NASA
National Aeronautics and
Space Administration

Washington, D.C.
20546

JUN 7 1982

Reply to Attn of: GP-4

TO: NST-44/Scientific and Technical Information Division
Attn: Shirley Peigare

FROM: GP-4/Office of Assistant General Counsel
for Patent Matters

SUBJECT: Announcement of NASA-Owned U.S. Patents in STAR

In accordance with the procedures agreed upon by Code GP-4 and Code NST-44, the attached NASA-owned U.S. Patent is being forwarded for abstracting and announcement in NASA STAR.

The following information is provided:

U.S. Patent No. : 3,785,836

Government or Contractor Employee: United Technologies Corp
Hartford, CT

NASA Case No. : HQN-10,931-2

NOTE - If this patent covers an invention made by a contractor employee under a NASA contract, the following is applicable:

YES ☒ NO ☐

Pursuant to Section 305(a) of the National Aeronautics and Space Act, the name of the Administrator of NASA appears on the first page of the patent; however, the name of the actual inventor (author) appears at the heading of Column No. 1 of the specification, following the words "...with respect to an invention of...."

JUN 1982
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(NASA-Case-HQN-10931-2) HIGH MODULUS INVERT ANALOG GLASS COMPOSITIONS CONTAINING BERYLLIA Patent (National Aeronautics and Space Administration) 6 p CSCL 11C

N82-29452

Unclas
00/27 22766

PO-1050
(5/69)

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,785,836 Dated January 15, 1974

Inventor(s) JAMES F. BACON

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 2, line 15: "ZnO_2" should read --ZrO_2--.

Signed and sealed this 21st day of May 1974.

(SEAL)
Attest:

EDWARD M.FLETHCER,JR.
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents

Revoked W-1040
6-7-82

HQN-10,931-2

United States Patent [19]

Bacon

[11] **3,785,836**

[45] **Jan. 15, 1974**

[54] **HIGH MODULUS INVERT ANALOG GLASS COMPOSITIONS CONTAINING BERYLLIA**

[75] Inventor: **James F. Bacon,** Manchester, Conn.

[73] Assignee: **United Aircraft Corporation,** East Hartford, Conn.

[22] Filed: **Apr. 21, 1972**

[21] Appl. No.: **246,295**

Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 874,674, Nov. 6, 1969, abandoned.

[52] **U.S. Cl.** **106/50,** 106/52, 106/54
[51] **Int. Cl.** **C03c 3/04**
[58] **Field of Search** 106/50, 52, 54

[56] **References Cited**

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Primary Examiner—Helen M. McCarthy
Attorney—John D. Del Ponti

[57] **ABSTRACT**

Glass compositions having a Young's modulus of at least 15 million psi and a specific modulus of at least 110 million inches consisting essentially of, in mols, 10–45% SiO_2, 2–15% Li_2O, 3–34% BeO, 12–36% of at least one bivalent oxide selected from the group consisting of CaO, ZnO, MgO and CuO, 10–39% of at least one trivalent oxide selected from the group consisting of Al_2O_3, B_2O_3, La_2O_3, Y_2O_3, Fe_2O_3 and the mixed rare earth oxides, the total number of said bivalent and trivalent oxides being at least three, and up to 10% of a tetravalent oxide selected from the group consisting of ZrO_2, TiO_2 and CeO_2.

3 Claims, No Drawings

HIGH MODULUS INVERT ANALOG GLASS COMPOSITIONS CONTAINING BERYLLIA

BACKGROUND OF THE INVENTION

This application is a continuation-in-part of application Ser. No. 874,674 filed Nov. 6, 1969 by the same inventor, now abandoned.

The invention described herein was made in performance of work under a NASA contract and is subject to the provisions of Section 305 of the National Aeronautics and Space Act of 1958, Public Law 85-568 (72 Stat. 435; 42 USC 2457).

This invention relates to high modulus glass and glass compositions and more particularly relates to invert beryllia-containing glasses having a Young's modulus of at least 15 million psi and a specific modulus of at least 110 million inches.

