D3 1981

# Laser biascope for surface stress measurement of tempered glasses

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The introduction of gas lasers has greatly increased the number of biascope applications. It has been found that optical waveguide effects caused by the refractive index gradient affected the biascope pattern but, provided that stress birefringence was distinguished, by analyser rotation, from intrinsic refractive index differences between guided modes, and that the birefringence and refractive index values were dissimilar, surface stress determination was possible. Birefringence and refraction patterns were recorded and compared for a variety of glasses.

The biascope, or Epibiaskop, was invented by Acloque and Guillemet[1] for the non-destructive surface stress measurement of thermally tempered glasses. The linearly polarized optical surface wave was excited by light incident beyond the critical angle (Fig. 1). A difference in phase $R$ between two linearly polarized component waves with propagation path length $x$ was observed as an alternation in intensity of patterns by using scattered or refracted light. One period corresponded to a retardation of one wavelength and $dR/dx$ was assumed to be proportional to surface stress. Biascopes have been used in the plate glass industry[2] for quite a while.

Optical surface waves have been excited along a thermally tempered glass surface using a gas laser as a light source.[3] A method for surface stress measurement was proposed by detecting refraction angle differences between two linearly polarized component waves. In this analysis the wave was considered essentially as a critical ray.

Although biascopes are effective for practical and industrial applications,[2] some feel that the dark-bright patterns are often faint and hardly observable. Application of a gas laser improves the biascope in two ways:

1. High light flux makes the pattern clearly visible.
2. Laser light coherency makes patterns better defined.

Although the author's method[3-6] is useful for tempered glasses, it is based on refractometry and therefore the sensitivity is not high. A biascope, with its higher sensitivity, can be a complementary means for surface stress measurement. Since the biascope uses optical surface waves, surface structure, especially refractive index distribution near the surface, greatly affects the apparatus applicability. The latter half of this paper gives detailed observation on the behaviour of light in many kinds of glass; float glass, chemically tempered glass and so on. Conventional notations TM and TE in integrated optics are used in this paper; they correspond to light waves propagating along sample surface and vibrating in directions perpendicular to and parallel to the surface respectively.

## Apparatus

### Biascope arrangement

The optical arrangement is shown in Fig. 2. The 1 mW HeNe laser beam is focused by a condenser lens ($f = 100$ cm) and is injected through a polarizer and an input prism into the glass surface at a critical angle $\psi_0$. The polarization axis is at 45° to the plane of incidence. The critical ray is excited and partly refracted by an output prism during propagation. The angle of the second refraction is again $\psi_0$.

Refracted light is projected by the objective lens of a micrometer onto the reticle of an ocular micrometer. The micro-

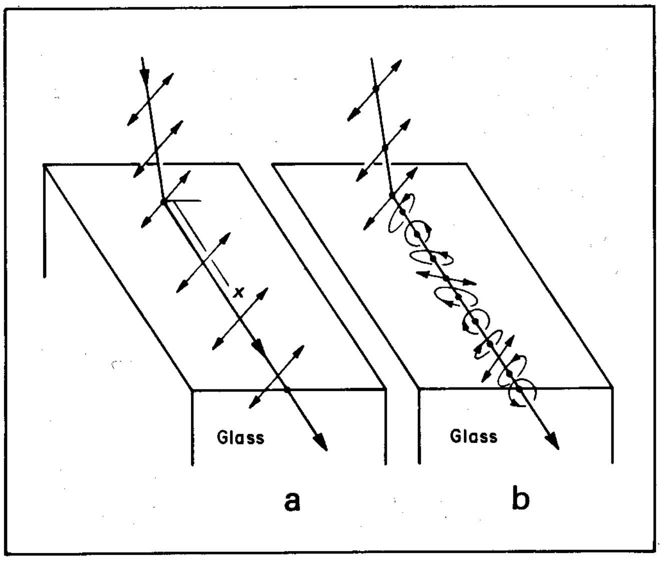

Fig. 1 Change in optical surface wave polarization with propagation path length $x$ for: a — stress-free surface; b — stressed surface

