Conference Paper

Glass Material and Their Advanced Applications

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Abstract

The present review summarizes the progress made in the area of glass science and also propose new definition of glass. The applications of glasses in everyday life and especially glasses used for light emitting devices, optical displays, optical fibers, amplifiers, lasers which are of special interest. Among these materials rare earth ions doped glasses are of great important to optoelectronics and are widely used in optical fiber amplifiers and solid state high power lasers for telecommunications and light emitting diodes. Optical fiber revolutionized the glass industry and is been used as sensing applications which depends upon light wavelength, fiber parameters, fiber geometry, and metal layer properties. Even smart glasses play a vital role in the medical field.

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1. What is Glass?

Several theoretical and empirical models have been proposed to explain the definition of glass in the literature for almost a century and even more, invoking control parameters such as density, temperature, gas like or solid like structures, specific molecular shape and interactions. Many previous literatures are given definitions on glass but in this review article we propose an improved definition.

> **”Glass is an amorphous solid which exhibits glass transition temperature by arresting the kinetics below supercooled liquid region when bypassed crystallization”**

Here we list all possible definition for glass as previously published and available in literature:

Sl No	Definition	Author / Publisher (Y)
1.	*“Glasses are under cooled solidified melts.”*	*Gustav Heinrich Johan Apollon Tammann (1933) [1]*
2.	*“A material formed by cooling from the normal liquid state which has shown no discontinuous change in properties at any temperature, but has become more or less rigid through a progressive increase in its viscosity.”*	*H. Doremus (1973) [2]*

Sl No	Definition	Author / Publisher (Y)
3.	*"An inorganic product of fusion which has been cooled to a rigid condition without crystallizing"*	*American Society for Testing Materials (ASTM)*
4.	*"Glass is an X-ray amorphous material that exhibits the glass transition. This being defined as that phenomenon in which a solid amorphous phase exhibits with changing temperature (heating) a more or less sudden change in its derivative thermodynamic properties such as heat capacity and expansion coefficient, from crystal-like to liquid-like values."*	*J. Wong and C. Austen Angell (1976) [3]*
5.	*"Amorphous solids that are obtained by fast cooling a molten mass averting its crystallization."*	*Eduardo Mari (1976) [4]*
6.	*"A noncrystalline solid that presents the phenomenon of glass transition."*	*Jerzy Zarzycki (1982) [5]*
7.	*"A solid obtained by supercooling a liquid and that is X-ray amorphous."*	*K.J.Rao (2002) [6]*
8.	*"Glasses are thermodynamically non-equilibrium kinetically stabilized amorphous solids, in which the molecular disorder and the thermodynamic properties corresponding to the state of the respective under-cooled melt at a temperature T^* are frozen-in. Hereby T^* differs from the actual temperature T."*	*Ivan S. Gutzow and Juern W. Schmelzer (2013) [7]*
9.	*"Glass is a solid having a non-crystalline structure, which continuously converts to a liquid upon heating."*	*Arun K. Varshneya [8-9]*
10.	*"Any of various amorphous materials formed from a melt by cooling to rigidity without crystallization"*	*Merriam-Webster [10]*
11.	*"A hard, brittle, non-crystalline, more or less transparent substance produced by fusion usually consistingof mutually dissolved sil-ica and silicates that also contain soda and lime, as in the ordinary variety used for windows and bottles. "*	*Dictionary.com [11]*
12.	*" A hard, brittle substance, typically transparent or translucent, made by fusing sand with soda and lime and cooling rapidly. It is used to make windows, drinking containers, and other articles."*	*English Oxford Living Dictionary [12]*
13.	*"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 that exhibits a glass transition when heated towards the liquid state".*	*Wikipedia [13]*
14.	*"Glass is an isotropic material with relaxation time $\gg 10^3$ s and $\chi \sim 1$". χ was defined as a normalized correlation range, which is zero for a dilute gas and close to 1 for a normal liquid or a glass.*	*Alfred R. Cooper and Prabhat K. Gupta (1975) [14]*
15.	*"Glass is a nonequilibrium, non-crystalline state of matter that appears solid on a short time scale but continuously relaxes towards the liquid state."*	*general public and young students [15]*
16.	*"Glass is a nonequilibrium, noncrystalline condensed state of matter that exhibits a glass transition. The structure of glasses is similar to that of their parent supercooled liquids (SCL), and they spontaneously relax toward the SCL state. Their ultimate fate, in the limit of infinite time, is to crystallize."*	*advanced students, researchers, professors [15]*
17.	*"An amorphous solid completely lacking in long range, periodic atomic structure, and exhibiting a region of glass transformation behavior."*	*James E. Shelby [16]*
18.	*"Any material, inorganic, organic, or metallic, formed by any technique, which exhibits glass transformation behavior is a glass."*	*James E. Shelby [16]*
19.	*"Glass is a non-crystalline solid. That is, it does not consist of an ordered arrangement of its constituent cations and anions."*	*R.C. Ropp [17]*