In the present age, there has been a continuing search for glasses of high modulus and low density, capable for use as reinforcements, preferably in fiber form, in composite structures ranging from high strength missile cases and helicopter blades to propeller spinners and gas turbine engine parts. Glass offers promise as the reinforcements in such applications since it may be quickly and cheaply produced by relatively conventional techniques and, generally, presents no compatibility problems with the matrix materials with which it is normally used. There is a need, however, to provide glass formulations which possess a high modulus of elasticity, and more particularly a high modulus/density ratio. It is more preferable if the glass possess the aforementioned two characteristics in combination with an appropriate liquidus-viscosity relationship to permit fiberization.

SUMMARY OF THE INVENTION

The glass compositions of the present invention are a high modulus, low density invert glass which, in their preferred form consist essentially of a combination of silica, the monovalent oxide of lithium, beryllia, one or more bivalent oxides selected from the group consisting of CaO, ZnO, MgO and CuO, at least one trivalent oxide selected from the group consisting of Al_2O_3, B_2O_3, La_2O_3, Y_2O_3, Fe_2O_3 and the mixed rare earth oxides. More particularly, the inventive glasses contemplated are those having a Young's modulus of at least 15 million psi and a specific modulus of at least 110 million inches which consist essentially of 10–45 mol % SiO_2, 2–15 mol % Li_2O, 3–34 mol % BeO, 12–36 mol % of at least one bivalent oxide selected from the group consisting of CaO, ZnO, MgO and CuO, 10–39 mol % of at least one trivalent oxide selected from the group consisting of Al_2O_3, B_2O_3, La_2O_3, Y_2O_3, Fe_2O_3 and the mixed rare earth oxides, the total number of bivalent and trivalent oxides being at least three, and up to 10% of a tetravalent oxide selected from the group consisting of ZrO_2, TiO_2 and CeO_2. It will be noted that the glasses are comprised of only one alkali oxide and a combination of alkaline earth oxides and trivalent and tetravalent oxides.

More particularly, the inventive glasses are those having a Young's modulus of at least 15 million psi and a specific modulus of at least 110 million inches which consist essentially of 10–45 mol % SiO_2, 2–15 mol % Li_2O, 3–34 mol % BeO, 12–36 mol % of at least one bivalent oxide selected from the group consisting of CaO, ZnO, MgO and CuO, MgO being present in the amount of 2–24 mol %, 10–39% of at least one trivalent oxide selected from the group consisting of Al_2O_3, B_2O_3, La_2O_3, Y_2O_3, Fe_2O_3 and the mixed rare earth oxides, the total number of said bivalent and trivalent oxides being at least three, and up to 10 mol % of a tetravalent oxide selected from the group consisting of ZrO_2, TiO_2 and CeO_2. Preferably, the bivalent oxides are present in amounts of up to 30 mol % CaO, up to 15 mol % ZnO, 2–24 mol % MgO and up to 10 mol % CuO and the trivalent oxides are present in amounts of up to 16 mol % Al_2O_3, up to 14 mol % B_2O_3, up to 10 mol % La_2O_3, up to 14 mol % Y_2O_3, up to 3 mol % Fe_2O_3 and up to 12 mol % mixed rare earth oxides. The tetravalent oxides, when present, are in amounts of up to 10 mol % ZnO_2, up to 4 mol % TiO_2 and up to 3 mol % CeO_2.

In several preferred embodiments, formulations having a Young's modulus of at least 19 million psi and a specific modulus of at least 150 million inches that are readily formed into fibers having a relatively high fiber modulus, above 16 million psi, are described. These include glasses consisting essentially of about, in mols:

39% SiO_2, 6% Li_2O, 25% BeO, 6% CaO, 12% MgO, 12% Al_2O_3, 10% Y_2O_3 and 2% CeO_2;

42–45% SiO_2, 3% Li_2O, 15–18% BeO, 12–15% MgO 12–15% Al_2O_3 and 7–10% Y_2O_3; and

42% SiO_2, 3% Li_2O, 15% BeO, 3% ZnO, 15% MgO, 12% Al_2O_3 and 10% Y_2O_3.

In the latter two formulations, the glasses have a Young's modulus of at least 19 million psi, a specific modulus of at least 160 million inches and a fiber modulus of at least 18 million psi.

In several formulations, glasses having a Young's modulus of at least 20 million psi with a specific modulus of at least 150 million inches are described.

