3-dimensional stress profiling of highly birefringent optical-fibre preforms

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Introduction

In the fabrication of highly-birefringent, e.g. "Bow-Tie", optical-fibre it is required to maximise the stress, and hence the birefringence, within the core of the preform. Conversely, the stresses in other regions of the preform should be minimised to prevent the preforms shattering. This is particularly true for the so-called 'Stress-Guide' preforms(1) in which the refractive index difference in the core is obtained by using the stress-optic effect, rather than by the more usual method of incorporating a dopant. The ability to measure the stress distribution within such preforms would therefore be extremely useful.

We have previously described(2,3) the theoretical derivation of a method which may be applied to the measurement of axial stress in both axially-symmetric and non-axially-symmetric preforms. The technique may be summarised by noting that the axial stress distribution within a preform, $\sigma_z(r,\psi)$, is related to the reconstructed index-profiles $n_{\theta e}(r,\psi)$, $n_{ze}(r,\psi)$, measured by light polarised respectively transversely and axially to the preform axis by:-

$$n_{ze}(r,\psi) - n_{\theta e}(r,\psi) = -(C_1-C_2)\sigma_z(r,\psi) \qquad (1)$$

Here r,ψ are the preform cylindrical coordinates and C_1,C_2 are the stress optic coefficients. Thus the axial stress distribution is given by a simple subtraction of the two index profiles measured using conventional preform-profiling techniques with the addition of a polariser placed parallel and then orthogonal to the preform axis.

The use of this technique to measure two-dimensional stress profiles in axially-symmetric preforms has already been reported(2,3). We have now refined the measurement technique using tomography to obtain three-dimensional stress profiles of both axially-symmetric and non-axially-symmetric preforms.

Experimental technique

The experimental arrangement for stress profiling uses the spatial filtering technique for preform profiling(4) and is shown schematically in Fig 1. The implementation differs from our previous technique in that a fixed polariser is now placed between the preform and the detector, rather than having a rotating polariser between the source and the preform as before. The new approach removes the difficulties formerly encountered due to angular beam steering when the rotating polariser was rotated. The consequent errors in the deflection function gave rather poor accuracy, particularly in the reconstruction of 3-D stress profiles. In the modified apparatus, the unpolarised deflected beam from the preform passes through a fixed polarising beamsplitter which separates the beam into two orthogonally-polarised components.The two components, polarised axially and transverseley to the preform axis, are then focussed onto separate detectors to yield two separate deflection functions. The effective refractive indices, $n_{\theta e}$ and n_{ze} are reconstructed from these two deflection functions.

To obtain a three-dimensional representation of the stress profile, a number of measurements of the deflection functions must be made at different rotational positions of the preform. The two tomographic representations of the effective refractive index profiles can then be calculated, whereupon it is a simple matter to obtain the stress profile by subtracting the two profiles and scaling using the stress optic coefficients (eqn.1).

Results

The tomographic refractive-index profile and corresponding stress profile for a circularly-symmetric preform are shown in Fig 2. The preform consists of a silica substrate tube, a lightly doped phosphorous/fluorine outer cladding, a highly boron-doped inner cladding and a germania doped core. The raised section with a peak stress of 17 kg/mm^2 which is visible in the stress profile corresponds to the boron cladding layers, where the glass is in tension. Similarly, the dip in the centre of the profile is due to the core of the preform, where the glass is in compression.

Fig 3 shows similar results for a highly-birefringent "Bow-Tie" preform. Here, the stress within the boron-doped sectors can be clearly seen and is approximately 11 kg/mm^2. Also visible is a region of high tensile stress in the core of the preform. These measurements give levels of stress which are consistent with calculations and with results obtained elsewhere. We are therefore confident that the method is accurate. However, since no more-precise methods of stress measurement are known at present, it is difficult to obtain experimental justification. In particular, tomographic methods suffer least accuracy at the preform centre and the core stress, therefore, can be expected to contain the greatest error. A discussion of these points, as well as further results, will be presented.

Conclusions

We have developed a technique which allows the quantitative measurement of the stresses within both axially-symmetric and non-axially-symmetric optical fibre preforms. The technique uses commercially available hardware and software, and so should find considerable applications where knowledge of the stress distribution within a preform is required.

