Measuring inclusion depth

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ABSTRACT

The measurement herein determines the depth of an inclusion (10) in a solid media (2) such as fused silica. A trigonometric function such as the tangent calculates the depth of the inclusion (10). A light source having a primary incident beam of light enters a solid media (2) having at least one inclusion therein. The primary incident beam of light enters the solid media (2) on a straight line path at an angle to a horizontal axis and secondary scattered light is detected at an angle to the horizontal axis. Preferably, the detector is positioned on a perpendicular axis above the inclusion and the angle of the primary beam to the horizontal axis is 45 degrees. The solid media (2) has an exterior surface parallel to the horizontal axis and the primary beam of light and the perpendicular axis intersect the exterior surface. As a result, the perpendicular axis intersect is equidistant from the primary beam intersect and the inclusion (10). The scattered light can be viewed from many directions with varying intensities.

DESCRIPTION (OCR text may contain errors)

MEASURING INCLUSION DEPTH

TECHNICAL FIELD

This invention relates to a method and apparatus for measuring inclusion depth in solid media such as bulk glass. The invention uses a unique means to easily and accurately measure the depth of an inclusion object within a transparent bulk.

BACKGROUND OF THE INVENTION Detecting small (micron and submicron) inclusions in glass always has been a challenge. Measuring the actual depth is even more of a challenge. The difficulties associated with various practices are sensitivity, resolution, depth of focus, to name a few.

Microscopy has the capability to detect inclusions down to the submicron range, yet it has an extremely narrow depth of focus and a small sampling area at high magnification.

reflection/scattering has been used to identify inclusions. After mapping their location, the inclusion can be further determined by microscopy. The thickness of the glass is again somewhat restricted by the narrow depth of focus of the microscopy technique.

Both process engineers and layout associates have a need to find and to determine the location and depth of inclusion objects buried within substrates such as a high purity fused silica (HPFS®) boule. After a boule is formed, the process engineer would like to be able to correlate inclusion objects with observed furnace events. By knowing the depth of an inclusion object and the forming rate of the furnace, it is possible to extrapolate backwards in time and find the inclusion causing event. The layout associate needs to know the depth of inclusion objects in order to plan the optimal locations for extraction of parts from the boule.

The process engineer only has the experienced guess available. The layout associate has a cumbersome microscope, which requires a fair amount of finesse and time to place and adjust. It also requires a certain amount of interpolation. Other areas of glass manufacture, such as photomask substrates,

CLAIMS (OCR text may contain errors)

WE CLAIM:

1. An apparatus for measuring inclusion depth in a transparent solid media comprising: a light source having a primary incident beam of light; a solid media having at least one inclusion therein, wherein the inclusion intercepts the primary incident beam of light and creates a secondary radiation source of forward scattered light; wherein the primary beam of light enters the solid media on a straight line path at an angle to a horizontal axis; and a detector positioned at an angle to the horizontal axis for detecting the secondary scattered light.

2. An apparatus according to claim 1 wherein the detector angle is a 90° angle.

3. An apparatus according to claim 1 wherein the detector is positioned on a peφendicular axis directly above the inclusion.

4. An apparatus according to claim 3 wherein the angle of the primary beam to the horizontal axis is 45°.

peφendicular axis intersect the exterior surface.

6. An apparatus according to claim 5 wherein the peφendicular axis intersect is equidistant from the primary beam intersect and the inclusion.

7. An apparatus according to claim 1 wherein the angle of the primary beam is corrected for the refractive index of the solid media.

8. An apparatus according to claim 5 including a measuring base adjacent the exterior surface.

9. An apparatus according to claim 1 wherein the solid media is a glassy material or plastic.

10. An apparatus according to claim 1 wherein the solid media is bulk glass.

1 1. An apparatus according to claim 1 wherein the solid media is high purity fused silica.

12. An apparatus according to claim 1 wherein the primary beam of light is a laser beam.

NIF optics and Space Station/Shuttle windows also suffer from a lack of ability to efficiently find, identify and locate inclusion objects.