The features of the invention will be discussed in greater detail in the description which follows or will be evident therefrom to those skilled in the art.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

In general, it will be appreciated that the glasses of the present invention are a combination of silica, the alkali oxide lithia, beryllia and a combination of alkaline earth, trivalent and tetravalent oxides. Like known invert glasses, such as those of Trap and Stevels, which, however, are comprised of several alkaline oxides and several kinds of alkaline earth oxides but do not include any trivalent oxides, the glasses of the present invention contain so little silica that a continuous silica network is not possible. It will be appreciated that such glasses may be characterized by a structural parameter Y which denotes the average number of bridging 0 ions. According to a rule of Zachariason for silicate glass formation, which postulates that these silicate glasses should have a three-dimensional network in which the SiO_4 tetrahedra share approximately three of their four oxygens with neighboring tetrahedra, commercial silicate glasses have Y values between 3.0 and 3.5. For ternary soda lime silica glasses it is not possible to lower appreciably the parameter Y below 3.0 and still obtain stable glasses. In contrast, the strongly "basic" or invert glasses of this invention generally have Y values of 2.0 or below and in some cases values of zero. In calculating the parameter Y, the following formula is used:

$$Y = 6 - 200/P$$

where P = mol % SiO_2. It is readily seen that for an orthosilicate such as Na_4SiO_4 with 33⅓ mol % SiO_2, Y has a value of 0 while for a meta silicate with a 40 mol % SiO_2, Y has a value of 1.0 and leads to the formation of a single tetrahedra. As will be seen hereinafter, all of the glasses of this invention have a total SiO_2, content of less than 50 mol %, more precisely 45 mol % or less, and in some cases as little as 10%. It thus becomes apparent that the prior concept that silicate glasses must have a three-dimensional network of SiO_4 tetrehedra cannot be maintained, even if the network modifiers are cations of the noble gas type. It is therefore considered that the present glasses lie between the tetrahedral structures of the conventional special glasses such as the Morey-Eastman Kodak optical glasses. In any event, the advantages of the present glasses will be recognized, not only because of their consistently high Young's modulus, specific modulus and, in some cases, ready fiberizability, but also because they permit lowering of the liquidus temperature, greatly increase the field of glass formation and allow the study of the effect of the atomic structure of a glass upon its properties. As indicated above, invert glasses have been made according to the present invention with an elastic modulus in excess of 20 million pounds per square inch.

It has been determined that while low atomic number oxide components are a primary choice in achieving high modulus glass compositions of high specific modulus, they are not the only choice since contributions per mol % to Young's modulus of several of the heavier elements were high, as follows:

Oxide	Contribution to Young's modulus per mol % (kilobars)
SiO_2	7.3
Al_2O_3	12.1
CaO	12.6
Li_2O	7.0
B_2O_3	7.2
ZnO	1.72 and rising with increasing R_2O
TiO_2	13.3
BeO	19.0
ZrO_2	18.9
MgO	12.0 and rising with decreasing R_2O and SiO_2 to 14.8
Y_2O_3	24.3
La_2O_3	22.4
Ce_2O_3	18.6

It thus has been found that the judicious use of the heavier oxides is obviously to be considered in cases where they improve viscosity, surface tension, working range and other characteristics.

It is to be noted that several rules which are predicated on experience with glasses comprised of silica networks do not hold true for the non-network invert glasses. It has, for example, been found that substitution of B_2O_3 for SiO_2 fails to decrease the density while the substitution of CuO for ZnO markedly lowers the density. It has also been found that the addition of beryllia to glasses having appreciable borate content does not raise Young's modulus as much as does the addition of beryllia to a silica-alumina-magnesia glass.

All of the compositions investigated were made by melting 500 gram batches of the specified raw materials in high purity (99.9%) alumina crucibles in air using kilns heated by Super-Kanthal hairpin electrical resistance elements. The starting materials used were 5 micron particle-size high purity silica, high purity alumina of 325 mesh, laboratory reagent grade magnesium oxide, 99.9% lanthanum oxalate, and other comparable materials such as reagent grade zinc carbonate or calcium carbonate. These materials yielded a water-white optical grade glass free of seed, stone and bubbles when properly compounded and held at temperatures of 1,000°–1,650° C for at least 2 hours. With the above technique, alumina crucibles of even slightly lower purity (99.3–99.7%) cannot be used. It is recognized however that the glasses may be prepared in beryllia crucibles in air and in the same kilns or in platinum crucibles in air in a platform kiln or in tungsten crucibles in purified argon or vacuum atmospheres.

