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The Latest Developments in Glass Science and Technology

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Abstract: The aim of this study is to give detailed information about the latest developments/ applications in the glass science and technology. In this aspect, smart glass, security glass, thin glass, amorphous metal, electrolytes, molecular liquid, colloidal glass, glass added polymer, glass-ceramic, fiberglass, double glazing, Dragontrail glass, Gorilla glass, fluorescent lamp, glass to metal seal, glassphalt, heatable glass, lamination, nano channel glass, photochromic lenses, night vision glasses, glass cockpit, porous glass, self—cleaning glass and bioactive glass were mentioned.

Keywords: Glass, Science, Technology, Innovation, Application

Cam Bilimi ve Teknolojisindeki En Son Gelişmeler

Özet: Bu çalışmanın amacı cam bilimi ve teknolojisindeki en son gelişmeler hakkında detaylı bilgi sunmaktır. İlgili bağlamda, güvenlik camı, ince cam, camsı metal, elektrolitler, moleküler sıvı, koloidal cam, cam katkılı polimer, cam-seramik, cam lifi, izolasyon camı, Dragontrail camı, Gorilla camı, flüoresan lamba, cam-metal sızdırmazlığı, cam katkılı asfalt, ısıtılabilir cam, tabakalama, nano kanallı cam, fotokromik lensler, gece görüş camları, cam pilot kabini, porlu cam, kendi kendini temizleyebilen cam ve biyo-aktif camdan bahsedilmiştir.

Anahtar kelimeler: Cam, Bilim, Teknoloji, Yenilik, Uygulama

1. Introduction

Glass is a non-crystalline solid being usually transparent and has widespread practical, technological, and decorative usage in things like window panes, tableware, optoelectronics and etc. Scientifically, the term "glass" is often defined in a broader sense, encompassing every solid that possesses a non-crystalline (that is, amorphous) structure at the atomic scale and exhibits a glass transition when heated towards the liquid state [1]. Glass will transmit, reflect and refract light; these qualities can be enhanced by cutting and polishing to make optical lenses, prisms, fine glassware, and optical fibres for high speed data transmission by light. It can be coloured by adding metallic salts, and can also be painted. These qualities have led to the extensive use of glass in the manufacture of art objects and in particular, stained glass windows. Although brittle, silicate glass is extremely durable, and many examples of glass fragments exist from early glass-making cultures. Because glass can be formed or moulded into any shape, and also because it is a sterile product, it has been traditionally used for vessels: bowls, vases, bottles, jars and drinking glasses. In its most

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Bu makaleye atıf için
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solid forms it has also been used for paper weights, marbles, and beads. When extruded as glass fibre and matted as glass wool in a way to trap air, it becomes a thermal insulating material, and when these glass fibres are embedded into an organic polymer plastic, they are a key structural reinforcement part of the composite material fiberglass. Some objects are so commonly made of glass that they are simply called by the name of the material, such as drinking glasses and reading glasses [2]. These sorts of glasses can be made of quite different kinds of materials than silica: metallic alloys, ionic melts, aqueous solutions, molecular liquids, and polymers. For many applications, like glass bottles or eyewear, polymer glasses (acrylic glass, polycarbonate or polyethylene terephthalate-PET) are a lighter alternative than traditional silicate-based glass [3].

2. History of Glass

People had used naturally occurring glass, especially obsidian (the volcanic glass) before they learned how to make it. Obsidian was used for the production of knives, arrowheads, jewellery and money. The ancient Roman historian Pliny suggested that Phoenician merchants had made the first glass in the region of Syria around 5000 BC. But according to the archaeological evidence, the first man made glass was in Eastern Mesopotamia and Egypt around 3500 BC and the first glass vessels were made about 1500 BC in Egypt and Mesopotamia. For the next 300 years, the glass industry was increased rapidly and then declined. In Mesopotamia it was revived in the 700 BC and in Egypt in the 500's BC. For the next 500 years, Egypt, Syria and the other countries along the eastern coast of the Mediterranean Sea were centres for glass manufacturing. In the beginning it was very hard and slow to manufacture glass. Glass melting furnaces were small and the heat they produced was hardly enough to melt glass. But in the 1st century BC, Syrian craftsmen invented the blow pipe. This revolutionary discovery made glass production easier, faster and cheaper. Glass production flourished in the Roman Empire and spread from Italy to all countries under its rule (Fig. 1). In 1000 AD the Egyptian city of Alexandria was the most important centre of glass manufacture.

(a) (b) (c) (d)

Figure 1. (a) A Roman glass aryballos circa, 1st century AD [4], (b) A Roman glass cinerary urn,1st-2nd century AD [4], (c) Roman blown glass cup engraved with grape vines, 3rd century AD [4], (d) Munich Cage cup from Cologne, dated to the mid-4th century [5].

A flourishing glass industry was developed in Europe at the end of 13th century when the glass industry was established in Venice by the time of Crusades (AD 1096-1270). In 1291, equipment for glassmaking was transferred to the Venetian island Murano where "cristallo" (colourless glass) was invented by Angelo Barovier. Despite the efforts of the Venetian artisans who dominated the glass industry to keep the technology secret, it soon spread around Europe. In Germany and other northern European countries glassmaking became important by the late 1400's and early 1500`s and during the 1500's it became important in England. George Ravenscroft (1618-1681), an English glassmaker, invented lead glass in 1674 which was a major breakthrough in the glass history. After 1890, the development, manufacture and use of glass increased rapidly. After 1890, glass use, development and manufacture began to increase rapidly. Machinery has been developed for precise, continuous manufacture of a host of products. In 1902, Irving W. Colburn invented the sheet glass drawing machine which made possible the mass production of window glass. Mechanical technology for mass production began in the latter stages of the Industrial Revolution with Michael Owens`s invention of an automatic bottle blowing machine in 1903 that could produce 2500 bottles per hour. In 1904, the American engineer Michael Owens patented the automatic bottle-blowing machine. In 1959 Sir Alastair Pilkington invented the revolutionary float glass production technique. His method involves the pouring of glass on flat surfaces of molten metal, either tin or led. Pilkington's method is used in 90 % of glass manufacture today. Float glass production makes glass sheets suitable for commercial markets including the manufacture of windows, shower screens and the like. Glass has evolved through advancing technologies and technological evolution naturally continues. Today, glass-making is a modern, hi-tech industry. Modern glass plants are capable of making millions of glass containers a day in many different colours and have been developed for precise continuous production of sheet glass tubing, containers, bulbs and host of other products (Fig. 2) [6-10].

Figure 2. Different glass products [11].

3. Some Technologically Important Glasses

Beside conventional soda-lime-silica glasses known for centuries, new chemical glass compositions or new treatment techniques can be initially investigated in small-scale laboratory experiments. To make glass from materials with poor glass forming tendencies, novel techniques are used to increase cooling rate, or reduce crystal nucleation triggers. Examples of these techniques include aerodynamic levitation (cooling the melt whilst it floats on a gas stream), splat quenching (pressing the melt between two metal anvils) and roller quenching (pouring the melt through rollers) [12]. Some glasses that do not include silica as a major constituent may have physico-chemical properties useful for their application in fibre optics and other specialized technical applications. These include fluoride glasses, aluminosilicates, phosphate glasses, borate glasses, and chalcogenide glasses [13].

