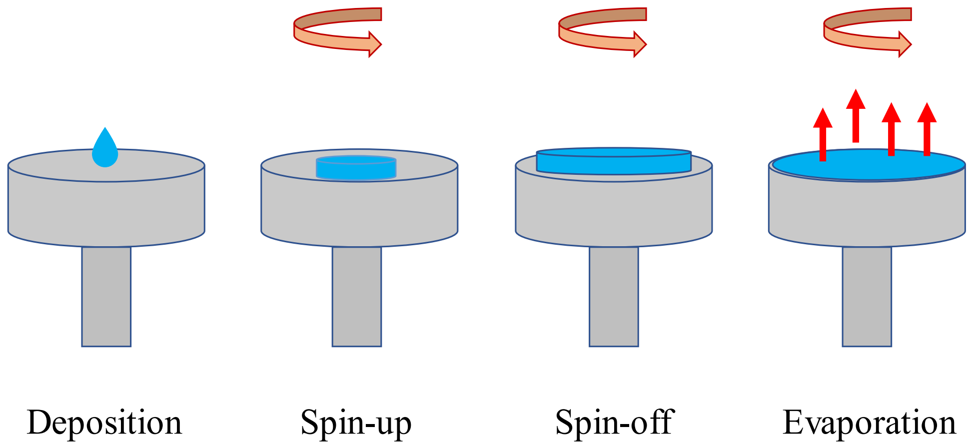

Figure 3. Spin coating process.

5.3. Magnetron Sputtering Deposition

Sputtering is a kind of plasma deposition process which utilizes the ions to strike the surface. It uses the closed magnetic field over the target surface. Figure 4 represents the magnetron sputtering deposition. Magnetron sputtering is the deposition technology which uses plasma. The liberated ions from the target travel via vacuum and deposit in the surface as the thin material. In this method, initially the chamber changed to the high vacuum section and the gas purged inside the cylinder using the pressure controller. High electric voltage is supplied to form the plasma gas between the cathode and anode to create ionization of inert gas. Due to the collision of the ions, the target ejected into the surface of the substrate [119]. As the magnetic field is higher the density of the plasma is also high which eventually increases the rate of deposition. Sputtering method uses argon as the operating gas. This method is usually applied for thin film deposition. The major advantages of this process are high deposition rate, coverage ratio, high purity films, uniform coating and low temperature. There are two types of sputtering, RF and DC. DC magnetron sputtering applied high conducting materials and non-insulator materials [120]. Whereas, RF applied to low conducting and insulator materials. Very low deposition rates and high cost are the major barriers of the sputtering coating process. Further, this process requires a high vacuum during coating.

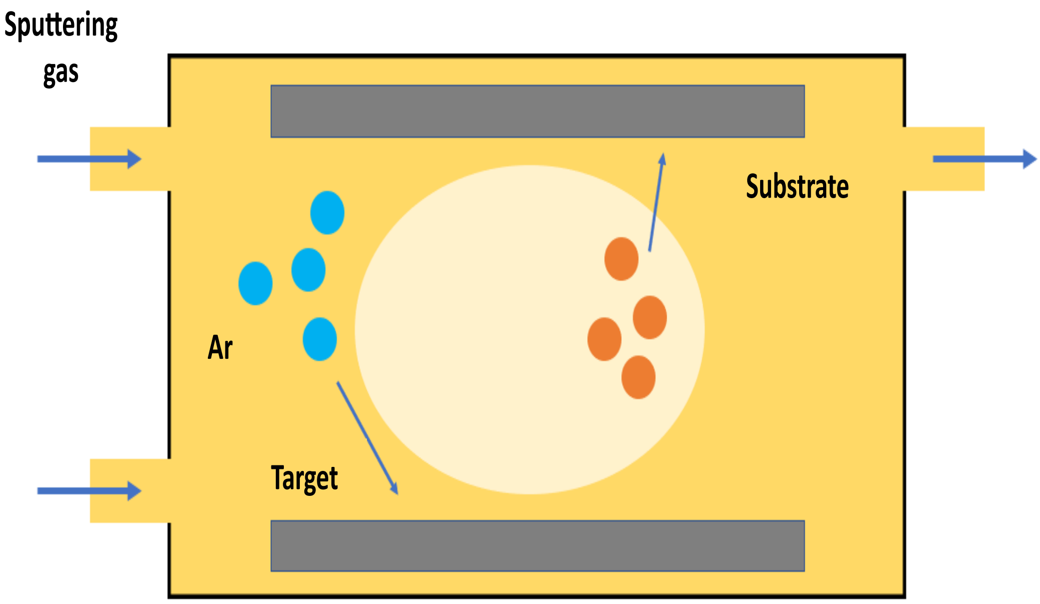

Figure 4. Magnetron sputtering deposition.