The compositions of some of the representative glasses formulated in the course of the experimental program are set forth in Table I.

Table I

Compositions of Representative Glasses (Mol Percent)

Ex.	SiO_2	Li_2O	BeO	CaO	ZnO	MgO	CuO	Al_2O_3	B_2O_3	La_2O_3	Y_2O_3	Fe_2O_3	Re_2O_3	ZrO_2	TiO_2	CeO_2
1	30	12	22	12	—	12	—	12	—	—	—	—	—	—	—	—
2	25	15	15	—	15	15	—	15	—	—	—	—	—	—	—	—
3	30	10	10	—	10	20	—	10	—	—	10	—	—	—	—	—
4	30	10	10	—	10	20	—	10	—	—	—	—	—	10	—	—
5	25	10	15	—	10	20	—	10	—	—	10	—	—	—	—	—
6	30	10	10	—	10	20	—	10	—	10	—	—	—	—	—	—
7	24	13	24	13	—	13	—	13	—	—	—	—	—	—	—	—
8	25	10	10	—	10	15	—	10	—	—	10	—	—	10	—	—
9	30	10	20	—	10	10	—	10	—	10	—	—	—	—	—	—
10	24	12	3	12	8	16	—	3	10	—	—	—	12	—	—	—
11	10	8	34	30	4	2	—	—	6	4	—	—	—	—	2	—
12	24	12	14	12	—	12	—	—	10	—	—	—	12	—	4	—
13	39	6	25	6	—	12	—	12	—	—	10	—	—	—	—	2
14	25	5	3	3	—	20	2	8	14	—	14	3	—	—	3	—
15	45	3	15	—	—	15	—	12	—	—	10	—	—	—	—	—
16	45	3	15	—	—	15	—	15	—	—	7	—	—	—	—	—
17	45	3	18	—	—	12	—	15	—	—	7	—	—	—	—	—
18	42	3	15	—	—	15	—	15	—	—	10	—	—	—	—	—
19	42	3	15	—	3	15	—	12	—	—	10	—	—	—	—	—
20	42	3	15	—	—	20	—	10	—	—	10	—	—	—	—	—
21	40	5	18	—	—	18	—	9	—	—	10	—	—	—	—	—
22	40	2	18	—	3	18	—	9	—	—	10	—	—	—	—	—

Table I – Continued

Compositions of Representative Glasses (Mol Percent)

Ex.	SiO_2	Li_2O	BeO	CaO	ZnO	MgO	CuO	Al_2O_3	B_2O_3	La_2O_3	Y_2O_3	Fe_2O_3	Re_2O_3	ZrO_2	TiO_2	CeO_2
23	16	10	16	16	—	16	—	16	—	—	10	—	—	—	—	—
24	29	6	15	2	6	10	2	10	10	—	10	—	—	—	—	—
25	39	6	15	2	6	10	—	10	—	—	10	2	—	—	—	—
26	39	6	6	—	—	24	—	12	—	—	10	—	—	—	—	3
27	14	13	16	16	—	16	—	9	6	—	10	—	—	—	—	—
28	40	10	10	—	—	10	10	10	—	10	—	—	—	—	—	—
29	20	11	16	14	—	10	—	9	10	—	10	—	—	—	—	—
30	39	6	15	2	10	16	2	—	—	—	10	—	—	—	—	—
31	39	6	15	8	10	10	2	—	—	—	10	—	—	—	—	—
32	39	6	15	2	6	14	2	6	—	—	10	—	—	—	—	—

Table IA – (Weight Percent)

