Chalcogenide Microspheres

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Abstract: Gallium-Lanthanum-Sulphide microspheres have been produced with diameters from 0.5µm up to 580µm and quality factor of up to $1.2x10^5$ at 1.5µm. An ultimate quality factor of $4x10^{10}$ is possible with improvements in the glass.

Introduction

Micro-resonators have attracted considerable attention as a potential geometry for photonic devices used in multiplexing [1], memory [2] and switching [3,4]. These all-optical-resonators allow light at certain wavelengths to build up in intensity allowing nonlinear effects to be seen for much lower input power than in a bulk material. We report here on microspheres made from gallium-lanthanum-sulphide glass (Figure 1).

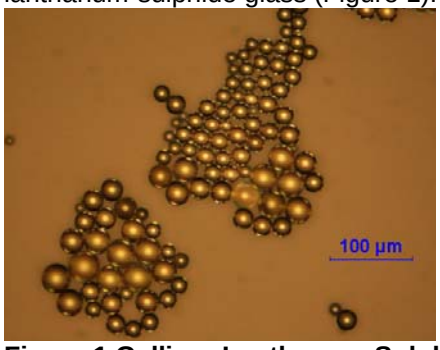

Figure 1 Gallium-Lanthanum-Sulphide Microspheres

Microspheres can be made by a number of methods, these include polishing, chemical etching and rapid quenching of liquid droplets. The method of microsphere production used here was to drop crushed glass through a vertical furnace purged with an inert gas, typically argon. Bulk glass was crushed to a suitable size and uniformity before microsphere production. The glass was crushed with a pestle and mortar, and sieved to achieve glass particles of the required size.

Early trials were performed on an optical fibre drawing tower, which provided proof of principle after which a dedicated vertical furnace, with a longer hot zone and more precise gas flow was utilized. In the fabrication process, the crushed glass melts as it drops through the furnace, where surface tension pulls it into a sphere which quenches into an amorphous state as it drops to the cooler region below the hot zone.

If GLS is melted in an air atmosphere it will react with the oxygen and water in the air, which will produce a poor surface and increase attenuation [5]. Therefore chalcogenide microspheres are produced in a continually purged inert atmosphere, typically argon.

In order to assert control over the size of microspheres produced, crushed particles are separated according to size before they are put into the furnace. It has been found that small particles of GLS are strongly attracted to surfaces and each other, however when placed in solvent (isopropanol or methanol) this problem is over come. Large particles can be separated by sieving, but for small particles sieving was found to be impractical. As an alternative, a process of sedimentation has been used, taking advantage of the slow terminal velocity of small particles in liquids.

Our best results were obtaining using a method of particle separation which combines sedimentation and sieving. The smallest particles are separated by sedimentation, the larger particles of crushed glass can then be sieved.

The terminal velocity of small particles also has an influence in the sphere formation process within the furnace. Due to the chimney effect associated with having a tube running vertically through a furnace it is necessary to have the inert gas running vertically upwards. However according to Stoke's law small particles will be buoyant in this gas flow. Therefore to make the smallest spheres it is necessary to introduce the GLS with the gas at the bottom of the tube and collect at the top.

The method of blowing small particles into the furnace has successfully produced a range of sphere sizes down to approximately 0.5µm in diameter. The failure to confirm spheres of a smaller size than this owes more to the equipment used to analyze the samples rather than a lack of spheres themselves. At the other end of the scale spheres have been produced up to 580µm in diameter.

The material that has passed through the furnace will typically contain a mixture of particles that have melted into spheres and particles that have not. This material can be separated according to the quality of the spheres [6].

The quality of resonators is given by the Q factor, which is influenced by a number of factors. However by making improvements in production and having a sufficiently large sphere the contribution of all factors other than material loss can theoretically be minimized. Therefore the Q factor due to bulk attenuation represents the

ultimate limit of Q [7]. This can be calculated as follows

$$Q \approx \frac{2\pi n}{\lambda \alpha}$$

where n is the refractive index and α is the linear attenuation.

This limit of intrinsic attenuation is a combination of electronic absorption, multiphonon absorption and Rayleigh scattering. The point at which this ultimate limit on attenuation occurs has been examined in detail for gallium lanthanum sulphide based glasses (GLS/GLSO) [8] and this data can be used to predict an ultimate Q for GLS and GLSO spheres (Figure 2).

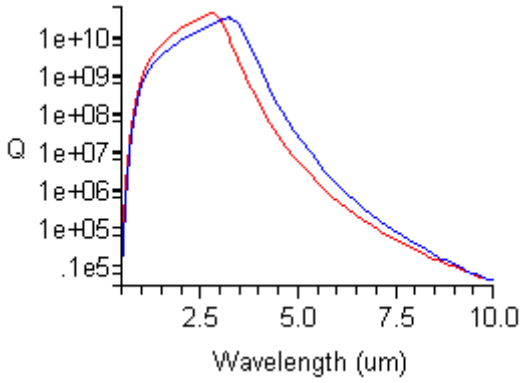

Figure 2 Maximum theoretically possible Q as a function of wavelength, for two GLS glass compositions (red = GLSO, blue = GLS).

Using the minimum attenuation data for GLS/GLSO [8] we can predict a maximum Q value of over $4x10^{10}$ possible in GLSO at 3µm and 10^9 at 1µm. The values quoted here for GLS/GLSO are for specific compositions in [8], but these are typical of GLS/GLSO in general. The minimum attenuation data used here are calculated values, while these low values of attenuation are theoretically possible, they relate to a glass quality that has not been achieved. The current state of the art for minimum attenuation measured in GLS / GLSO glass fibres is detailed in [4]. The values are lower than that achieved in bulk glass, however optical fibre drawn from bulk glass preforms are processed in an environment and manner not dissimilar to our sphere fabrication methods and are therefore more representative of the true Q which could be experimentally achieved. Using this data to calculate a theoretical maximum Q gives a value of $1.6x10^7$ at 1µm.

To measure the Q factor a sphere is placed on a silicate waveguide, which is coupled to a tuneable laser. Light is coupled into the sphere from the waveguide and the scattered light is observed from above the sphere, through a microscope [6]. The Q value is then calculated from the observed spectra. Using this method a maximum Q value of $1.2x10^5$ has been observed.

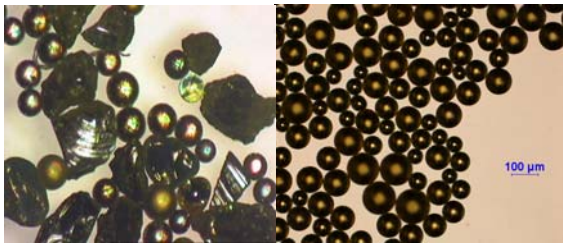

Figure 3 sorted and un-sorted spheres

It is often necessary to separate spheres from particles that did not melt in the furnace. This is done by rolling them down successively shallower slopes, whilst submerged in solvent.

Conclusion

Production of GLS microspheres over a considerable range of sizes has been demonstrated. Whispering gallery modes have been observed and the peak value of Q was found to be $1.2x10^5$ at 1.55µm. It has been shown that it is theoretically possible to achieve a Q up to three orders of magnitude higher, at a wavelength of 1µm, with GLSO glass that has previously been produced. It has also been shown that with improvements in the quality of bulk glass it would be possible to produce spheres with a Q over $4x10^{10}$ at 3µm and 10^9 at 1µm. There exist flaws in the production process of GLS/GLSO microspheres and these would need to be addressed before such high Q values could be achieved.

References

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