5.4. Antifogging

Fogging is the condensation of the water droplets on the glass surface. In general, the water droplets present in the glass reflect the light and give blurry vision. This type of reflection of light occurs due to the dew point of the water droplet. Flogging usually occurs due to humidity, temperature, and airflow. The intensity of the fogging depends on the droplets condensed in the glass surface [121]. This effect can be avoided by providing an anti-fogging coating. The anti-fogging coating is provided using two typical methods such as superhydrophilicity [122]. The literature followed a few strategies for antifogging properties such as doping, a combination of metal oxides, and surface treatments.

6. Selective Nanoparticles Used as Nanocatalysts for Enhancing the Optical and Thermal Properties

The utilization of nanotechnology in mechanical engineering aims to intensively enhance the heat transfer mechanism by manipulating the thermal and conductivity properties of the selective antiparticles interfering with the glass materials to reduce energy consumption by creating an internally stable environment in the classroom, especially in huge buildings [25–28,36,57,58,85,87,96,104,108,116]. Due to the thermal and optical properties, the functionalized carbon nanotubes, graphene derivatives and other selective NPs considered excellent nanomaterials and have grown the attention towards the other nanomaterials to increase the nanofabrication biocompatibility towards nanocatalysts mechanical engineering applications [123,124] (see Table 1). Several studies have been investigating the critical role of carbon nanomaterials in improving the thermal performance of glass materials by connecting and controlling the heat transfer rates inside with the outside of the room (see Figure 5). The work of Cheng et al. [125] shows that novel carbon nanotubes have been developed by using the phase change materials (PCMs) to the thermal performance and composite structure. Their results indicate that the shell of the carbon nanotube plays a major role, at the initial phase transmission of PCM is 28.97 °C, in improving the efficiency of heat transfer and working as a channel connects between the internal and external environment by increasing the stability. Roy's work et al. [87] demonstrate that the flexible and developed graphene oxide (FGO) is implemented as a thermal catalyst for thermal comfort purpose. Their investigation show that FGO has increased the stability of heat transfer by maintaining the indoor temperature and reducing the transfer of temperature from outside to inside environment, this has led to reducing energy consumption and the difference of temperature approaches to zero during the hot and cooling periods [87]. The experimental results of the various literature studies indicate that noble NPs have played a significant role in enhancing the efficiency of thermal performance, especially during the hot and mid-day times such as titanium oxide (TiO_2), iron oxide (Fe_2O_3), aluminum oxide (Al_2O_3) and silicon oxide (SiO_2) (see Figure 6). The glazing materials consist of four periodic pairs of SiO_2 with variant thicknesses fabricated on a glass sheet showing that the filter transmits 70–80% of the visible light and reflects almost all the infrared radiation [126,127]. The glass treated at the nanoscale sizes coated with the TiO_2, NPs have risen up the thermal performance rate by maintaining the lower indoor temperature compared to the standard and commercial glasses in the order of 2.7 °C [128]. The recent literature studies have shed light on the utilization of selective and efficient NPs such as TiO_2 and Al_2O_3 functionalized as anti-absorbent tools connecting with the glass materials to reduce the pavement temperature during the daytime and also increase the human thermal comfort [128–132]. The significant outcomes of this review provide a unique opportunity for scientific researchers to develop long-lasting and sustainable engineering solutions in the specific field of thermal comfort and glazing coating systems. The recent experimental results have shown that the graphene derivatives—paraffin, carbon nanotubes and other selective nanoparticles components using the PCMs helmet technique provides faster cooling compared to the normal PCM due to the manipulation in the thermal and conductivity properties of these utilized nanomaterials [133–136].

Table 1. Thermal and mechanical properties of varian nanoparticles involved in this review.

Nanoparticle	Specific Heat (J/KG·K)	Thermal Conductivity (W/m·K)	Density (m^3/kg)	Visocity (kg/ms)	Molecular Weight (g/mol)
CNT	710	2–3 [137]	380	0.00125–0.00730 [138] at 25–65 °C	12.01
GO	509	2–5 [139]	380	0.0199–0.0027 [140] at 25–65 °C	12.01
Titanium oxide (TiO_2)	683	8.5 [141]	423	0.127–0.207 [142] at 25–65 °C	79.87
Iron oxide (Fe_2O_3)	104 [143]	7 [141]	5240	0.007–0.092 [144] at 10–65 °C	159.69
Aluminium oxide (AL_2O_3)	880 [143]	40 [141]	2120	0.006–0.071 [144] at 25–65 °C	101.96