Example	SiO_2	Li_2O	BeO	CaO	ZnO	MgO	CuO	Al_2O_3	B_2O_3	La_2O_3	Y_2O_3	Fe_2O_3	Re_2O_3	ZrO_2	TiO_2	CeO_2
1	35.4	7.1	10.8	13.2		9.5		24.1								
2	26.5	7.9	6.6		21.5	10.7		26.9								
3	24.9	4.1	3.4		11.2	11.1		14.0			31.2					
4	29.0	4.8	4.0		13.1	12.9		16.4						19.8		
5	21.2	4.2	5.3		11.5	11.4		14.4			31.8					
6	21.9	3.6	3.0		9.9	9.8		12.4		39.6						
7	28.9	7.8	12.0	14.6		10.5		26.6								
8	18.8	3.7	3.1		10.2	7.1		12.8			28.3			15.4		
9	22.3	3.7	6.2		10.1	5.0		12.6		40.2						
10	16.4	4.1	0.9	7.7	7.4	7.3		3.5	7.9				44.8			
11	10.6	4.2	15.0	29.7	5.8	1.4			7.1	23.0					2.8	
12	17.5	4.3	4.2	8.1		5.9							47.6		3.9	
13	30.8	2.4	8.2	4.4				16.1			29.7					8.6
14	17.6	1.7	0.9	2.0		9.4	1.9	9.6	11.4		37.0	5.6			2.8	
15	37.2	1.2	5.2			8.3		16.8			31.1					
16	39.2	1.3	5.5			8.8		22.2			23.0					
17	38.9	1.3	6.5			8.7		22.0			22.7					
18	34.2	1.2	5.1			8.2		20.7			30.6					
19	34.6	1.2	5.1		3.3	8.3		16.7			30.9					
20	35.7	1.3	5.3			11.4		14.4			31.9					
21	34.8	2.2	6.5			10.5		13.3			32.7					
22	34.1	0.9	6.4		3.5	10.3		13.0			32.0					
23	13.6	4.1	5.6	12.7		9.1		23.0			31.9					
24	23.5	2.4	5.1	1.5	6.6	5.4	2.1	13.7	9.4		30.4					
25	32.3	2.5	5.1	1.5	6.7	5.6		14.0			31.1	4.4				
26	28.9	2.2	1.9			11.9		15.1			27.9					12.1
27	12.4	5.7	5.9	13.3		9.5		13.6	6.2		33.4					
28	28.5	3.6	3.0			4.8	9.4	12.1		38.6						
29	17.2	4.7	5.7	11.3		5.8		13.1	10.0		32.3					
30	34.0	2.6	5.5	1.6	11.8	9.4	2.3				32.8					
31	33.6	2.5	5.4	6.4	11.6	5.8	2.3				32.4					
32	33.1	2.5	5.3	1.6	6.9	8.0	2.2	8.6			31.9					

In order to characterize the various glasses, measurements of the density and Young's modulus of bulk samples as well as Young's modulus of mechanically drawn fibers were made. As a standard density measuring technique, the heavy-liquid-of-known density comparison procedure was used for samples with densities less than 3.00 gms/cm^3 while the Archimedean method was employed for samples with densities greater than 3.00 gms/cm^3.

Bulk sample for modulus measurement were prepared using the technique whereby the samples were drawn directly from the crucibles of molten glass into fused silica tubes previously dusted lightly with powdered magnesia. Controlled suction for pulling the sample into the tube was supplied by a hypodermic syringe. Since all of the experimental glasses had coefficients of thermal expansion at least higher than that of fused silica, the aspirated bars shrank away from the tube upon cooling and thus were readily removable.

Table II lists the values for a number of glasses made and tested in accordance with the teachings herein.

As is evident from the Tables, several of the formulations have proved to display extremely high modulus as well as modulus/density ratios superior to the best of glass compositions heretofore known. The particular formulation selected in a given application, however, will be dependent usually not only upon the properties of the end product but also upon the cost of the ingredi-

Table II

Glass Density, Young's Modulus and Specific Modulus

Example	Density lb./in.^{3}	Young's Modulus psi × 10^6	Specific Modulus 10^6 in.
1	0.0988	18.4	186
2	0.1077	17.2	159
3	0.1280	20.2	158
4	0.1115	17.0	153
5	0.1283	20.9	163
6	0.1413	18.9	134
7	0.1006	19.8	197
8	0.1368	20.0	146
9	0.1383	19.4	140
10	0.1407	18.6	132
11	0.1183	17.8	151
12	0.1293	17.3	134
13	0.1262	19.0	150
14	0.1292	18.1	140
15	0.1193	19.6	164
16	0.1121	19.4	172
17	0.1121	19.3	172
18	0.1185	20.2	170
19	0.1220	19.5	161
20	0.1208	20.4	168
21	0.1207	20.6	170
22	0.1252	20.7	165
23	0.1248	20.6	164
24	0.1165	18.2	156
25	0.1265	19.4	154
26	0.1281	19.0	149
27	0.1164	18.2	156
28	0.1375	16.3	119
29	0.1146	15.7	137
30	0.1297	20.0	154
31	0.1326	20.1	152
32	0.1263	20.0	158

ents included. This is particularly true in commercial production.