3.1. Smart Glasses

Electrochromic windows darken when voltage is added and are transparent when voltage is taken away. Like suspended particle devices, electrochromic windows can be adjusted to allow varying levels of visibility (Fig. 3).

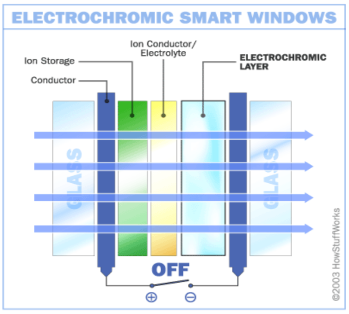

Figure 3. When switched off, an electrochromic window remains transparent [14].

Since the early 20th century, people have got used to the idea of buildings that are increasingly automated. The use of intelligent smart glass provides added value and increased flexibility in new building design, improves working environments and building ergonomics, saves energy, and increases the well being of occupants [15]. Smart windows (also referred to by the names smart glass, switchable windows, and dynamic windows) do exactly that using a scientific idea called electrochromism, in which materials change colour (or switch from transparent to opaque) when an electrical voltage applied across them. Typically smart windows start off a blueish colour and gradually (over a few minutes) turn transparent when the electric current passes through them. More sophisticated windows (using low-E heat-reflective glass) are coated with a thin layer of metallic chemicals so they keep home warm in winter and cool in summer. Electrochromic windows work a little bit like this, only the metal-oxide coatings they use are much more sophisticated and deposited by processes similar to those used in the manufacture of integrated circuits (silicon computer chips). Much like the early days of the resistive touchscreen, one won't find optical scanners used in anything but the most cost effective pieces of hardware these days. With increasing demand for tougher security, smartphones have unanimously adopted superior capacitive scanners. Instead of creating a traditional image of a fingerprint, capacitive fingerprint scanners use arrays tiny capacitor circuits to collect data about a fingerprint (Fig. 4).

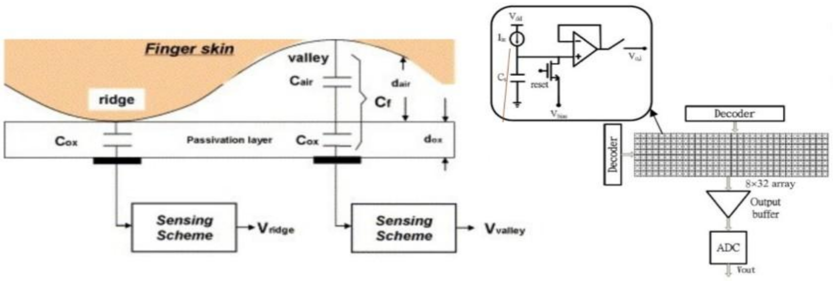

Figure 4. The theory and architecture behind a capacitive fingerprint scanning chip [16].

3.2. Vision Security Glasses

Polytronix PDLC film is the most "private" and of the highest quality in the industry, and is internationally-known and recognized for privacy and quality by major glass companies worldwide. It is superior to imported films: it is a thicker, more substantial film package than the imports, making easier to handle and to apply, yet it's still only about four times the thickness of a human hair. It has better optical properties, including better uniformity without the variations and blotches that mar other films, higher clarity (lower haze) in clear mode, and the best privacy (light scattering) performance available. In addition to privacy, Polytronix PDLC film-enabled glass panes can provide several other significant benefits for energy efficiency and creative applications. It expands your product line with dramatic functionality that is low cost to operate, low maintenance, and highly energy-efficient. The polytronix PDLC film package consists of a layer of liquid crystal sandwiched between two polyethylene terephthalate (PET) conductive films. In its rest state, it is a translucent white. When the electricity is switched on, the glass instantly changes to transparent. The power drawn by a window is roughly equivalent to operating a 25-watt light bulb. The liquid crystal privacy glass is constructed in a way similar to the construction of laminated glass. The outside skins are made up of glass (normally 5 or 6 mm annealed glass) each side, then a PVB interlayer is inserted on each side to trap and hold the liquid crystal privacy film. The liquid crystal privacy film is made up of electrically conductive coatings, a polymer matrix and liquid crystals. This film has electrical wiring to be connected to a transformer to supply power for the "on" (clear state) mode (Fig. 5) [17]. Privacy and security with architectural integrity, eliminates need for shutters, blinds, and drapes, ultraviolet and infrared radiation protection, day-lighting control, solar heat-gain control and replacement for whiteboards and projection screens.

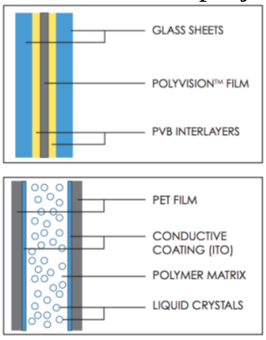

Figure 5. The polytronix PDLC film package [17].

Goggles or safety glasses are forms of protective eyewear that usually enclose or protect the area surrounding the eye in order to prevent particulates, water or chemicals from striking the eyes. They are used in chemistry laboratories and in woodworking. They are often used in snow sports as well, and in swimming. Goggles are often worn when using power tools such as drills or chainsaws to prevent flying particles from damaging the eyes. Many types of goggles are available as prescription goggles for those with vision problems (Fig. 6) [18].

Figure 6. Some products for eye security glasses [19].

3.3. Thin-Glass Technology for Solar Applications

Tempered thin glass is light, extremely flexible and highly robust-ideal conditions for the use in the solar industry, whether as cold-bent parabolic reflectors or for glass-glass modules. The LiSEC encapsulation technique for glass-glass modules combines all advantages of tempered thin glass, making use of 50 years of experience in the insulating glass business. Their hermetic sealing renders the modules completely diffusion tight and UV resistant. Thin glass used on the front and rear side allows easy installation using back rails. The LiSEC encapsulation technique is perfectly suitable for crystalline, organic and thin-film solar cells, and the laminating film can be chosen according to your requirements too [20-21]. The perfect combination of thin glass, AR coating and laminating film yields up to 6 % more energy. This is a plus in energy output of 450 kWh of a standard module (72 cells, 300 Wp) after 25 years. Increased lifetime LiSEC's know-how leads in sealing technologies as well as the solid thin glass make the modules absolutely diffusion tight and UV resistant. For the symmetric construction of the module, the cells are within the module's neutral zone, preventing them from breaking when exposed to bending stress. The thin glass used makes the modules very lightweight compared to conventional ones. As a result, simpler and more cost-effective sub constructions can be used [22-23].

3.4. Amorphous Metals

In the past, small batches of amorphous metals with high surface area configurations (ribbons, wires, films, etc.) have been produced through the implementation of extremely rapid rates of cooling. This was initially termed "splat cooling" by doctoral student W. Klement at Caltech, who showed that cooling rates on the order of millions of degrees per second is sufficient to impede the formation of crystals, and the metallic atoms become "locked into" a glassy state. Amorphous metal wires have been produced by sputtering molten metal onto a spinning metal disk. More recently a number of alloys have been produced in layers with thickness exceeding 1 millimetre (Fig. 7). These are known as bulk metallic glasses (BMG). Liquid metal technologies sell a number of zirconium-based BMGs. Batches of amorphous steel have also been produced that demonstrate mechanical properties far exceeding those found in conventional steel alloys [21, 24-26].