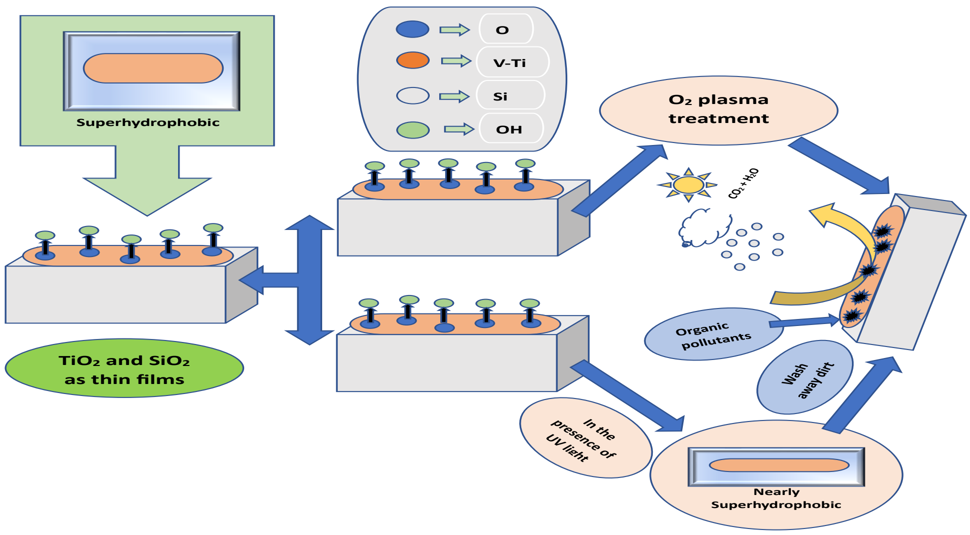

Figure 5. The realistic mechanism of TiO_2 and SiO_2 utilized as thin-films coatings for enhancing the thermal performance and maintaining the stability of heat transfer [132].

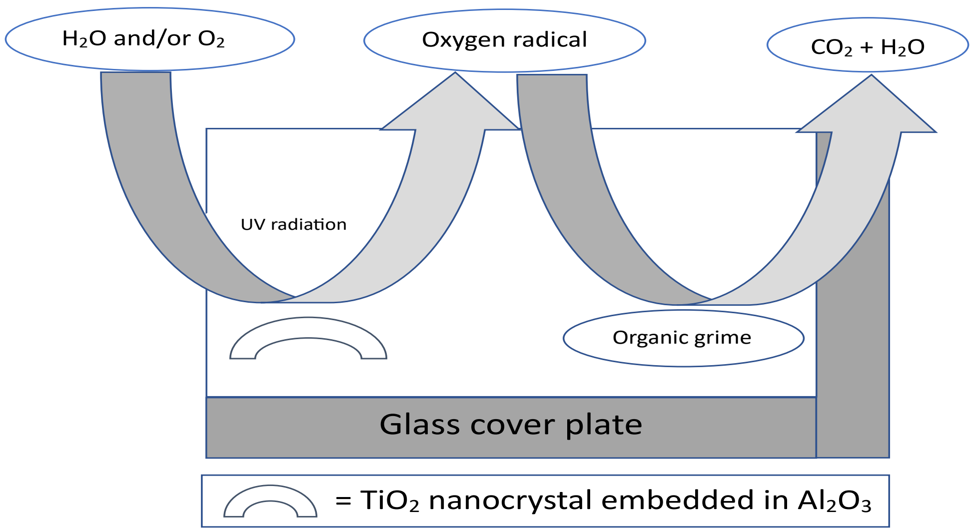

Figure 6. TiO_2 and Al_2O_3 NPs embedded in the glass treated at nanoscale size used as nanocrytals for self-cleaning and coating to increase the stability of heat transfer by improving the optical properties.

7. Conclusions

In summary, the review paper highlights the potential of nano-structured glasses and composites as suitable components for mechanical engineering applications due to their superior thermal, mechanical, optical, and magnetic properties. The paper also provides a brief overview of the fabrication methods of nano-structured glasses, including the PCM method. The comprehensive review of the thermal and optical properties of nano-structured glasses confirms that they exhibit both direct and indirect running of band gaps, depending on the selective nano-structuring samples. Additionally, electrical and magnetic properties also show enhancements in electrical conductivity on nano-structured glasses compared to their standard counterparts. The paper concludes that the realistic changes in thermal, optical and mechanical properties of nano-structured glasses and composites are attributed to many micro- and nano-structural distribution features. Furthermore, literature reports that nano-structuring materials lead to enhanced phonon boundary scattering, reducing thermal conductivity and energy consumption. The findings of this paper have promising implications for the development of advanced materials and technology, contributing to environmental sustainability and technological progress [132–136,145].

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