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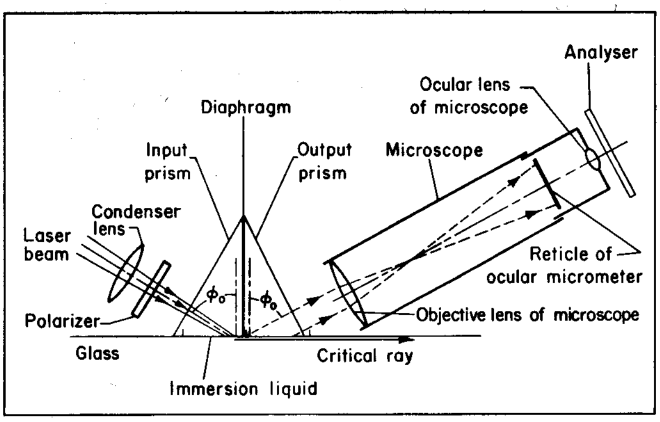

**Fig. 2** The optics of the laser biascope. Input and output prism refractive index $n$ = 1.75; immersion liquid ($CH_2I_2$, $n$ = 1.73)

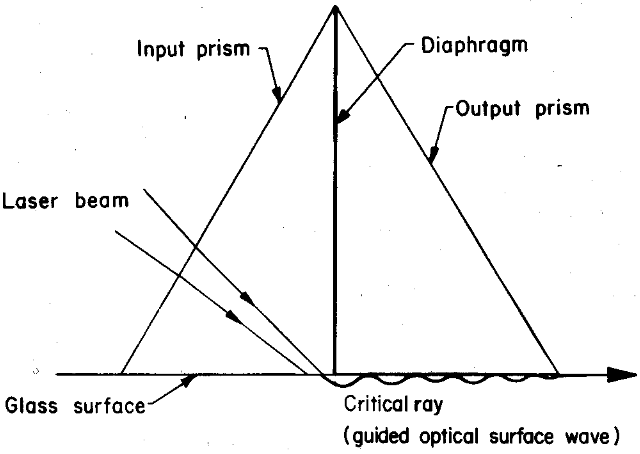

Fig. 3 Detail at the prisms

meter is focused onto the glass surface. Projected light on the reticle is observed through an ocular lens and an analyser. Apparatus parameters are given in the Figure caption.

When the polarizer and analyser vibration directions are parallel to each other, the locations on the path where $R$ values are $N\lambda$ and $(N + 1/2)\ \lambda$ are indicated by bright and dark areas respectively. Rotation of the analyser through 90° reverses the brightness distribution. Here $\lambda$ is the wavelength (632 nm). $N$ is an integer. Figure 3 gives details of the biascope.

### Refractometer arrangement

When the polarizer is removed and the micrometer is exchanged for a telescope, the apparatus behaves as a refractometer for observing the effective refractive index distribution of an optical surface wave mode or modes.[3-6] When photoelastic birefringence, ie a refractive index difference between corresponding TM and TE modes, is identified by the refractometer surface stress is indicated. In principle, the biascope and refractometer give identical birefringence and surface stress values.

## Experimental Results

### Optical glass

*Stress-free glass.* Stress-free, polished SK-3 optical glass surface gave a light path with a monotonic brightness distribution in the biascope, and a bright fringe by the critical ray in the refractometer.[3] Analyser rotation did not affect the patterns; TM and TE waves had identical effective refractive indices.

*Thermally tempered glass.* Biascope patterns gave dashed lines (Fig. 4). 90° analyser rotation reversed the brightness distribution. The refractometer gave fringes formed by two linearly polarized waves, TM and TE. Estimated birefringence was $0.0004_4$ for the biascope and $0.0005_0$ for the refractometer. The agreement was satisfactory considering the inhomogeneous surface stress distribution in the tempered glass. Surface stress was estimated to be $3_7$ kg $mm^{-2}$.

### Float glass

Each float glass sample had a tin-diffused surface and a gas-side surface. The former, with its high refractive index, gave a distinct optical waveguide effect.[5] The latter, by virtue of its increasing refractive index with depth, gave hardly any or no optical waveguide effect.[6]

*As-received float glass (gas-side surface).* The light path was barely observable using the biascope and no fringe was found using the refractometer.