Sl No	Definition	Author / Publisher (Y)
20.	*“Conventionally: cooled oxide melts”*	*R. K. Brow [18]*
21.	*“Glass is an amorphous solid exhibits glass transition temperature by arresting the kinetics below supercooled liquid region when bypassed crystallization.”*	**Present work**

2. Concept of Glass Materials

It was not clearly known when glasses were used / formed first but it is believed that glasses were first obtained by natural process (Obsidian), a glass formed by volcanic outburst of the molten magma from the entrails of the earth which when cooled to form glasses. Concept of using glass materials were known and has been documented in East Africa as early as 150,000 years ago and it was used at least to the end of the Stone Age in the New World, about 1500 years ago. Literary evidences reveal that the antiquity of Indian glass should be as old as *Vedic* period (use of the Sanskrit word *Kacha* for glass is found in *Yajurveda* dated -1200 B.C. and in *Shathapatha and Taithriya Brahmanas* dated -1000 B.C.). Analysis of glasses from Takshashila reveals that addition of Ca and Mg oxides and also of alumina was widely known even in 6^{th} century B.C. It is interesting to note that glass bangles have been an essential ornamental wear of Hindu women even in the pre- Buddhistic period *[6]* and still the tradition is followed. In recent times usage of glasses became inevitable in our daily life such as smart phones etc.

3. How Important is Glass

Glass is most attractive due its transparency and can be created in any shape for artistic displays. The most important products of the glass is, container glass sector and flat glass sector which are used as bottles for wine, beer, spirits, soft drinks, window panels, glass artistic chandeliers, glass doors and wide neck jars for the food industry. These products are generally considered as commodity items, but another important part of the sector is the production of higher value containers for the pharmaceutical and perfume industries. Glass industry has also been extended its variety of products depending on the requirement due to their cost effectiveness, eco-friendly and recyclable importance. Several sectors based on the product requirements are categorized below:

1. Container Glass
2. Flat Glass

3. Continuous Filament Glass Fibre
4. Domestic Glass
5. Special Glass (including water glass)
6. Mineral Wool (With two sub-sectors, glass wool and stone wool.)
7. Ceramic Fibre
8. Frits
9. Laser glasses (including special glasses*)
10. Display glasses

*Special glasses: This is an extremely diverse grouping, which covers the specialized low volume, high value products, the compositions of which vary very widely depending on the required properties of the products. Some of the applications include: specialist borosilicate products; optical glass, glass for electro technology and electronics; cathode ray tubes; fused silica items; glass seals; X-ray tubes; glass solders; sintered glass; electrodes; and glass ceramics.

