The use of Novel Engineering glass as speaker diaphragms: advantages, opportunities, and design hints

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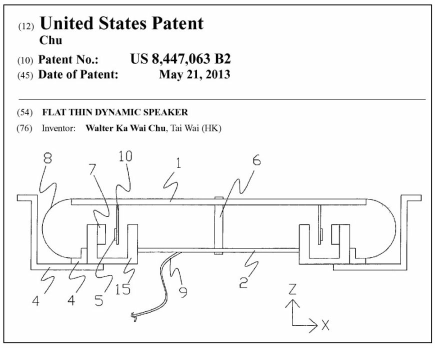
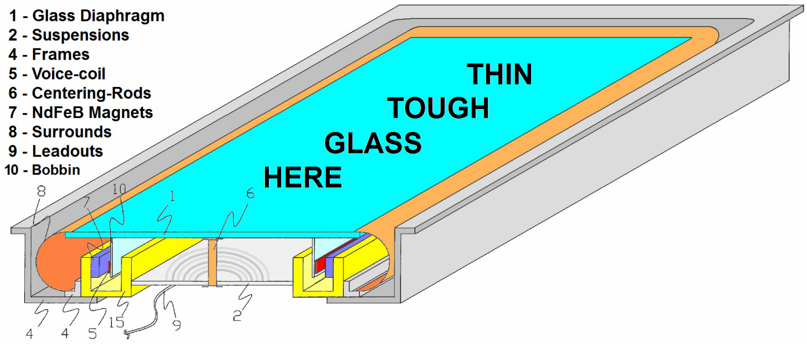
INTRODUCTION: BDNC, an electroacoustic company devoted into many breakthrough technologies, are now actively advocating the use of thin and tough glass (amorphous SiO_2) as the sound radiating diaphragms for various traditional and novel speaker drivers designs. By this, the performance or the speaker can be highly improved. This white-paper explains the reasons underneath.

Currently, the thickness of such thin and tough glass is available from 0.8mm down to 0.03mm! It can be used both as flat or (traditional) cone diaphragm, standalone or as composite parts.

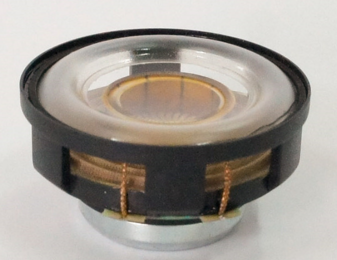
Examples of speaker designs using flat or cone glass:


(12) United States Patent
Chu
(10) Patent No.: US 8,447,063 B2
(45) Date of Patent: May 21, 2013
(54) FLAT THIN DYNAMIC SPEAKER
(76) Inventor: Walter Ka Wai Chu, Tai Wai (HK)

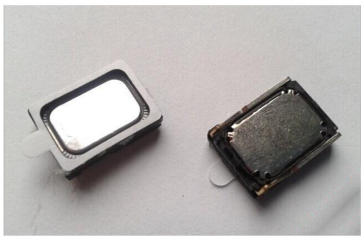


Actual product photo of first implementation

Using 0.21mm Glass diaphragm in our FP-SPK series


40mm full-range


1 inch dome tweeter


Miniature Speaker for Mobile Phone

Using Glass diaphragm in various traditional speaker designs

Comparisons of GLASS over other materials as speaker diaphragms:

A). Speed of Sound in shear mode of common speaker cone materials (faster are better):

Material	diamond	beryllium	sapphire	**GLASS**	titanium	aluminum	paper	TPX	polypropylene
Speed(m/s)	11650	8880	6035	**3535 ***	3125	3040	≅2000	890	700

* Calculated by √(75GPa x 0.4 / 2400kg·m³), where speed = √(shear-modulus / density), and assuming shear modulus ≅ Young's modulus x 0.4.
Data taken from Corning's "Willow Glass fact-sheet" (www.corning.com/media/worldwide/cdt/documents/Willow_2014_fact_sheet.pdf).

B). Density of common speaker cone materials (lighter are better):

Material	diamond	beryllium	sapphire	**GLASS**	titanium	aluminum	paper	TPX	polypropylene
rel. density	3.51	1.85	3.98	**2.4**	4.5	2.7	0.8-1.2	0.83	0.92

C). Young's Modulus (higher is better for flat or thin speakers, or inside a small box):

Material	diamond	beryllium	sapphire	**GLASS**	titanium	aluminum	paper	TPX	polypropylene
Young's(GPa)	1100	287	470	**70 - 80**	110	70	(soft)	1.9	0.9

D). Deformation (above elastic limit) / **Creeping** (low-stress) / **Break** properties of materials above:

Material	diamond	beryllium	sapphire	**GLASS**	titanium	aluminum	paper	TPX	polypropylene
Properties	Break only	Deform	Break only	**Break only**	Deform	Creep / Deform	Creep/ Deform	Creep/ Deform	Creep / Deform

E). Adhesion (easier to glue, better):

Material	diamond	beryllium	sapphire	**GLASS**	titanium	aluminum	paper	TPX	polypropylene
Adhesion	Very good	Good	Very good	**Very Good**	Poor (flexible glue only)	Good (flexible glue only)	Best!	V. Poor (flexible glue only)	V. Poor (flexible glue only)

F). Health / Environmental concerns:

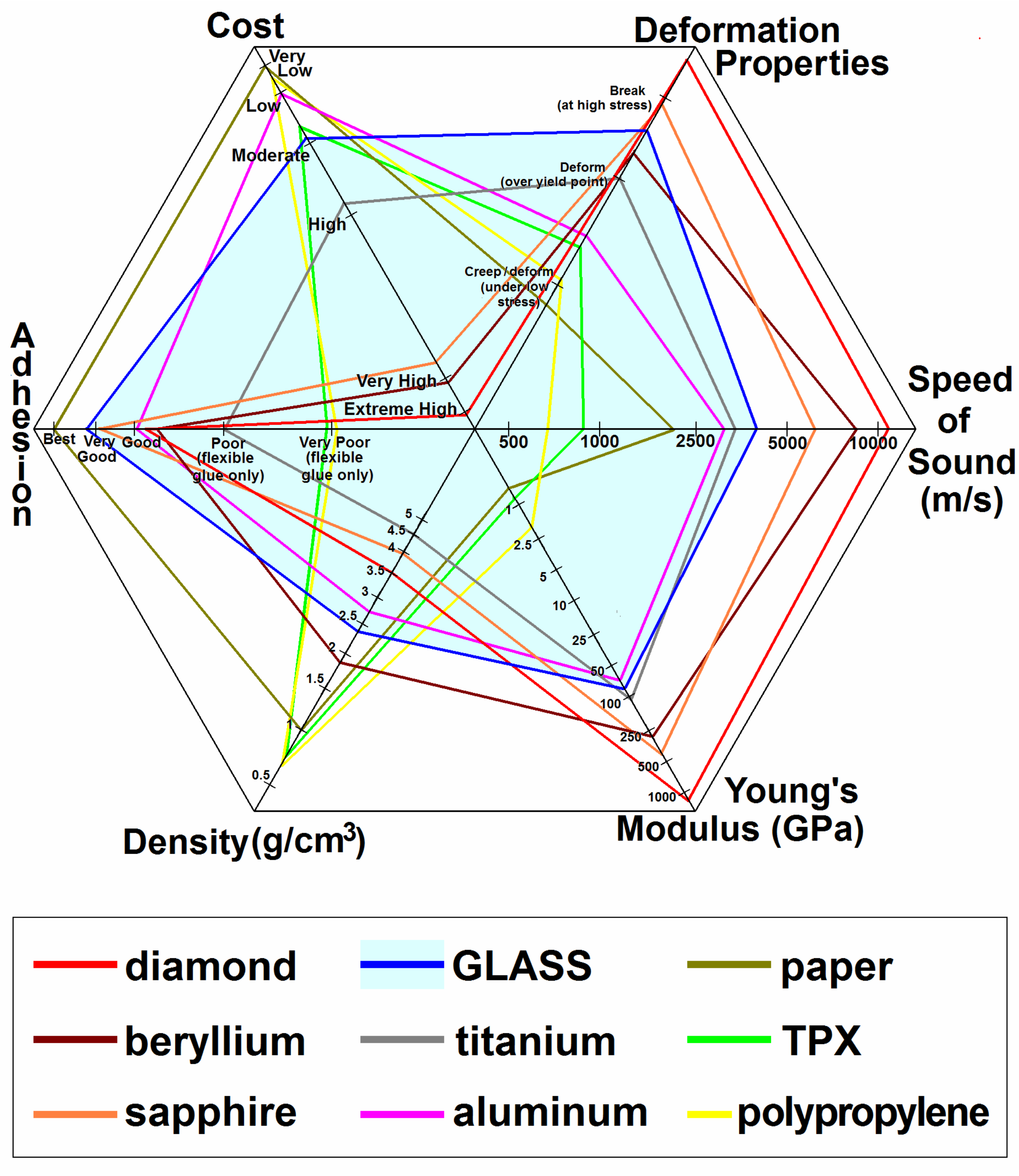
Material	diamond	beryllium	sapphire	**GLASS**	titanium	aluminum	paper	TPX	polypropylene
Concerns	High CO2 emission to make	Extremely **TOXIC!**	High CO2 emission to make	OK	OK	OK	OK	OK	OK

G). Cost index (lower is better, of course!):

Material	diamond	beryllium	sapphire	**GLASS**	titanium	aluminum	paper	TPX	polypropylene
Cost	Extreme High	Very High	Very High	**Moderate**	High	Low	Very Low	Mode-rate	Very Low

<u>Performance Comparison Chart</u>

(focused for flat speaker diaphragms instead of cones):



Note: The Scales are not linear, but rather reflects the actual Performance and cost in applications. For example, in cost, there have huge differences between [Extreme-High | Very High] to [High - Very Low].