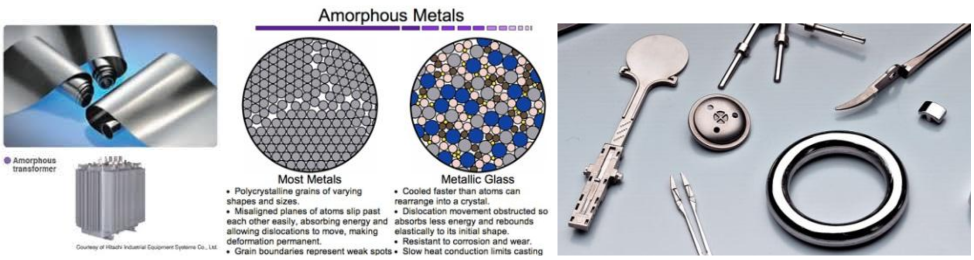

Figure 7. Amorphous metal foils and an amorphous metal alloys for producing highly complex parts via an efficient injection-moulding process exceeds the strength of its counterparts [27].

3.5. Electrolytes

Electrolytes or molten salts are mixtures of different ions. In a mixture of three or more ionic species of dissimilar size and shape, crystallization can be so difficult that the liquid can easily be super cooled into a glass. The best-studied example is $Ca_{0.4}K_{0.6}(NO_3)_{1.4}$. Some aqueous solutions can be super cooled into a glassy state, for instance $LiCl{:}RH_2O$ in the composition range of $4<R<8$ [28].

3.6. Molecular Liquids

A molecular liquid is composed of molecules that do not form a covalent network but interact only through weak Van der Waals forces or through transient hydrogen bonds. Many molecular liquids can be super cooled into a glass; some are excellent glass formers that normally do not crystallize. A widely known example is sugar glass. Under extremes of pressure and temperature solids may exhibit large structural and physical changes that can lead to polymorphic phase transitions [29]. In 2006 Italian scientists created an amorphous phase of carbon dioxide using extreme pressure. The substance was named amorphous carbonia and exhibits an atomic structure resembling that of silica [30].

3.7. Colloidal Glasses

Concentrated colloidal suspensions may exhibit a distinct glass transition as a function of particle concentration or density. In cell biology there is recent evidence suggesting that the cytoplasm behaves like a colloidal glass approaching the liquid-glass transition. During periods of low metabolic activity, as in dormancy, the cytoplasm vitrifies and prohibits the movement to larger cytoplasmic particles while allowing the diffusion of smaller ones throughout the cell [31-33].

3.8. Polymer Glasses

Important polymer glasses include amorphous and glassy pharmaceutical compounds. These are useful because the solubility of the compound is greatly increased when it is amorphous compared to the same crystalline composition. Many emerging pharmaceuticals are practically insoluble in their crystalline forms [34]. A question will definitely arise lots of times where polymer clay is used to cover the handles of cutlery or the outsides of glasses: Is polymer clay safe for that? Yes, it is absolutely safe to use polymer clay in this manner as long as it's not a food-contact region (Fig. 8).

Figure 8. Examples of polymer clay glasses [35].

3.9. Glass-ceramics

Glass-ceramic materials share many properties with both non-crystalline glass and crystalline ceramics. They are formed as a glass, and then partially crystallized by precisely controlled heat treatment. For example, the microstructure of white ware ceramics frequently contains both amorphous and crystalline phases. Crystalline grains are often embedded within a non-crystalline intergranular phase of grain boundaries. When applied to white ware ceramics, vitreous means the material has an extremely low permeability to liquids, often but not always water, when determined by a specified test regime [36-37]. The term mainly refers to a mix of lithium and aluminosilicates that yields an array of materials with interesting thermomechanical properties. The most commercially important of these have the distinction of being impervious to thermal shock. Thus, glass-ceramics have become extremely useful for countertop cooking (Fig. 9). The negative thermal expansion coefficient (CTE) of the crystalline phase can be balanced with the positive CTE of the glassy phase. At a certain point (~70 % crystalline) the glass-ceramic has a net CTE near zero. This type of glass-ceramic exhibits excellent mechanical properties and can sustain repeated and quick temperature changes up to 1000 °C [36].

Figure 9. Glass ceramic cooktop [38].

3.10. Fiberglass

Glass fibres have been produced for centuries, but mass production of glass strands was discovered in 1932 when Games Slayter, a researcher at Owens-Illinois, accidentally directed a jet of compressed air at a stream of molten glass and produced fibres. Originally, fibreglass was a glass wool with fibres entrapping a great deal of gas, making it useful as an insulator, especially at high temperatures [39]. A suitable resin for combining the "fibreglass" with a plastic to produce a composite material was developed in 1936 by du Pont. The first ancestor of modern polyester resins is Cyanamid's resin of 1942. Peroxide curing systems were used by then. With the combination of fiberglass and resin the gas content of the material was replaced by plastic. This reduced the insulation properties to values typical of the plastic, but now for the first time the composite showed great strength and promise as a structural and building material. Confusingly, many glass fibre composites continued to be called "fiberglass" (as a generic name) and the name was also used for the low-density glass wool product containing gas instead of plastic [40]. Ray Greene of Owens Corning is credited with producing the first composite boat in 1937, but did not proceed further at the time due to the brittle nature of the plastic used. In 1939 Russia was reported to have constructed a passenger boat of plastic materials, and the United States a fuselage and wings of an aircraft. The first car to have a fibre-glass body was a 1946 prototype of the Stout Scarab, but the model did not enter production [41]. The most common types of glass fibre used in fiberglass is E-glass, which is alumino-borosilicate glass with less than 1 % w/w alkali oxides, mainly used for glass-reinforced plastics. Other types of glass used are A-glass (Alkali-lime glass with little or no boron oxide), E-CR-glass (Electrical/Chemical Resistance; alumino-lime silicate with less than 1 % w/w alkali oxides, with high acid resistance), C-glass (alkali-lime glass with high boron oxide content, used for glass staple fibres and insulation), D-glass (borosilicate glass, named for its low dielectric constant), R-glass (alumino silicate glass without MgO and CaO with high mechanical requirements as reinforcement), and S-glass (alumino silicate glass without CaO but with high MgO content with high tensile strength) [42].

3.11. Double Glazing (Insulating Glazing)

Insulated glazing is an evolution from older technologies known as double-hung windows and storm windows. Traditional double-hung windows used a single pane of glass to separate the interior and exterior spaces. In the summer, a window screen would be installed on the exterior over the double-hung window to keep out animals and insects. In the winter, the screen was removed and replaced with a storm window, which created a two-layer separation between the interior and exterior spaces, increasing window insulation in cold winter months. Insulating glass units are sealed combinations of 2 or more lites of glass separated by a dry air space. Those units save energy, save money, reduce pollution and greatly improve the comfort inside a building. Insulated glazing (IG), more commonly known as double glazing (or double-pane, and increasingly triple glazing/pane) is double or triple glass window panes separated by a vacuum or gas filled space to reduce heat transfer across a part of the building envelope (Fig. 10) [43-45].