*As-received float glass (tin-diffused surface).* The refractometer pattern (Fig. 5a) was invariant under analyser rotation and indicated that the surface supported five TM and five TE modes. Because the surface was stress-free, effective refractive index distributions coincided with each other between

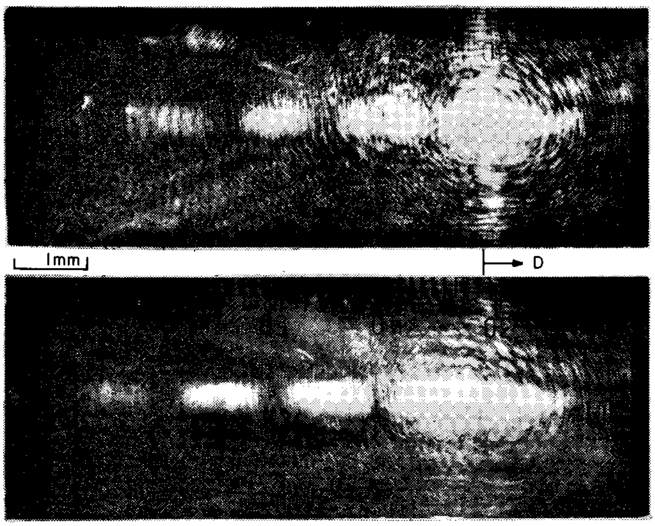

Fig. 4 Biascope patterns for thermally tempered SK-3 glass obtained by 90° analyser rotation. D – diaphragm.

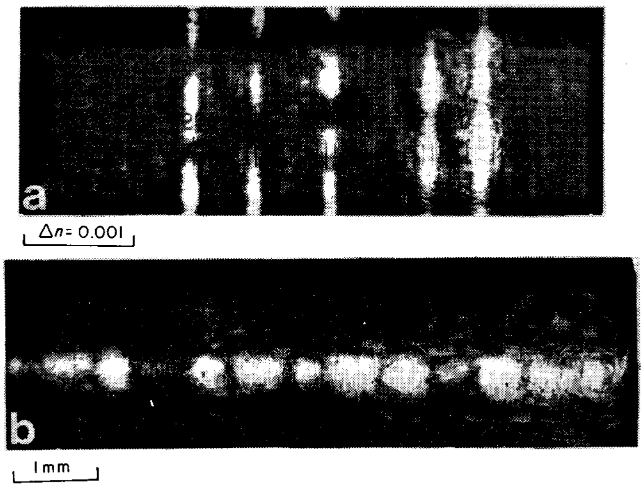

Fig. 5 Float glass tin-diffused, stress-free surface patterns: a – refractometer; b – biascope