Acknowledgements

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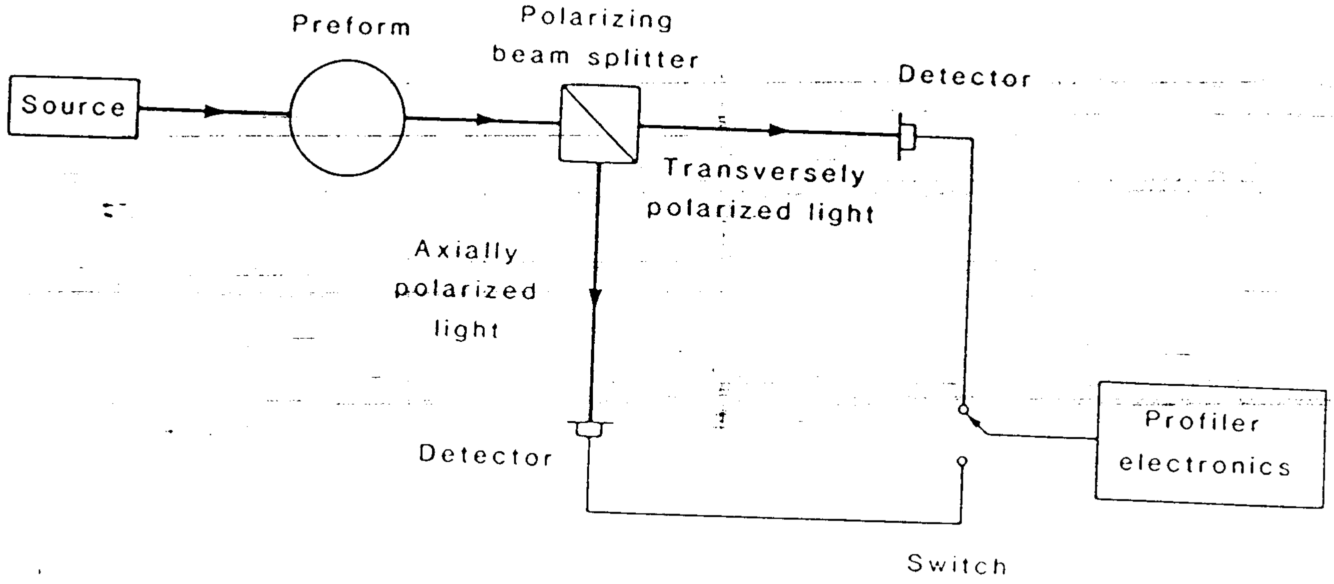

Fig 1 Schematic of Experimental Arrangement for Stress Profiling

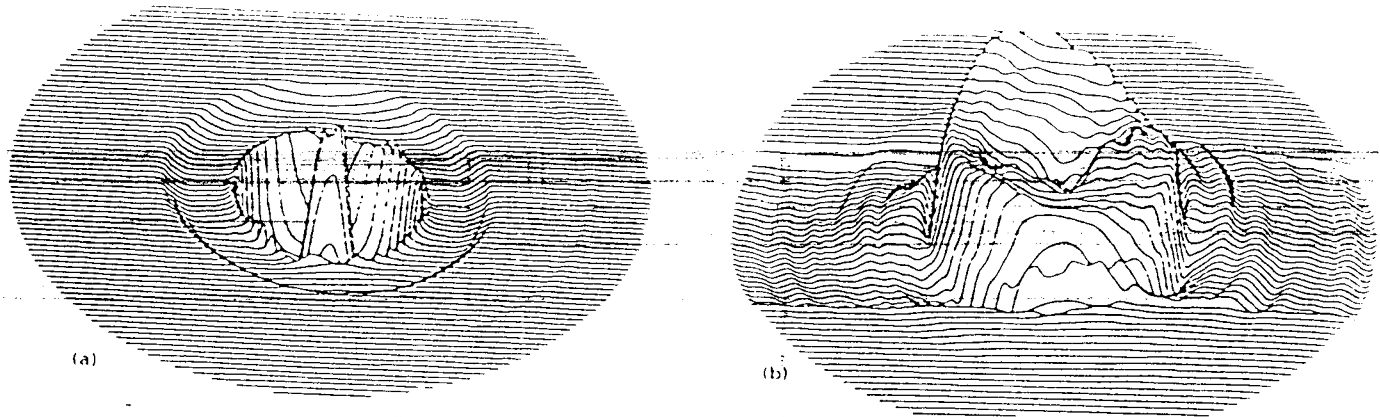

Fig 2 Refractive-Index Profile (a) and Stress Profile (b) of circularly symmetric stressed preform

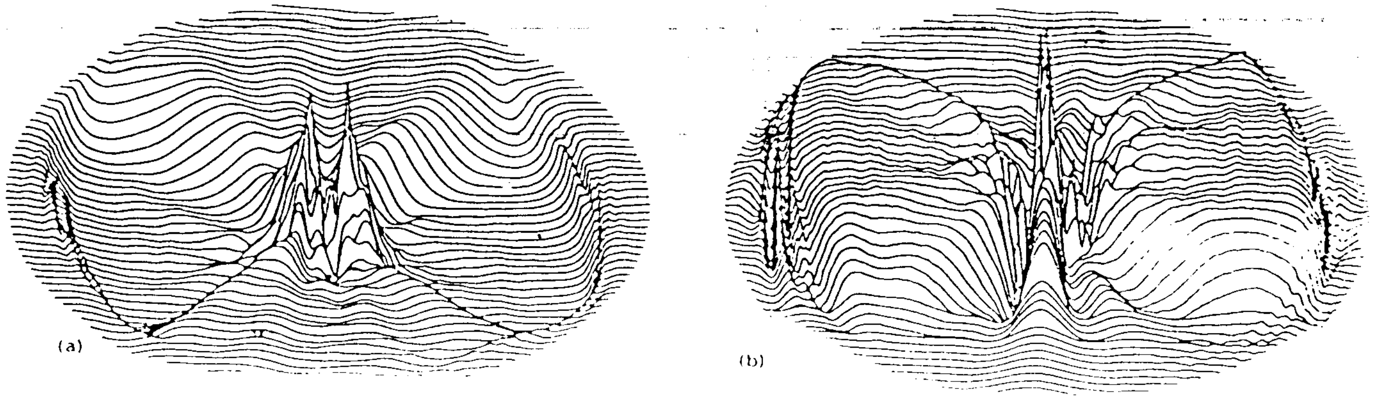

Fig 3 Refractive-Index Profile (a) and Stress Profile (b) of highly-birefringent preform