Figure 10. A glass window pane [45].

Insulated glass units are manufactured with glass in range of thickness from 3 to 10 mm or more in special applications. Laminated or tempered glass may also be used as part of the construction. Most units are manufactured with the same thickness of glass used on both panes but special applications such as acoustic attenuation or security may require wide ranges of thicknesses to be incorporated in the same unit [46].

3.12. Gorilla Glass

Gorilla Glass is a brand of specialized toughened glass developed and manufactured by Corning, now in its fourth generation, designed to be thin, light and damage-resistant (Fig. 11). This type of glass is not unique to Corning; similar glasses include Asahi Glass Co. Dragontrail and Schott AG Xensation. The alkali-aluminosilicate sheet glass is used primarily as cover glass for portable electronic devices, including mobile phones, portable media players, portable computer displays, and some television screens. It is manufactured in Harrodsburg, Kentucky, USA, in Asan, Korea, and in Taiwan. The glass gains its surface strength, ability to contain flaws, and crack-resistance by being immersed in a hot potassium salt ion-exchange bath.

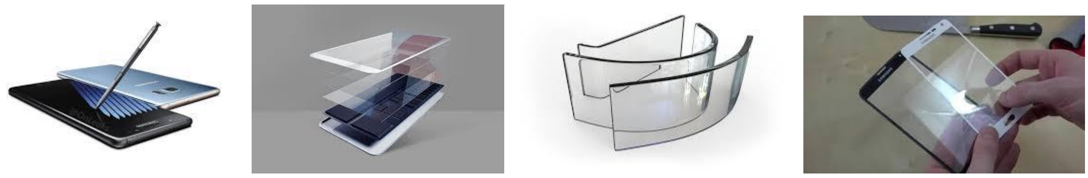

Figure 11. Some applications of Gorilla glass [47].

3.13. Dragontrail Glass

Dragontrail, manufactured by Asahi Glass Co., is an alkali-aluminosilicate sheet glass engineered for a combination of thinness, lightness and damage-resistance, similar to Corning's Gorilla Glass. The material's primary properties are its strength, allowing thin glass without fragility; its high scratch resistance; and its hardness–with a Vickers hardness test rating of 595 to 673 [48].

3.13.1. Gorilla glass vs Dragontrail glass comparison

Gorilla and Dragontrail glasses are both very hard and tough glasses. These glasses are scratch resistant and are very difficult to break. Here it is a clear comparison between these two to find out what makes them different from each other in terms of their properties and usage [49].

	Gorilla Glass	Dragontrail Glass
Manufacturer	Corning from USA	Asahi from Japan
Type of Glass	Alkali-aluminosilicate sheet glass	Alkali-aluminosilicate sheet glass
Vickers Hardness Rating	622 to 701	595 to 673
Versions	Gorilla glass, Gorilla glass 2, Gorilla glass 3, Gorilla glass 4. Gorilla glass 3 is 40% more strong and scratch resistant. Gorilla glass 4 is up to two times tougher & stronger than its competitive glasses	Dragontrial glass
Applications or Usage	Smartphones, laptops, tablets, portable media players, computer displays and some television displays	Smartphones, tablets
Manufacturing Process	Ion-exchange method	Float process
Popularity	Very popular and established product	Not much popular but gaining popularity
Properties	Scratch resistant, damage resistance, lightness and thinness	Scratch resistant, damage resistance, lightness and thinness

3.14. Fluorescent Lamp

A fluorescent lamp or a fluorescent tube is a low pressure mercury-vapour gas-discharge lamp that uses fluorescence to produce visible light. An electric current in the gas excites mercury vapour which produces short-wave ultraviolet light that then causes a phosphor coating on the inside of the bulb to glow (Fig. 12). A fluorescent lamp converts electrical energy into useful light much more efficiently than incandescent lamps. The typical luminous efficacy of fluorescent lighting systems is 50–100 lumens per watt, several times the efficacy of incandescent bulbs with comparable light output [50]. Fluorescent lamp fixtures are more costly than incandescent lamps because they require a ballast to regulate the current through the lamp, but the lower energy cost typically offsets the higher initial cost. Compact fluorescent lamps are now available in the same popular sizes as incandescent and are used as an energy-saving alternative in homes [51].

Figure 12. Some commercial products of fluorescent lamps [52].

Because they contain mercury, many fluorescent lamps are classified as hazardous waste. The United States Environmental Protection Agency recommends that fluorescent lamps be segregated from general waste for recycling or safe disposal. Light-emitting phosphors are applied as a paint-like coating to the inside of the tube. The organic solvents are allowed to evaporate, and then the tube is heated to nearly the melting point of glass to drive off remaining organic compounds and fuse the coating to the lamp tube [53].

3.15. Glass to Metal Seals

Glass-to-metal seals are a very important element of the construction of vacuum tubes, electric discharge tubes, incandescent light bulbs, glass encapsulated semiconductor diodes, reed switches, pressure tight glass windows in metal cases, and metal or ceramic packages of electronic components (Fig. 13). Properly done, such a seal is hermetic. To achieve such a seal, two properties must hold:

1. The molten glass must be capable of wetting the metal, in order to form a tight bond, and
2. The thermal expansion of the glass and metal must be closely matched so that the seal remains solid as the assembly cools. When one material goes through a hole in the other, such as a metal wire through a glass bulb, and the inner material's coefficient of thermal expansion is higher than that of the outer, it will shrink more as it cools, cracking the seal. If the inner material's coefficient of expansion is slightly less, the seal will tighten as it cools, which is often beneficial. Since most metals expand much more with heat than most glasses, this is not easy to arrange [54].

Figure 13. Examples of glass-metal sealed products [55].

3.15.1. Glass-to-metal bond

Glass and metal can bond together by purely mechanical means, which usually gives weaker joints, or by chemical interaction, where the oxide layer on the metal surface forms a strong bond with the glass. The acid-base reactions are main causes of interaction between glass-metal in the presence of metal oxides on the surface of metal. After complete dissolution of the surface oxides into the glass, further progress of interaction depends on the oxygen activity at the interface. For achieving a vacuum-tight seal, the seal must not contain bubbles. The bubbles are most commonly created by gases escaping the metal at high temperature; degassing the metal before its sealing is therefore important, especially for nickel and iron and their alloys. Oxidizing of the metal surface also reduces gas evolution. Most of the evolved gas is produced due to the presence of carbon impurities in the metals; these can be removed by heating in hydrogen. The glass-oxide bond is stronger than glass-metal. The oxide forms a layer on the metal surface, with the proportion of oxygen changing from zero in the metal to the stoichiometry of the oxide and the glass itself. A too thick oxide layer tends to be porous on the surface and mechanically weak, flaking, compromising the bond strength and creating possible leakage paths along the metal-oxide interface. Proper thickness of the oxide layer is therefore critical. Also the mechanical design of a glass-to-metal seal has an important influence on the reliability of the seal. In practical glass-to-metal seals cracks usually start at the edge of the interface between glass and metal either inside or outside the glass container. Another important aspect is the wetting of the metal by the glass. If the thermal expansion of the metal is higher than the thermal expansion of the glass like with the Housekeeper seal, a high contact angle (bad wetting) means that there is a high tensile stress in the surface of the glass near the metal. Such seals usually break inside the glass and leave a thin cover of glass on the metal. Ordinary soda-lime glass does not flow on copper at temperatures below the melting point of the copper and, thus, does not give a low contact angle. The solution is to cover the copper with a solder glass which has a low melting point and does flow on copper and then to press the soft soda-lime glass onto the copper. The solder glass must have a coefficient of thermal expansion which is equal or a little lower than that of the soda-lime glass. Classically high lead containing glasses are used, but it is also possible to substitute these by multi-component glasses e.g. based on the system Li_2O-Na_2O-K_2O-CaO-SiO_2-B_2O_3-ZnO-TiO_2-BaO-Al_2O_3 [56].