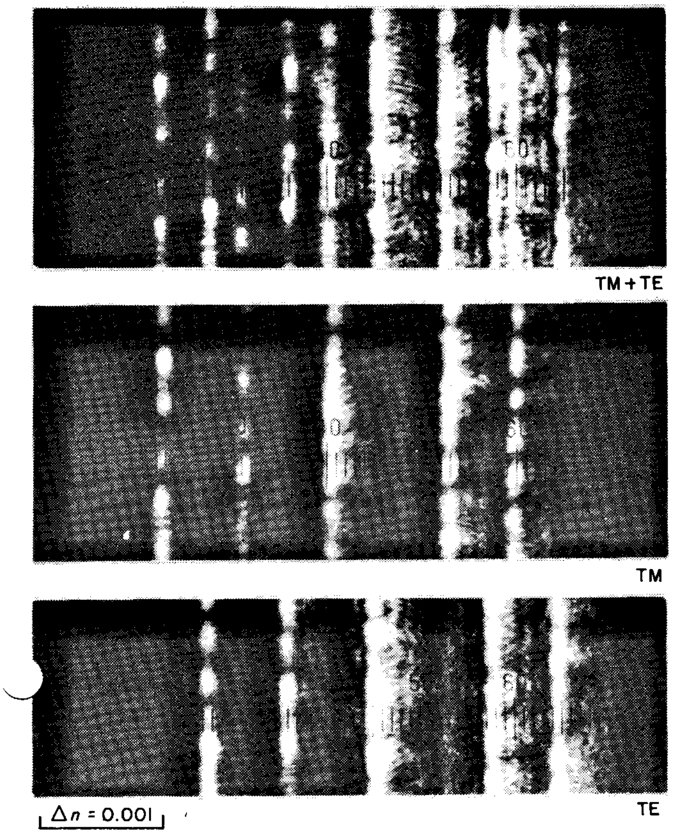

Fig. 6 Float glass stressed tin-diffused, surface refractometer patterns

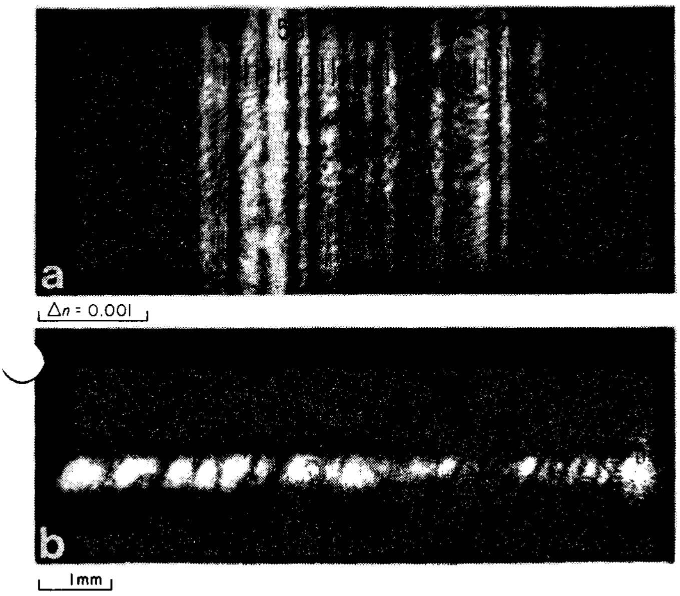

Fig. 7 Patterns for stress-free plate glass produced by a non-float process: a — refractometer; b — biascope

the TM and TE waves. The biascope pattern consisted of a brightness distribution with short periods (Fig. 5b). The periods seemed to correspond to refractive index differences between modes. The pattern was invariable under analyser rotation.

*Thermally tempered float glass (tin-diffused surface).* The refractometer patterns (Fig. 6) showed $0.0004_0$ stress birefringence between corresponding TM and TE modes. The corresponding biascope pattern showed a short period of brightness distribution modulated by a distribution of a longer period. The former was unchanged by analyser rotation but the latter reversed the brightness distribution. The longer period gave $0.0003_4$ birefringence which satisfactorily coincided with that recorded using the refractometer.

### Plate glass produced by non-float process

*As-received glass.* The glass gave an optical waveguide effect by striation near the surface[6] (Fig. 7a). The biascope showed a light path with a brightness distribution of short period (Fig. 7b). The period corresponded to refractive index difference of 0.002 to 0.004 which was of the same order of those between modes in Fig. 7a.

*Thermally tempered glass.* Refractometer patterns gave $0.0002_5$ photoelastic birefringence. Biascope patterns were of short period brightness distribution modulated by a longer period. The latter corresponded to $0.0002_3$ birefringence. The agreement between the two birefringences was satisfactory. As in the case of thermally tempered float glass, analyser rotation left the short period brightness distribution unchanged but that corresponding to photoelastic birefringence was reversed.

### Chemically tempered glass

The glass was produced by ($Na^+$ in glass) ↔ ($K^+$ in molten $KNO_3$) ion exchange. Compressive surface stress was built in by the process. The potassium ion-diffused glass layer behaved similarly to graded index planar optical waveguides. Guided waves in the layer enabled surface stress estimation by refractometry.[4]

The refractometer gave fringe patterns (Fig. 8) in which there were more than fifteen TM and TE modes supported in the guides. The patterns gave a $9_0$ kg mm$^{-2}$ surface stress value and $5_5$ $\mu$m compression layer thickness.[4] Biascope patterns (Fig. 9) showed a complicated brightness distribution. Although analyser rotation changed the distribution, the period corresponding to surface stress birefringence was not identified; the pattern was a complex composite of refractive index differences between TM modes, TE modes