4. Glass Former and Types

Glass formation occurs in materials of all chemical types; covalent, ionic, molecular, metallic and hydrogen bonded materials. Glasses have been made from elements, simple chemical compounds, complex organic molecules, salt mixtures and alloys. There is no particular advantageous way of grouping glass forming materials. Examples of variety glass forming materials are listed in Table 1. Main oxide elements are classified depending on their role to modify / change their glass structure, color and their properties:

Network Forming Oxides: SiO_2, B_2O_3, P_2O_5, GeO_2

Network Modifying Oxides: Na_2O, K_2O, Li_2O, CaO, BaO, MgO, SrO

Intermediate Oxides: Al_2O_3, PbO, ZnO, ZrO_2

Redo Active Oxides: Sulphates: Na_2SO_4, $CaSO_4$

Oxides: As_2O_3, Sb_2O_3, CeO_2

Chlorides: NaCl

Nitrates: KNO_3, $NaNO_3$

Coloring Agents:

Fe_2O_3, Cr_2O_3, CoO, Mn_2O_3, Se, Rare-Earth oxides, Sulphides, Selenides,

Cr^{++} blue, Cr^{+++} green, Co^{++} pink, Mn^{++} orange, Fe^{++} blue-green, Au (4-10 nm) pink, Au (10-75 nm) ruby, Au (75-110 nm) green, Au (110-170 nm) brown *[19-20]*.

TABLE 2: Examples of glass forming systems (Doremus, 1973).

Types	Examples
Elements	S, Se, Te, P
Oxides	B_2O_3, SiO_2, GeO_2, P_2O_5, As_2O_3, Sb_2O_3, In_2O_3, Tl_2O_3, Sn_2O_3, PbO_2, SeO_2. (glass formers) TeO_2, SeO_2, MoO_2, WO_3, Bi_2O_3, Al_2O_3, V_2O_5, SO_3, etc. (conditional glass formers)
Sulfides	As_2S_3, Sb_2S_3 and various sulphides of B, Ga, In, Te, Ge, Sn, N, P, Bi, CS_2, Li_2S-B_2S_3, P_2S_5-Li_2S etc.
Selenides	Various selenides of Tl, Sn, Pb, As, Sb, Bi, Si, P
Tellurides	Various tellurides of Tl, Sn, Pb, As, Sb, Bi, Si, P
Halides	BeF_3, AlF_3, $ZnCl_2$, Ag(Cl, Br, I), Pb(Cl_2, Br_2, I_2) & multi-component mixtures.
Nitrates	KNO_3-$Ca(NO_3)_2$ and many other binary mixtures containing alkali and alkaline earth nitrates.
Sulphates	$KHSO_4$, K_2SO_4-$ZnSO_4$-Na_2SO_4 and other binary and ternary mixtures.
Carbonates	K_2CO_3-$MgCO_3$

5. Melt Quenching Technique

The raw materials (oxides) discussed above is used as starting batch materials to prepare glass. The entire chemicals were weighted according to stoichiometric ratio and mixed homogeneously to fine powder in a pestle and mortar, then transferred to crucible and heated until melting point is reached. The melt is stirred for homogeneous mixing using platinum stirrer if required and then quickly poured on a brass block / stainless block kept at 300°C, and then pressed with brass disc / stainless discs to get glass. Once the glass is obtained they were subject to cut for required shape and size using cutting machine and then mirror polished using polishing machine the details are depicted in the Fig.1 for reader.

6. Glass: Everyday Life Application

Glass and light are inseparable. From time immemorial the refractory properties and transparency of glass have been used to protect, intensify and diffuse light. Glass is associated with the energy of light firstly for making a perfect match with lantern use. Cold countries were fond of building homes with glass windows so that they can have a good view and warm inside without any UV rays entering the home, nonetheless brown