3.16. Glassphalt

Glassphalt (also spelled "glasphalt") is a variety of asphalt that uses crushed glass (Fig. 14). It has been used as an alternative to conventional bituminous asphalt pavement since the early 1970s. Glassphalt must be properly mixed and placed if it is to meet roadway pavement standards, requiring some modifications to generally accepted asphalt procedures. Generally, there is about 10-20 % glass by weight in glassphalt [57].

Figure 14. Glassphalt and its application [58].

3.17. Heatable Glass

Electrically heatable glass and windows are relatively new products, which help solve problems in the design of buildings and vehicles. The idea of heating glass is based on the use of energy-efficient low-emissive glass, which is generally simple silicate glass with a special metallic oxides coating. Low-emissive coating decreases heat loss by approximately 30 %. Heatable glass can be used in all kinds of standard glazing systems, whether wood, plastic, aluminium or steel (Fig. 15). Heatable glass based on low-emissive coatings was first produced in high volume in the early 1980s. Today, heating glass is used in the construction of many kinds of buildings and in mass production of vehicles, ships and trains. Heatable glass removes discomfort and other disadvantages induced by the low heat-insulating features of silicate glass. The effect of “cold glass” disappears when the surface of the glass is heated. Condensation is eliminated, along with ice and snow covering, the window’s heat losses are compensated and room comfort is improved [59].

Figure 15. Samples of heatable glass applications [60].

Windows play a significant role in room comfort. As a result, the area of glazing of buildings is constantly being increased. A window technology always in progress and it is common today to use low-emissive glass. In spite of progress the low temperature of glass surface is still the problem of constructive glazing. Heatable glass helps to solve problems concerning low surface temperature and increase the level of comfort in the room significantly. It can be used in practically all kinds of glazing systems made of wood, plastic or aluminium. Heatable glass and multiple glass panes can be used both in blind and openable constructions. Multiple glass panes made of heating glass can have one or two chambers. The advantages of multiple glass panes are their hermiticity and ability to decrease heat transfer significantly. Heating glass is used for defogging and prevention of frosting of windows of pools, saunas and other buildings of such kind. Insofar as heatable glass has a current-carrying coating, it can be used as the sensor of alarm systems. When the glass is destroyed the system of protection is activated and it results in activation of alarm system. This kind of product is widely used on objects of tightened standards in questions of protection: nuclear power plants, stations of air navigation control, museums, special storehouses, etc. Heatable glass is also used in production of windows for different kinds of vehicles: electric and diesel locomotives, vessels and boats, various kinds of aircraft and automobiles. One of well-known examples of application of heating glass is armoured windows, because the protective glazing is very thick and is disposed to frosting. The usage of heating glass is especially urgent in terms of being the part of armoured multiple glass of smart glass of switchable transparency, because the heating significantly decreases the period of reaction of liquid crystals structure [59].

3.18. Lamination

Lamination is the technique of manufacturing a material in multiple layers, so that the composite material achieves improved strength, stability, sound insulation, appearance or other properties from the use of differing materials (Fig. 16). A laminate is a permanently assembled object by heat, pressure, welding, or adhesives [61].

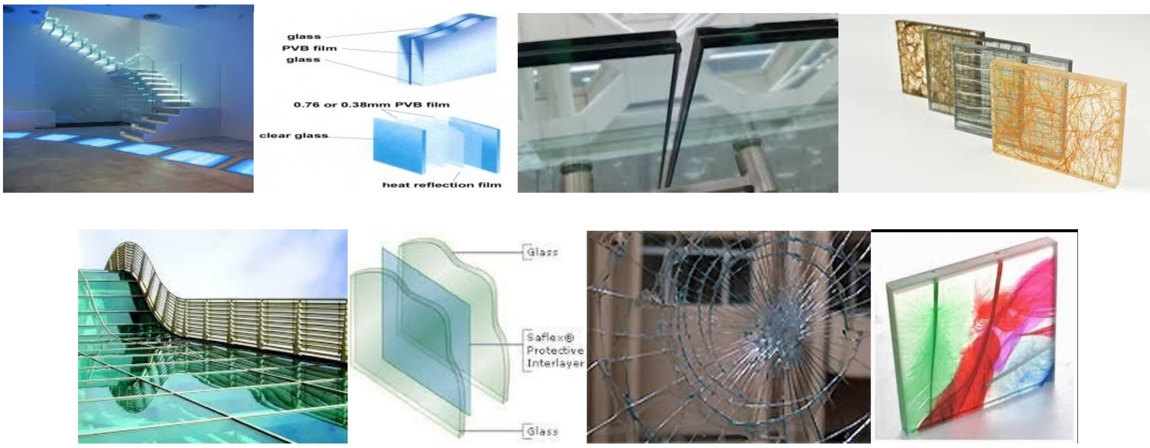

Figure 16. Laminated glass [62].

There are different lamination processes, depending on the type of materials to be laminated. The materials used in laminates can be the same or different, depending on the processes and the object to be laminated. An example of the type of laminate using different materials would be the application of a layer of plastic film—the "laminate"—on either side of a sheet of glass—the laminated subject. Vehicle windshields are commonly made by laminating a tough plastic film between two layers of glass. This is to prevent shards of glass detaching from the windshield in case it breaks [63-64]. Examples of laminate materials include melamine adhesive countertop surfacing and plywood. Decorative laminates are produced with decorative papers with a layer of overlay on top of the decorative paper, set before pressing them with thermos-processing into high-pressure decorative laminates [65].

3.19. Nano Channel Glass Materials

Nano channel glass materials are an experimental mask technology that is an alternate method for fabricating nanostructures, although optical lithography is the predominant patterning technique [66]. Nano channel glass materials are complex glass structures containing large numbers of parallel hollow channels (Fig. 17). In its simplest form, the hollow channels are arranged in geometric arrays with packing densities as great as 10^{11}channels/cm^2. Channel dimensions are controllable from micrometres to tens of nanometres, while retaining excellent channel uniformity. Exact replicas of the channel glass can be made from a variety of materials. This is a low cost method for creating identical structures with nanoscale features in large numbers. These materials have high density of uniform channels with diameters from 15 micrometres to 15 nanometres. These are rigid structures with serviceable temperatures to at least 300 °C, with potential up to 1000 °C. Furthermore, these are optically transparent photonic structures with high degree of reproducibility [67-69]. These can be used as a material for chromatographic columns, unidirectional conductors, Micro channel plate and nonlinear optical devices. Other uses are as masks for semiconductor development, including ion implantation, optical lithography, and reactive [67].