The impact of different physical, chemical, and other properties for speaker diaphragm selection:

a). **Speed of Sound** propagation in shear mode: as the single most important factor on speaker cone selection, this figure dominates the "cone-break-up frequency" (thus the upper working frequency) of a speaker in a given sound radiating area. In speaker diaphragm, such speed is approximately equal to √ (shear-modulus / solid-density) . Thus, simply speaking, the speed of sound is higher either if the material is stiffer, or it is less dense.

b). **Density**: since diaphragm mass per unit area is equal to density times thickness, and a speaker's efficiency is inversely proportional to the square of its moving mass, the density, together with the mechanical strength (which determines the minimum thickness), impacts the speaker efficiency directly. Please be noticed that while speaker efficiency (therefore, sensitivity) is a very important factor to portable speaker designs, it is far less critical if it is working under line-powered amplifiers.

c). **Mechanical strength**: It consist many physical factors like stiffness, Young's modulus, shear modulus, elongation before break, degree of bending before break, yield strength, creeping properties, fatigue properties... etc. Some factors are far less critical in cone or dome geometry (e.g. although very soft, paper or polypropylene are widely used in cones and domes). But all those mechanical strength related physical factors are vital to flat speaker diaphragms, or a speaker inside a very small box where the diaphragm needs to conquer the huge inside-outside air pressure difference.

d). **Internal loss** factor: this is a concern in audiophile communities, but less in consumer audio markets. A low internal loss cone tends to sound more "artificial" or "metallic", while a high internal loss cone tends to sound more "natural". Paper is the best in this scenario; magnesium (especially zirconium magnesium alloy), and fiber-composites are the second. Diamond is the "poorest" material in this scenario!

e). Minimum production **thickness** and working **thickness**: this is production point of view. Some materials cannot be made thin and large (like traditional glass, or single-crystal Al_2O_3 "sapphire"), while some others cannot be made thick enough for working (like PVD single-crystal diamond, single-crystal Boron, or single-crystal Boron-Nitride). So, no matter how good the acoustic properties are, such material cannot be used in mass-production (e.g. except of <1inch tweeters, no speaker is successfully made by real diamond film, pure boron, or cBN, although they are all "very good" theoretically).

f). **Health** / **environmental** concerns: some people attempt to use beryllium to make speakers or headphones (Xiaomi do this!) due to its excellent acoustic properties, while some craziest others install LPG flame tweeters (able to play up to 500kHz!) in their homes. But I will not allow me to have a chance to acquire berylliosis (a life-threatening disease), or carbon-monoxide poisoning from listening music!

g). **Adhesion** properties: a factor always under-looked outside. It impact the speaker by two ways:

i). some materials are very difficult to adhere (e.g. polypropylene, TPX, titanium etc) unless after special surface treatments (e.g. plasma-etching). It increases the production cost and lower the yield;

ii). For softer materials, especially the hard-to-bond one, soft-after-cured glue (e.g. solvent based chloroprene "yellow glue") should be used, otherwise the glue will peel-off after prolonged vibrations (as the substrate is soft and bends under vibration). But such bobbin-glue-diaphragm interface will introduce high frequency lost. Of course, it is not good...

h). **Thermal** properties: for diaphragm, high heat resistance and high thermal conduction is good; and for voice-coil bobbins, it is vital.

i). **Look** and appearance: an objective factor that varies over time. The translucent polypropylene cone looks "high-tech" and expensive in '60s, or anodized aluminum cone in '90s, but now all "cheap". Generally speaking, a "never-seem-before" speaker diaphragm appears to be "cutting-edge".

j). **Cost** and Availability: THE utmost factor. Accuton sells diamond diaphragm tweeter over USD1000. Materion offers cheapest beryllium diaphragm at USD50. As so, applications are severely limited.

CONCLUSION: Engineering Glass is a very high performance and competitive material ideal for speaker diaphragm applications with high SPL, either in flat or cone shapes.

If price or health is not concern, diamond, beryllium, or sapphire may offer better performance.