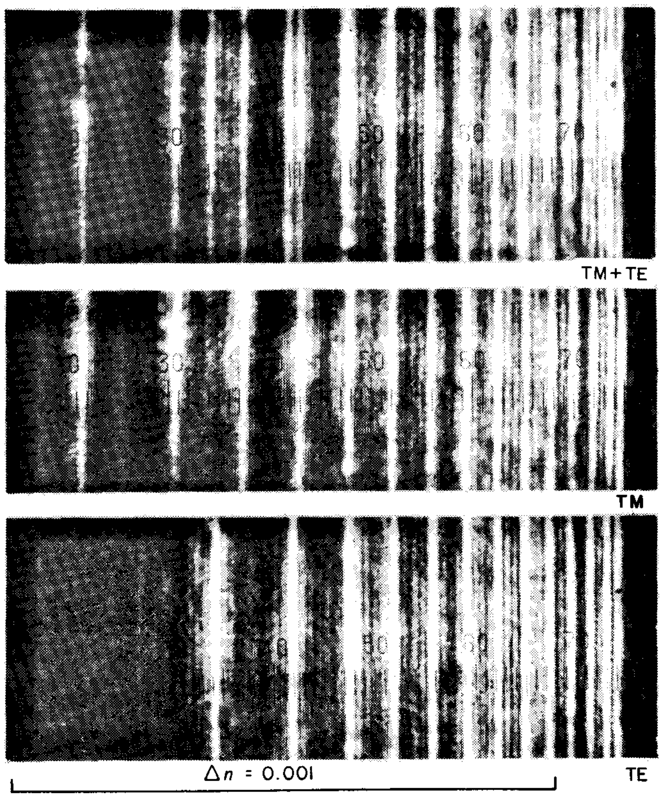

Fig. 8 Chemically tempered glass refractometer patterns

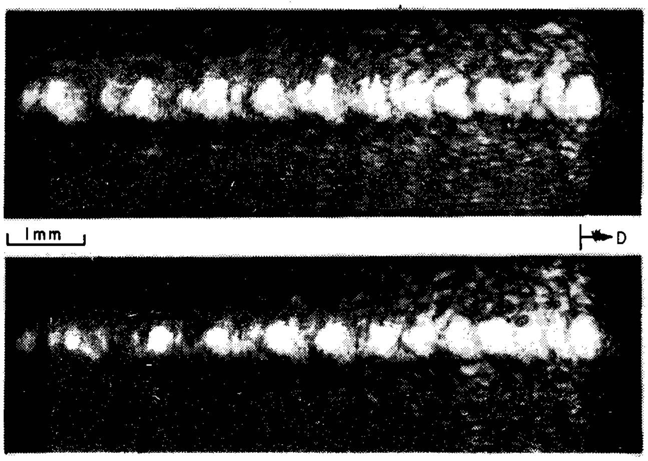

Fig. 9 Biascope patterns for chemically tempered glass obtained by 90° analyser rotation

and between TM and TE combined modes. Therefore, surface stress measurement was not possible.

### Boiler gauge glasses

Pyrex brand boiler gauge glasses were examined. They have polished surfaces which generally gave a distinct optical waveguide effect, presumably due to striation layers near the surface.[6]

*Stress-free gauge glass.* This glass showed a multi-fringe pattern in the refractometer. The biascope showed a light path with brightness distribution corresponding to a birefringence or refractive index difference of 0.00003. This was of the same order as that estimated by the refractometer pattern. Analyser rotation gave no change to either the refractometer or the biascope pattern.

*Thermally tempered gauge glass A.* Refractometer patterns (Fig. 10) by both TM and TE waves were composed of a group of fringes. $0.0001_7$ photoelastic birefringence was identified. Biascope patterns gave a brightness distribution which was reversed by analyser rotation. The period corresponded to $0.0001_9$ birefringence, satisfactorily coincident with the refractometer patterns. Superposition of another brightness distribution was also indicated. This might be caused by refractive index differences between the modes in the groups.