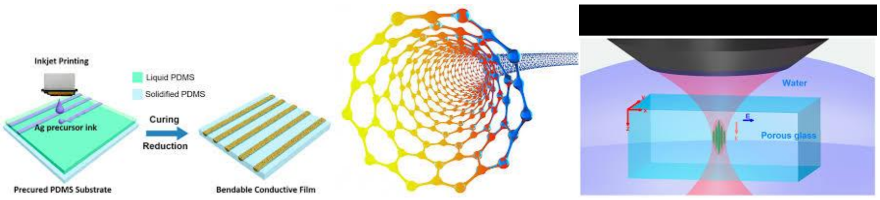

Figure 17. Structure and application of nano channel glass material [70].

3.20. Optical Fibre Cable

An optical fibre cable is a cable containing one or more optical fibres that are used to carry light. The optical fibre elements are typically individually coated with plastic layers and contained in a protective tube suitable for the environment where the cable will be deployed. Different types of cable are used for different applications, for example long distance telecommunication, or providing a high-speed data connection between different parts of a building [71]. For indoor applications, the jacketed fibre is generally enclosed, with a bundle of flexible fibrous polymer strength members like aramid (e.g. Twaron or Kevlar), in a lightweight plastic cover to form a simple cable (Fig. 18). Each end of the cable may be terminated with a specialized optical fibre connector to allow it to be easily connected and disconnected from transmitting and receiving equipment. A critical concern in outdoor cabling is to protect the fibre from contamination by water. This is accomplished by use of solid barriers such as copper tubes, and water-repellent jelly or water-absorbing powder surrounding the fibre. Finally, the cable may be armoured to protect it from environmental hazards, such as construction work or gnawing animals. Undersea cables are more heavily armoured in their near-shore portions to protect them from boat anchors, fishing gear, and even sharks, which may be attracted to the electrical power that is carried to power amplifiers or repeaters in the cable [72-74].

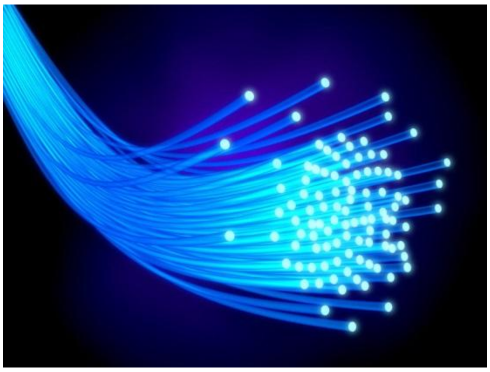

Figure 18. Optical fibres [75].

Modern cables come in a wide variety of sheathings and armour, designed for applications such as direct burial in trenches, dual use as power lines, installation in conduit, lashing to aerial telephone poles, submarine installation, and insertion in paved streets [76].

3.21. Photo Chromatic Lenses

Photochromic lenses are optical lenses that darken on exposure to specific types of light of sufficient intensity, most commonly ultraviolet (UV) radiation. In the absence of activating light the lenses return to their clear state. Photochromic lenses may be made of glass, polycarbonate, or another plastic. They are principally used in sunglasses that are dark in bright sunlight, but clear in low ambient light conditions. They darken significantly within about a minute of exposure to bright light, and take somewhat longer to clear. A range of clear and dark transmittances are available; one manufacturer makes one glass with transmittance reducing from 87 to 20 %, and another reducing from 45 to 9 %. Molecules of silver chloride or another silver halide are embedded in photo chromatic lenses. They are transparent to visible light without significant ultraviolet component, which is normal for artificial lighting. When exposed to ultraviolet (UV) rays, as in direct sunlight, the molecules undergo a chemical process that causes them to change shape and absorb a significant percentage of the visible light, i.e., they darken (Fig. 19). This process is reversible; once the lens is removed from strong sources of UV rays the silver compounds return to their transparent state.

With the photochromic material dispersed in the glass substrate, the degree of darkening depends on the thickness of glass, which poses problems with variable-thickness lenses in prescription glasses. With plastic lenses, the material is typically embedded into the surface layer of the plastic in a uniform thickness of up to 150 µm. Typically, photochromic lenses darken substantially in response to UV light in less than one minute, and continue to darken a little more over the next fifteen minutes. The lenses begin to clear in the absence of UV light, and will be noticeably lighter within two minutes, mostly clear within five minutes, and fully back to their non-exposed state in about fifteen minutes [77-79].

Figure 19. Photo chromatic lenses [80].

3.22. Night Vision Glasses

Night vision is the ability to see in low light conditions. Whether by biological or technological means, night vision is made possible by a combination of two approaches: sufficient spectral range, and sufficient intensity range. Humans have poor night vision compared to many animals, in part because the human eye lacks a tapetum lucidum [81]. Night-useful spectral range techniques can sense radiation that is invisible to a human observer. Human vision is confined to a small portion of the electromagnetic spectrum called visible light. Enhanced spectral range allows the viewer to take advantage of non-visible sources of electromagnetic radiation (such as near-infrared or ultraviolet radiation). Some animals such as the mantis shrimp can see using much more of the infrared and/or ultraviolet spectrum than humans. Sufficient intensity range is simply the ability to see with very small quantities of light. Many animals have better night vision than humans do the result of one or more differences in the morphology and anatomy of their eyes. These include having a larger eyeball, a larger lens, a larger optical aperture (the pupils may expand to the physical limit of the eyelids), more rods than cones (or rods exclusively) in the retina, and a tapetum lucidum. Enhanced intensity range is achieved via technological means through the use of an image intensifier, gain multiplication CCD, or other very low-noise and high-sensitivity array of photodetectors (Fig. 20) [82-83].

Figure 20. 1974 US Army film about the development of military night vision technology [84].

3.23. Glass Cockpit

Glass cockpits originated in military aircraft in the late 1960's and early 1970's; an early example is the Mark II avionics of the F-111D (first ordered in 1967, delivered from 1970–73), which featured a multi-function display. Prior to the 1970's, air transport operations were not considered sufficiently demanding to require advanced equipment like electronic flight displays. Also, computer technology was not at a level where sufficiently light and powerful circuits were available [85]. The increasing complexity of transport aircraft, the advent of digital systems and the growing air traffic congestion around airports began to change that (Fig. 21). The average transport aircraft in the mid-1970's had more than one hundred cockpit instruments and controls, and the primary flight instruments were already crowded with indicators, crossbars, and symbols, and the growing number of cockpit elements were competing for cockpit space and pilot attention [86]. As a result, NASA conducted research on displays that could process the raw aircraft system and flight data into an integrated, easily understood picture of the flight situation, culminating in a series of flights demonstrating a full glass cockpit system. The success of the NASA-led glass cockpit work is reflected in the total acceptance of electronic flight displays beginning with the introduction of the MD-80 in 1979. Airlines and their passengers alike have benefited. The safety and efficiency of flights have been increased with improved pilot understanding of the aircraft's situation relative to its environment (or "situational awareness").