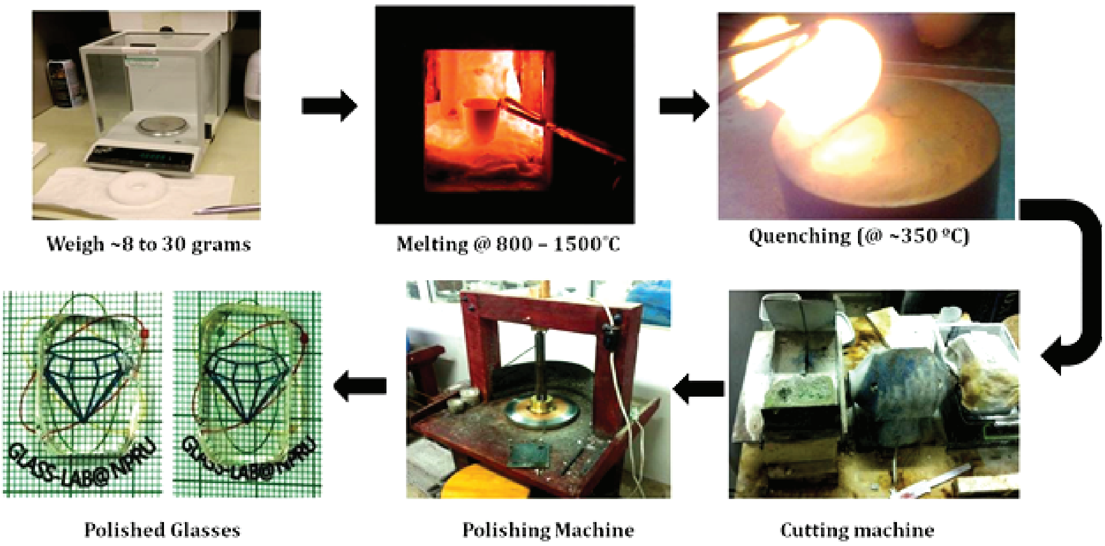

Figure 1: Synthesis of Glass.

/ colored bottles were very popular for storing whiskey and other beverages just not to spoil the flavor and protect the liquid from sun light.

Later 1970's glasses were began to popular for their glass reinforced plastics which revolutionized the automobile / ship industry due their weightless and good strength. Then late 1980's glasses were used to reinforce with concretes and popularized in medical field after its invention. Utilizing various glass fibers in the composite results in beneficial mechanical strengths of a tubular Fiber Rein-enforced Composites structures (used for bone replacements). Glass beads were also used to attract women's due to their refractive lustrous shining property and cost effective. There is been plenty of room to describe the characteristics and usage of glass which has been unknowingly striking our daily life activities as shown in the Fig.2. "A mystery of glass can be understood only when we examine its transparency property".

7. Glass: Advanced Photonic Material Application

Researchers were concerned with the improvement of solid state lasers utilize the luminescence of RE ions in glasses and crystals. The Nd: YAG laser is probably the most central triumph from this period *[28]*, and there is persistent interest in novel rare earth doped materials for lasers. All the rare earth ions (Pr^{3+}*[29]*, Ce^{3+}*[30]*, Nd^{3+}*[31]*, Sm^{3+}*[32]*, Eu^{3+}*[33]*, Gd^{3+}*[33]*, Tb^{3+}*[34]*, Dy^{3+}*[35]*, Ho^{3+}*[36]*, Er^{3+}*[37]*and Tm^{3+}*[38]*) have their respective applications in the production of optical devices, photonic materials to extend advanced lasers, optical amplifiers to optoelectronics and optical communication applications in the field of RE luminescence. More recently, however, optoelectronics has

Figure 2: Glasses used in various field. (*[courtesy: lanterns: 21 glass bottles: 22, coloured glass: 23, Glass beads: 23,Glass fibre: 24 Plasticon - 25, fiber-reinforced composite femur rabit bone: 26, BioMin toothpaste- 27]*)

emerged as the principal area of research into RE luminescence, and the current article therefore focus on the different ways in which RE luminescence has been interpreted.

White LED's were of special interest in recent times and many researchers are working to mimic the characteristics of the Phosphor using rare-earth doped glasses as shown in the Fig.3. The most common approaches to produce white light are:

(1) Mixing of Red, Green, and Blue LEDs,

(2) Blue LED chip fabricated yellow phosphor on top,

(3) Ultraviolet (UV) LED chip with a combination of two (blue and yellow) or three (red, blue, and green) phosphors, and

(4) UV LED chip combined to a single multi-chromatic phosphor.