*Thermally tempered gauge glass B.* Refractometer patterns recorded for both TM and TE waves were composed of two or three groups of fringes. $0.0001_7$ photoelastic birefringence was identified. A discussion similar to those for tempered tin-diffused float and plate glass seemed applicable for the biascope patterns (Fig. 11). The longer period gave $0.0002_0$ photoelastic birefringence which agreed with that from the refractometer pattern. Shorter periods corresponded to a range from 0.0007 to 0.002 for refractive index differences, coinciding with those between the groups.

## Conclusion

Using a laser as the light source, it was found that the refractive index distribution near the glass surface affected the biascope pattern. Stress birefringence was identified and distinguished from intrinsic refractive index differences between guided modes by rotating the analyser. This made surface stress determination possible, except when the birefringence was of the same order of magnitude as refractive index differences between intrinsic modes.

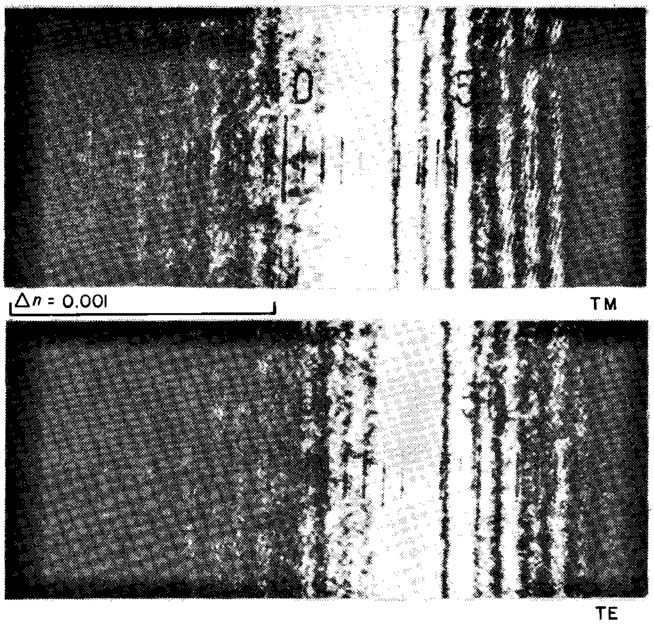

Fig. 10 Refractometer patterns for thermally tempered Pyrex brand boiler gauge glass

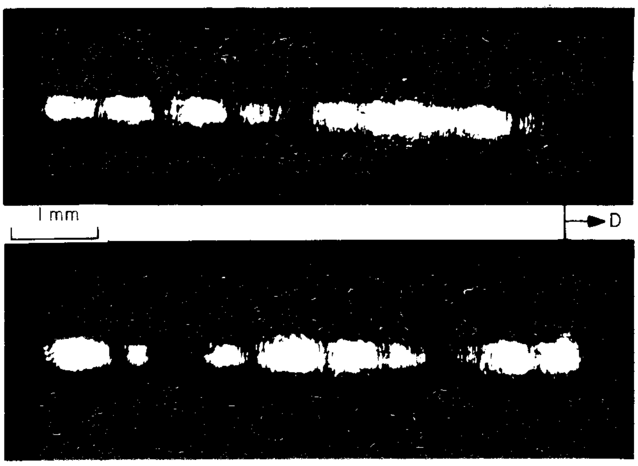

Fig. 11 Biascope patterns for thermally tempered Pyrex brand boiler gauge glass

## References

1 **Acloque, P., Guillemet, C.** *Compt Rend* 250 (1960) 4328; 'Compt rendu du colloque sur la nature des surfaces vitreuses polies' (Union Scientifique Continental du Verre, Charleroi, Belgium, 1959) 121; US Pat 3 286 581 (1966); *Glass Industry* (August 1960)
2 **Blank, D.** *Glastech Ber* 59 (1979) 1
3 **Kishii, T.** *Opt Laser Technol* 12 (1980) 99
4 **Kishii, T.** *Yōgyō Kyōkai-Shi (J Ceram Soc Jap)* 87 (1979) 119; *Opt Laser Technol* 10 (1978) 164
5 **Kishii, T.** *Opt Laser Technol* 11 (1979) 259
6 **Kishii, T.** *Opt Laser Technol* 11 (1979) 197