BRIEF SUMMARY OF THE INVENTION This invention is an apparatus and process for measuring inclusion depth in a solid media. We project a light source having a primary incident beam of light into a solid media having at least one inclusion therein. The primary incident beam of light intercepts the inclusion and creates a secondary radiation source of forward scattered light. The primary beam of light enters the solid media on a straight line path at an angle to a horizontal axis. We next detect the secondary scattered light at a 90° angle to the horizontal axis. We position the detector on a perpendicular axis directly above the inclusion. Preferably, the angle of the primary beam to the horizontal axis is 45°. The solid media has an exterior surface usually parallel to the horizontal axis and the primary beam of light and the peφendicular axis intersect the exterior surface. As a result, the perpendicular axis intersect is equidistant from the primary beam intersect and the inclusion. The scattered light can be viewed from many directions with varying intensities.

This means easily and accurately measures the depth of an inclusion object within a transparent bulk. A refractive index (R.I.) corrected laser sheet is transmitted within the bulk, wherein the observer notes the object's position on a calibrated, transparent screen. The distance from the zero index mark is the absolute depth of said object. BRIEF DESCRIPTION OF THE DRAWINGS Fig. 1 illustrates a schematic view of inclusion depth measurement for bulk glass. Fig. 2 is a schematic view showing the measurement base.

DETAILED DESCRIPTION OF THE INVENTION

Fig. 1 shows transparent bulk 2 and inclusion 10 contained herein. Laser beam 6 of a known but arbitrary value enters transparent bulk 2 at an angle 8, which is approximately 45° with respect to the surface. We prefer a 45° angle because of the ease of which it illustrates our invention. Angle 18 is adjusted to precisely 45° if a 1 :1 ratio between inclusion depth 12 and the distance from zero index 26 and observed location 14 is to be maintained. Inclusion 10 is viewed by operator 4 by sight line 16 normal to inclusion 10 and the surface of bulk 2.

Fig. 2 details the preferred embodiment of the invention. Base 22 is comprised of a transparent material. Conserving the presented orientation, laser line generator 28 is mounted on the left side emitting light sheet 32. Angle 30 may be altered to change resolution and to accommodate different laser light wavelengths or bulk refractive indices.

Zero index 20 is where the beam enters the surface of bulk 2. All distances measured are referenced from this point. Major tick marks 26 are a uniform arbitrary distance from zero index 20 and represent integer values. Minor tick marks 24 represent uniform fractional values from zero index 20. Sight line 16 is normal to the surface of base 22 and inclusion 10. To assist in this process, loupe 36 is used. Any deviation from normal would make the inclusion object unviewable. Loupe 36 would also assist in reading finer distance gradation lines.

13. An apparatus according to claim 1 wherein the detector is a photo diode.

14. An apparatus according to claim 1 wherein the detector is a two dimensional CCD array.

15. A process for measuring inclusion depth in a solid media comprising the steps of: projecting a light source having a primary incident beam of light through a solid media having at least one inclusion therein; intercepting the primary incident beam of light with the inclusion and creating a secondary radiation source of forward scattered light; passing the projection of the primary beam of light through the solid media on a straight line path at an angle to a horizontal axis; and detecting the secondary scattered light at a 90° angle to the horizontal axis.

16. A process according to claim 15 wherein the angle is a 90° angle.

17. A process according to claim 14 including the step of positioning the detector on a peφendicular axis directly above the inclusion.

18. A process according to claim 17 wherein the angle of the primary beam to the horizontal axis is 45°.

19. A process according to claim 18 wherein the solid media has an exterior surface parallel to the horizontal axis, and the primary beam of light and the peφendicular axis intersect the exterior surface.

20. A process according to claim 19 wherein the peφendicular axis intersect is equidistant from the primary beam intersect and the inclusion.

21. A process according to claim 15 including the step of correcting the angle of the primary beam for the refractive index of the solid media.