Several of the glasses proved to be fiberizable. In order to evaluate these glasses, a "poor man's bushing" was used to prepare mechanically drawn fibers. The bushing comprises a 20 cm^3 platinum crucible with a reinforced bottom and central orifice. The orifice is formed by welding several thicknesses of platinum foil to the bottom of a normal platinum crucible until a bottom thickness of 3/16 in. is obtained. A central orifice 0.088 in. at top, 0.063 in. at bottom and 3/16 in. long in the crucible is made by taper reaming. Once the orifice is made, the crucible is filled with glass and introduced into a platform furnace having high temperature Super-Kanthal hairpin heating elements together with a first ring orifice to provide water cooling immediately below the crucible and a second ring orifice to cool the fiber with helium jets as it forms. The fibers were drawn at speeds of 4,000–8,000 feet/minute and yielded circular glass fibers having a diameter of approximately 1 mil. The fibers were then evaluated on an Instron CRE tester operated with a machine speed of 0.2 in./minute, a chart speed of 20 in./minute, a gage length of 5 in. and a full scale capacity of 1.0 lb. The specimens were held in air actuated clamps with flat rubber coated faces.

Table III lists the values for several glasses which were mechanically drawn into fibers.

Table III

Example	Fiber Modulus Young's Modulus psi × 10^6
13	16.8
15	19.8
16	18.8
17	18.5
18	19.0
19	19.6

In general for the purposes of this invention, the lower molecular weight divalent oxides are preferable to the higher molecular weight divalent oxides. For example, BeO and MgO are preferred in comparison to CaO which is preferred in comparison to SrO and BaO and ZnO and CuO in comparison to CdO and HgO. Further, the lower weight trivalent oxides Al_2O_3, B_2O_3 and Fe_2O_3 are preferred in comparison to Ga_2O_3 and In_2O_3 and likewise Sc_2O_3, Y_2O_3 and La_2O_3 (lower molecular weight trivalent oxides of Group IIIB) are preferred in comparison to Nd_2O_3, Sm_2O_3, Gd_2O_3 and En_2O_3. Similarly, the lower molecular weight tetravalent oxide SiO_2 is preferred to GeO_2, SnO_2 and PbO_2 and the lower molecular weight tetravalent oxides TiO_2 and ZrO_2 of Group IVB are to be preferred as compared to HfO_2 and ThO_2. Finally the lowest molecular weight monovalent oxide Li_2O is preferred in comparison to Na_2O, K_2O, Rb_2O and Cs_2O. The above preferences are based on the requirements that the densities of the resulting glasses must be as low as possible, the cohesive bond energy as great as possible, and the field strength of the ions as high as possible.

Of course, the glass compositions may contain certain additional tetravalent or sesquivalent oxides or fluorides commonly employed in optical glassmaking such as tantalum pentoxide (Ta_2O_5) or tungsten trioxide (WO_3) in minor amounts.

While the invention has been described in connection with a number of particular preferred embodiments, they are considered illustrative only and no limitation is intended thereby. Various alterations and modifications will be evident to those skilled in the art within the true spirit and scope of the invention as set forth in the appended claims.

What is claimed is:

1. A fiberizable glass composition having a Young's modulus of approximately 19 million psi and a specific modulus of approximately 150 million inches consisting essentially of about, in mols:

39% SiO_2; 6% Li_2O; 25% BeO; 6% CaO; 12% MgO; 12% Al_2O_3; 10% Y_2O_3 and 2% CeO_2.

2. A fiberizable glass composition having a Young's modulus of at least 19 million psi and a specific modulus of at least 160 million inches consisting essentially of, in mols:

42–45% SiO_2; 3% Li_2O; 15–18% BeO; 12–15% MgO; 12–15% Al_2O_3 and 7–10% Y_2O_3.

3. A fiberizable glass composition having a Young's modulus of at least 19 million psi and a specific modulus of at least 160 million inches consisting essentially of about, in mols:

42% SiO_2; 3% Li_2O; 15% BeO; 3% ZnO; 15% MgO; 12% Al_2O_3 and 10% Y_2O_3.

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