Figure 21. The Airbus A380 glass cockpit featuring "pull out keyboards and 2 wide computer screens on the sides for pilots" [85].

By the end of the 1990's, liquid-crystal display (LCD) panels were increasingly favoured among aircraft manufacturers because of their efficiency, reliability and legibility. Earlier LCD panels suffered from poor legibility at some viewing angles and poor response times, making them unsuitable for aviation. Modern aircraft such as the Boeing 737 Next Generation, 777, 717, 747-400ER, 747-8F 767-400ER, 747-8, and 787, Airbus A320 family (later versions), A330 (later versions), A340-500/600, A340-300 (later versions), A380 and A350 are fitted with glass cockpits consisting of LCD units [86]. The glass cockpit has become standard equipment in airliners, business jets, and military aircraft. It was fitted into NASA's Space Shuttle orbiters *Atlantis*, *Columbia*, *Discovery*, and *Endeavour*, and the current Russian Soyuz TMA model spacecraft that was launched in 2002. By the end of the century glass cockpits began appearing in general aviation aircraft as well. In 2003, Cirrus Design's SR20 and SR22 became the first light aircraft equipped with glass cockpits, which they made standard on all Cirrus aircraft. By 2005, even basic trainers like the Piper Cherokee and Cessna 172 were shipping with glass cockpits as options (which nearly all customers chose), as well as many modern aircraft such as the Diamond DA42 twin-engine travel and training aircraft. The Lockheed Martin F-35 Lightning II features a "panoramic cockpit display" touchscreen that replaces most of the switches and toggles found in an aircraft cockpit [87].

3.24. Porous Glasses

Porous glasses can be formed by sintering glass powders, by leaching of phase separated glasses, or by the sol-gel method. These glasses can be used in the porous state or can serve as precursors to fully consolidated glasses. Porous glasses are currently under intense investigation as potential selective separation membranes for a variety of gases and liquids. Impregnation of porous glasses before consolidation can be used to produce continuously graded glass seals, conductive glasses containing continuous carbon filaments, red glasses coloured by colloidal spinel particles, and optical fibre preforms. The formation of porous glasses by leaching of phase separated glasses is frequently called the Vycor® process, after the commercial material produced by Corning. These glasses are formed from phase separated borosilicate glasses which have microstructures consisting of two continuous phases. One of these phases is silica-rich, while the other contains most of the alkali and boron oxides. Since the alkali borate phase readily dissolves in hot acids such as HCl, HNO_3, or H_2SO_4, this phase can be leached from the glass by exposure to such acids, leaving a very porous silica-rich skeleton known as thirsty glass. The pores in thirsty glasses are often in the range of 2 to 10 nm in diameter, and form continuous pathways through the glass. Internal surface areas may be as great as 200 m^2 g^{-1} of glass (Fig. 22) [88].

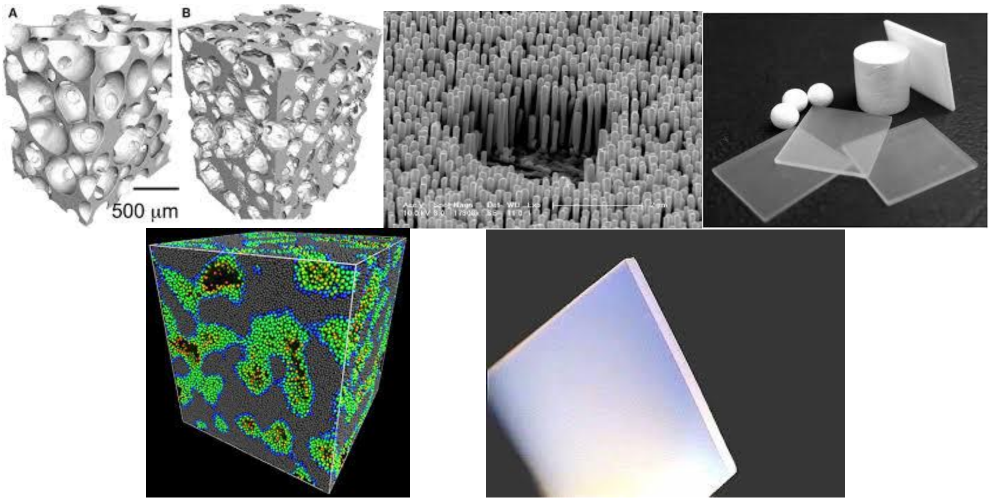

Figure 22. Microstructure and product form of porous glass [89].

3.25. Solid and Hollow Glass Spheres

Since glass forming melts are liquids, any droplet of melt allowed to fall freely through a sufficient distance will assume a spherical shape due to surface tension forces. Small spheres are routinely produced by allowing a stream of melt to flow through the bottom of a container. The stream is broken into small segments by an air jet or flame just below the container. If the temperature is high enough and the fall distance is great enough, these segments will become spherical before the melt solidifies. The same effect will occur if a pre-sized glass frit is used. In this case, the frit particles are heated in the upper portion of the vertical furnace, or drop tower, become fluid, and then are transformed to spheres as they fall through the hot zone. Frit particles can also be converted into spheres by blowing the frit through the flame of a gas jet. Small glass spheres can also be formed by a variation of a process used to form glass fibres. A stream of melt is poured onto a rotating disk. The melt is thrown off the edge of the disk and broken into small segments. If the disk is cool and the surrounding temperature is low, the segments will remain in fibre form. If, however, the disk is heated and the surroundings are hot enough to allow the glass to form spheres before freezing to a glass, small spherical beads will be formed [90]. Large glass spheres (marbles) are formed by cutting small gobs from a melt stream. These gobs fall onto a pair of counter-rotating screws with thread depth equal to one half the 27 desired marble diameters. The gobs are converted into spheres and cooled as the gobs travel down the length of the screw, where the finished marbles are collected. Formation of hollow glass spheres requires the release of gas from the starting material during the sphere formation (Fig. 23). The batch components are mixed in a liquid, which may include a “blowing agent” such as urea. This solution is spray dried to form uniform, but non-spherical particles. These particles are then introduced directly into the flame from a burner or dropped down a vertical furnace. As the particles melt, the blowing agents decompose, releasing gases which blow the molten sphere into a hollow shell. As the melt begins to cool, it becomes impermeable to any remaining gases, which prevent the collapse of the shell.

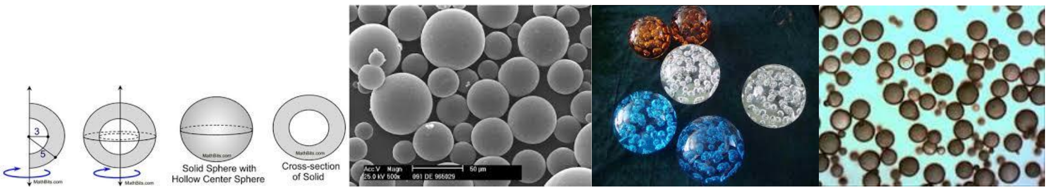

Figure 23. Glass spheres [91].