22. A process according to claim 19 including the step of placing a measuring base adjacent to the exterior surface.

23. A process according to claim 19 including the step of using a trigonometric function to calculate the distance from the peφendicular axis intersect to the inclusion.

24. A process according to claim 23 wherein the trigonometric function is the tangent function.

25. A process according to claim 15 wherein the solid media is a glassy material or plastic.

26. A process according to claim 15 wherein the solid media is bulk glass.

27. A process according to claim 15 wherein the solid media is high purity fused silica.

28. A process according to claim 15 wherein the primary beam of light is a laser beam.

The solid media we can measure may vary widely. Generally, the solid media may be any transparent glass, plastic, crystalline material, glass-ceramic and the like. Specifically, our big challenge was measuring inclusions in high purity fused silica (HPFS®). We want to detect both gaseous and refractory inclusions in the HPFS®. A boule of HPFS ' is roughly in the form of a disc several feet in diameter and may vary in thickness up to 24 inches. For making a 6" size photomask substrate, for example, a 60" diameter disc is first cut into about 6 1/4" x 6 1/4" square blocks of full thickness of the disc. The blocks are polished on three sides and fed through the inspection process. In addition, the boule itself may be measured. Our inspection process is designed to eliminate or reduce the cutting and polishing steps.

The transparency of the solid media varies widely. Obviously, if the media is too translucent or cloudy, the detection system will not be accurate. We have found that the media should have an internal transparency of at least 65%. Preferably, the transparency should be at least 90%.

Possible illumination sources include halogen lamps, strobe lamps, or lasers. Halogen and strobe lamps have the advantage of being non-coherent and are most useful in high magnification high-resolution applications. In addition, halogen illuminators can achieve very high source stability for precise radiometric measurements. In the proposed system, however, optimum operation requires the use of a highly collimated small cross- section light beam. This is best achieved with a laser so that a near diffraction limited beam with a low divergence will equally illuminate inclusions across the full width of the glass boule. A laser diode provides a small package, as well as the required of power for good signal to noise ratio performance. Lasers of several watts are available from multiple sources. In general, the amount of power input will determine the instrument's sensitivity. Observer's eye 4 in Fig. 1 may be a single detector element that utilizes a high sensitivity detector such as a photo-multiplier tube or avalanche photodiode. This non- imaging system does not require dynamic focus and provides very uniform coverage because of the single elements.

An array with area scan laser (a two dimensional CCD camera) also may be used, as well as a large area collimated beam from either a strobe or an incandescent lamp. The detector or array is positioned at an angle peφendicular to the horizontal plane.

Fig. 1 shows angle 18 to be 45°. Distance 12, however, can be calculated for any angle 18 and any distance 14 using the tangent trigonometric function. The tangent of an acute angle of a right triangle is the ratio of the opposite side to the adjacent side, tanθ = b/a In Fig. 1, tan angle 18 = distance 14/distance 12. Tangent values for common angles Eire:

Angle θ Tan θ

O° O

15° .2679

30° .5774

45° 1.000

60° 1.7321

75° 3.7321

90° _

Other trigonometric functions such as sine and cosine, as well as the Pythagorean Theorem may be used. These, however, would be more difficult to apply. Other triangular postulates such as those for an isosceles and equilateral triangle could be used. Again, however, they would be more difficult to apply in a practical setting. Inclusions generally are classified in two groups: solid inclusions, which are formed by bits of unmelted or foreign material; and void inclusions, commonly formed by bubbles of gas. Solid inclusions generally are formed by minute impurities or crystallized glass in the starting materials which are fused to form a glass; bits of refractory material from the walls of the vessel in which the glass is prepared; or bits of platinum from the walls of conduits through which the glass stream flows. The solid inclusions may be opaque or clear. Void inclusions, or gas bubbles also present difficulties in visual inspection. Nonetheless, such inclusions need to be counted and properly characterized.