As discussed above, by triple-doping with Tm_2O_3(Blue), Tb_4O_7(Green) and Eu_2O_3 (Red) in the Lithium alumino-borate glass matrix represents a promising means to achieve white light emission as shown in Fig.3.

8. Scintillating Glasses for Medical Applications

The CaGdSiB glass doped with 0.30 mol% Eu^{3+} *[39]* are compared with ($Bi_4Ge_3O_{12}$-Bismuth Germanate) BGO crystal show the comparative integral scintillation efficiency as shown in Fig.4. The integral scintillation efficiency of glass is about 13% of the BGO. These Glasses perform as similar to their crystal counterpart and better luminescence decay time than crystal with few millisecond that it can be used in the integration mode of scintillation for the X-ray imaging inspection systems in medical and industrial purpose as well as portal imaging system at MeV energies.

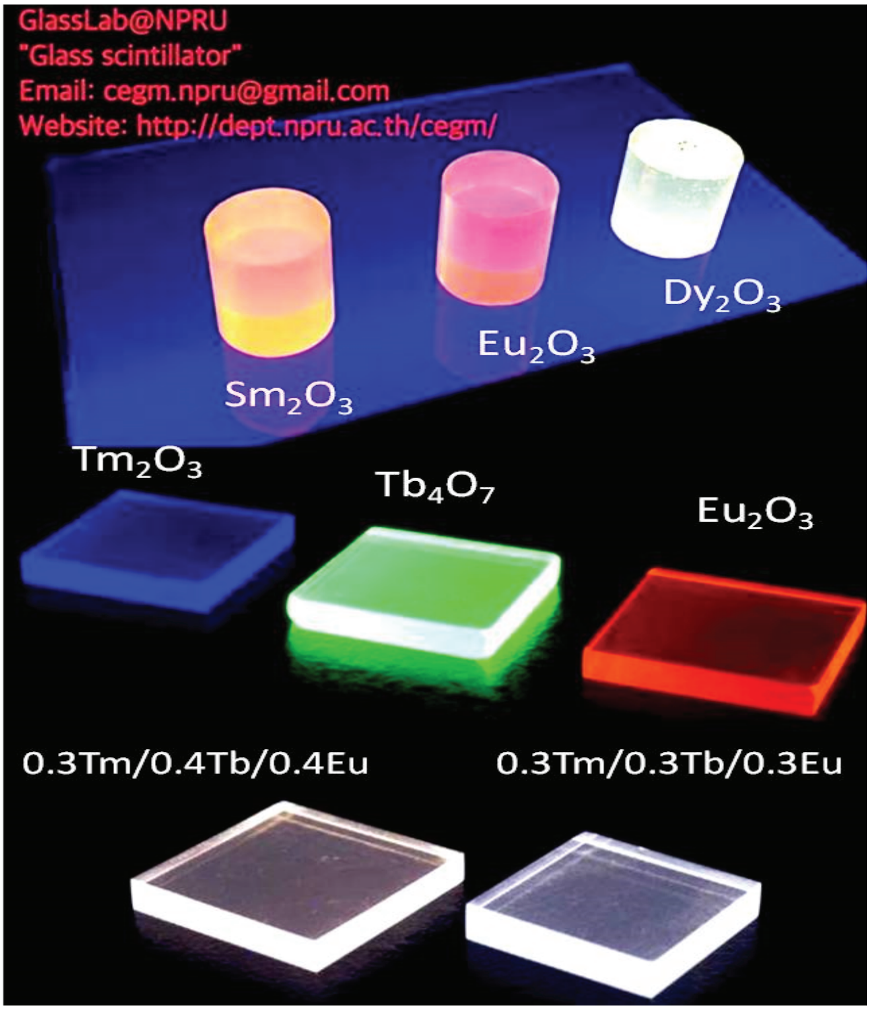

Figure 3: Luminescent glasses *[courtesy: 23, 38]*.