3.26. Self-Cleaning Glass

Self-cleaning glass is a specific type of glass with a surface that keeps itself free of dirt and grime (Fig. 24). The field of self-cleaning coatings on glass is divided into two categories: hydrophobic and hydrophilic. These two types of coating both clean themselves through the action of water, the former by rolling droplets and the latter by sheeting water that carries away dirt. Hydrophilic coatings based on titania, however, have an additional property: they can chemically break down absorbed dirt in sunlight.

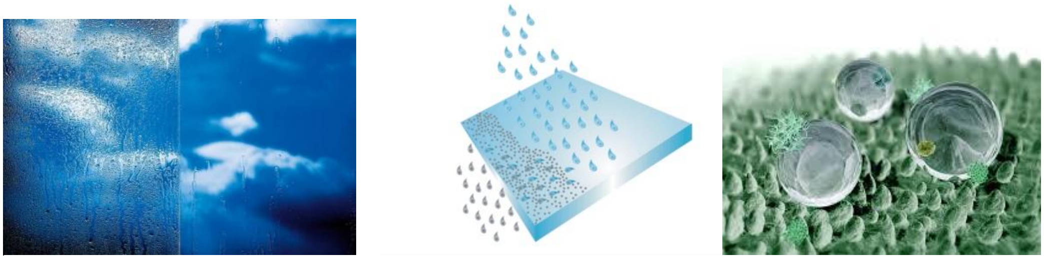

Figure 24. Self-cleaning glasses [92].

The requirements for a self-cleaning hydrophobic surface are a very high static water contact angle θ; the condition often quoted is $\theta > 160°$, and a very low roll-off angle, i.e. the minimum inclination angle necessary for a droplet to roll off the surface [93]. Several techniques are known for the patterning of hydrophobic surfaces through the use of moulded polymers and waxes, by physical processing methods such as ion etching and compression of polymer beads, and by chemical methods such as plasma-chemical roughening, which can all result in ultra-hydrophobic coatings [94]. While these surfaces are effective self-cleaners, they suffer from a number of drawbacks which have so far prevented widespread application. These coatings chemically break down dirt when exposed to light, a process known as photo catalysis. Despite the commercialization of a hydrophilic self-cleaning coating in a number of products, the field is far from mature; investigations into the fundamental mechanisms of self-cleaning and characterizations of new coatings are regularly published in the primary literature [95].

The glass cleans itself in two stages. The "photocatalytic" stage of the process breaks down the organic dirt on the glass using ultraviolet light and makes the glass super hydrophilic (normally glass is hydrophobic). During the following "super hydrophilic" stage, rain washes away the dirt, leaving almost no streaks, because water spreads evenly on super hydrophilic surfaces [96-97]. In

2001, Pilkington Glass announced the development of the first self-cleaning windows, Pilkington Activ™, and in the following months several other major glass companies released similar products. As a result, glazing is perhaps the largest commercial application of self-cleaning coatings to date. Titanium dioxide has become the material of choice for self-cleaning windows, and hydrophilic self-cleaning surfaces in general, because of its favourable physical and chemical properties. Not only is titanium dioxide highly efficient at photo catalysing dirt in sunlight and reaching the super hydrophilic state, it is also non-toxic, chemically inert in the absence of light, inexpensive, relatively easy to handle and deposit into thin films and is an established household chemical that is used as a pigment in cosmetics and paint and as a food additive [98]. The anatase phase is the most photocatalytic among its polymorphic structures. Moreover, ultraviolet irradiation creates surface oxygen vacancies at bridging sites, resulting in the conversion of relevant Ti^{4+} sites to Ti^{3+} sites which are favourable for dissociative water adsorption. These defects presumably influence the affinity to chemisorbed water of their surrounding sites, forming hydrophilic domains, whereas the rest of the surface remains oleophilic. Hydrophilic domains are areas where dissociative water is adsorbed, associated with oxygen vacancies that are preferentially photo generated along the [001] direction of the (110) plane; the same direction in which oxygen bridging sites align [99].

3.27. Bioactive Glass

One of the first major developments leading to saving of life was the optical microscope. Invention of the microscope using glass spheres to focus light on objects was the seminal step towards discovering microscopic life forms of bacteria, viruses and fungi, e.g. pathogens. This discovery led to treatment and eventually elimination of many diseases that was instrumental in creating the improvements in public health and healthcare that occurred in the 19th and 20th centuries. This enormous social change can be termed a revolution in Life Preservation. A major consequence of life preservation was an expansion of the human lifespan from an average of 45 years to 80+ years. It is projected that by 2050 there will be more than 1 billion people alive on earth aged 60 years old or older. Second revolution in healthcare has occurred during the last 50 years, i.e. a revolution in Tissue Replacement. From the age of 30 years old onwards, all tissues progressively deteriorate. Thus, an increase in length of life is usually accompanied by a decrease in quality of life. To repair, replace and restore the function of hips, knees, eyes, ears, teeth, hearts, kidneys, etc. is now commonplace. Human “spare parts” is a huge business worth tens of billions of dollars. The first generation of materials used for tissue replacement was selected by surgeons and materials scientists and engineers to be as biologically inert as possible; therefore they are called bio-inert materials. Corrosion resistant metals and insoluble, non-toxic polymeric materials became the standard biomaterials. However, all bio-inert materials are a compromise because of the incompatibility of the interface between the material and living tissue. Tissue breakdown and loosening over time is a common mode of failure of devices made from bio-inert materials. Stress shielding due to mismatch of elastic moduli of high strength biomaterials and bone leads to resorption of bone and long term implant failure and revision surgeries. Wear of articulating surfaces also leads to creation of wear debris and osteolysis leading to degradation of the interfacial supporting bone. An alternative, second generation concept for tissue replacement using a special type of glass was discovered in 1969. This concept of “bioactivity” has made it possible to expand greatly the approaches taken in tissue replacement. Bioactive materials form a bond with living tissues (Fig. 25). The chronology of discovery and development of bioactive glasses become an important range of clinical materials used worldwide for tissue replacement and regeneration. Recent research has discovered that glasses with especially high levels of bioactivity can also be used to activate genes to stimulate the body to repair itself. This discovery has led to the concept of using slowly resorbable bioactive glasses as a third generation of biomaterials designed for tissue regeneration. In 1991 it was discovered that bioactive glasses could be made using a low temperature sol-gel chemical process. A much broader compositional range for bioactivity was possible with bioactive gel-glasses due to the high surface area of the final product. Sol-gel processing also made it possible to produce bioactive gel glass foams with the highly controlled hierarchical porosity required for cell infiltration into large interconnected 3-D pores, a requirement for viable tissue engineered constructs A comprehensive review by Dr. Julian R. Jones describes development of such TE constructs, historical aspects and other recent topics in this field. The discovery of bonding of bone to specific compositions of glasses led to a new, second generation of bioactive materials for tissue replacement. Understanding gene activation of human progenitor cells by controlled release of ionic dissolution products from bioactive glasses provides the basis for design of third generation biomaterials that can be used for tissue regeneration. Use of bioactive glass particulate in prevention of oral disease and damage is an example of a fourth generation of biomaterials bioactive materials for prevention of tissue damage. Bioactive glass science and technology continues to be at the forefront of providing innovative approaches to medicine [100-102].

Figure 25. Bioactive glasses [103].

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