The following Example provides an excelled technique for detecting these interior inclusions. Example

The following example shows a means to measure the depth of an inclusion object that is located between the two surfaces of a transparent bulk (for example, a boule). A visible laser beam is generated at an angle such that the angle below the surface precisely equals 45.0°. Any inclusion objects located in the light path will scatter a portion of this energy and therefore, appear to be illuminated to the user. Because of the relationship: Tan 45° = 1.0, D_A = Di .'. The depth of the inclusion object equals the distance from the point where the beam enters the bulk (zero index) to the point at which it is observed. Referring to Fig. 1 , the line of sight, with respect to the observer, must be normal or peφendicular to the surface of the bulk. The incident laser light could be adjustable to account for the different R.I. various substances. In any case, angle 8 must be adjusted to account for the wavelength (color) of the laser and the R.I. of the substance so that angle 18 is precisely 45.0°. With the laser set to above parameters, the depth of an illuminated object will equal the distance from the point where the laser beam enters the glass (zero index).

For a practical instrument, locating the inclusion object with a single cylindrical beam would prove to be cumbersome. To enhance the opportunity to locate inclusions, a laser sheet is recommended. This sheet could be generated by a laser line generating means. The same rules for orientation of the beam apply. Transparent base 22 has equidistant parallel lines places across its surface, starting from the O-index or laser entry line 20. In Fig. 2, the spacing of the major tick marks 26 is 1.0" and the minor tick marks

24 is 0.5 inch. For clarity, a minimum spacing of 0.1" could be used. If greater accuracy is required, angle 30 could be increased. This would have the effect of spreading out the divisions allowing greater accuracy. However, the length of the base 22 would also increase to achieve the same maximum depth. With an internal angle 18 of 45° for a 6" boule, the length of the instrument would equal 6". The width of the instrument is a function of how much boule volume needs to be evaluated during a given pass. In the experience of the inventor, a wavelength in the Green band tends to illuminate inclusion objects more effectively than the longer wavelengths, such as the Red band generated by a diode or HeNe. This may be due to the eye's sensitivity to green. In use, the base 22 is slid across the surface in an organized means. When the laser sheet encounters an inclusion object, it will illuminate. The operator would stop the motion of the tool and observe the location of the inclusion object directly below a tick mark (or inteφolated position). The distance below the surface is read directly from the scale. Regarding refractive index, fused silica has a refractive index of about 1.457. This means that light travels slower through the glass than through air, by a factor of 1.457. So, if an object is buried under 10 inches of fused silica, the working distance required to focus on it is not 10 inches. To a lens or camera, 10 inches would

appear to be 14.57 inches in depth. As discussed, a camera may take the place of observer eye 4. Angle 8 then is corrected for refractive index.

In addition to these embodiments, persons skilled in the art can see that numerous modifications and changes may be made to the above invention without departing from the intended spirit and scope thereof.

PATENT CITATIONS

Cited Patent	Filing date	Publication date	Applicant	Title
US4681442 *	Mar 18, 1985	Jul 21, 1987	International Business Machines Corporation	Method for surface testing

* Cited by examiner

CLASSIFICATIONS

International Classification	G01N21/49, G01N21/88
Cooperative Classification	G01N21/88, G01N21/49, G01N21/8803
European Classification	G01N21/88, G01N21/49

LEGAL EVENTS

Date	Code	Event	Description
Oct 4, 2001	AK	Designated states	**Kind code of ref document:** A1 **Designated state(s):** JP KR US
Oct 4, 2001	AL	Designated countries for regional patents	**Kind code of ref document:** A1 **Designated state(s):** AT BE CH CY DE DK ES FI FR GB GR IE IT LU MC NL PT SE TR
Nov 28, 2001	121	Ep: the epo has been informed by wipo that ep was designated in this application	
May 14, 2003	122	Ep: pct application non-entry in european phase	
Nov 12, 2004	NENP	Non-entry into the national phase in:	**Ref country code:** JP