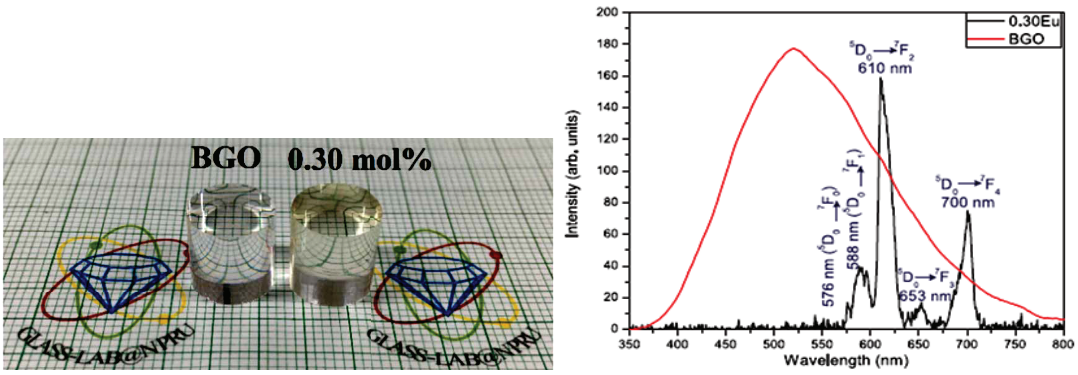

Figure 4: BGO and 0.30 mol% Eu^{3+} doped CaGdSiB glass *[39]*.

9. Smart Glasses for Computing

The release of the Google Glass device into the public realm, have changed further dimension of glass. People are now able to buy a variety of different wearable computing devices and integrate them into their daily lives. It goes beyond saying that wearable computing does not only incorporate smart glasses, but also smart watches, fitness-trackers and all other technology that could be worn on the body and change everyday life. Although other devices will be partly mentioned and discussed in this dissertation, the main focus lies on smart glasses. Google Glass works similar to a smart phone which displays information in front of the glasses via a prism located above eye as shown in the Fig.5. Eyewear Computers are expected to be the ”next big thing” in the evolution of mobile computing (Mc Naney et al., 2014 *[40]*). The first device to actually be commercially available was ”Google Glass”. The device has been designed with the intention to replicate normal eyeglasses as much as possible.

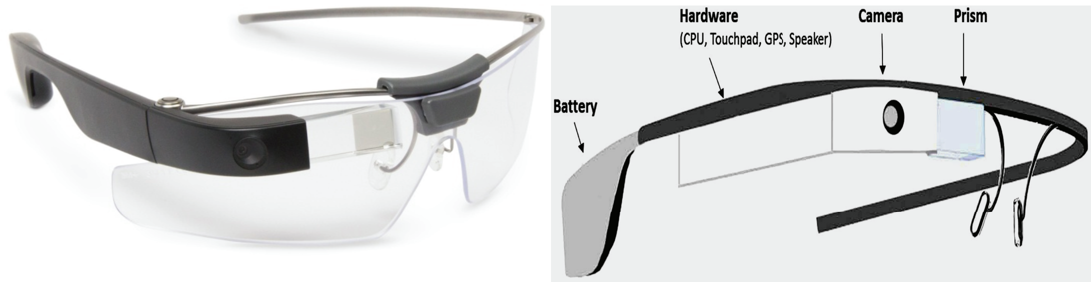

Figure 5: Google smart glasses *[courtesy: Google glass - 41, 42]*.

10. Conclusion

The paper summarizes about all possible definitions available for ’glass’ and also been reviewed scientific and technological background required for understanding of glass applications. We propose our new definition keeping in mind that the complexity of glassy state which can be applied technically and termed as “standard” form for all researchers and academicians, this statement combines features of both liquids and solids state reasoning and provides distinctive characteristics for all certain scientific community. Research and development (R&D) stands at the meeting point where tailoring between material composites and glasses together could bring an further new inventions in reinforced glass materials. Advanced glass science technology such as: White light generation has been demonstrated by mixing with proper rare-earth ions to generate their potential use as white luminescence materials. Smart glasses in

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upcoming years could be rule the entire world and termed as ”next big thing” in the evolution of mobile computing.

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