ON THE DEVELOPMENT OF A CALIBRATION STANDARD

FOR FIBRE GEOMETRY MEASUREMENT

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Introduction.

The optical fibre industry is now sufficiently advanced as to require traceable and transferable calibration standards for both optical fibre manufacturers and system designers. Improvements in optical fibre fabrication techniques and the need for tighter tolerances in splice technology have generated a requirement for high accuracy measurement of fibre geometry.

This paper reports on investigations into the development of a chrome-on-glass mask suitable for geometrical calibration of refracted near-field (RNF) instruments. The mask takes the form of a clear circular aperture, 125um in diameter, surrounded by opaque chromium. Chrome-on-glass artefacts have been investigated because of their convenience of use, stability and longevity. In addition, dimensional measurements of such objects are well understood since they are frequently used in the microelectronics industry for calibration purposes, (1).

The use of RNF for Geometry Measurements.

Refracted near-field (RNF) instruments determine fibre geometry from the coordinates of points corresponding to 50% of the refractive index step at the oil/cladding or cladding/core boundary. In the case of graded-index cores some arbitrary level (eg 5%) is used. A computer program is used to calculate the geometrical properties such as average diameter, non-circularity and core concentricity error.

The normal mode of operation of the RNF instrument is analogous to the idea of a scanning spot phase-contrast microscope. However the transmission object considered in this work is unlike an optical fibre, which is a refractive object, and may introduce different systematic effects into the measurement. These effects have therefore been investigated.

Measurements.

The chrome aperture (nominally 125um in diameter) and the cladding diameter of a number of optical fibres were measured using an interferometrically calibrated image-shearing microscope with a numerical aperture (NA) of 0.45. The overall uncertainty was +/-0.3um. When these fibres were used to calibrate an RNF instrument (launch NA 0.85, blocking NA 0.47) it was consistently found that the chrome aperture was measured by the profiler to be about 0.5um smaller than when measured by image-shearing. Similarly, if the aperture was used to calibrate the RNF instrument this led to fibre diameters being measured about 0.5um too large.

However a similar mask used on a second RNF instrument having lower launch and collecting NA's (0.54 and 0.41 respectively) did not exhibit this effect, although, as can be seen in the following section, this result was incidental and due to the particular operating conditions used.

Diffraction Effects.

The measurements show that the use of a chrome-on-glass mask for the geometrical calibration of RNF instruments can lead to a systematic error. This arises because as the opaque chromium film cuts across the focussed spot, the reduction in size of the unobscured light spot forces it to diffract through larger angles. Since the collecting NA is greater than the launch NA the amount of light collected when the focussed spot is initially intercepted will be proportionately larger than expected. This is because some of the light which would have been intercepted by the blocking disc is now diffracted past it. The magnitude of this effect will clearly depend on the difference between the launch and collecting NA's. As more of the spot becomes obscured the diffraction angle soon reaches 90 degrees and the collecting optics is no longer able to capture all of the light. The resultant reduction in the measured light power from that expected from geometrical arguments is dependent on the collecting NA and possible changes in the angular light distribution which could provide some compensation. Thus there are two opposing mechanisms which can distort the edge profile. The overall effect is not easy to calculate but is obviously determined by the launch NA, collecting NA and blocking NA. For example, if loss of light from the collecting optics is a dominant factor then an opaque chromium disc will appear too large whereas a clear aperture will be measured too small.

To demonstrate this, clear and opaque discs nominally 125um and 60um in diameter respectively were measured as a function of blocking NA. The results are shown in Fig 1. It can be seen that the smaller blocking NA leads to smaller diameters of the aperture (dashed curve), while the opaque disc shows the opposite effect (solid curve) . This is because in this RNF instrument the collecting NA is only slightly larger than the launch NA. Thus, when the blocking NA is small the amount of light gained through diffraction into the full collecting NA is a proportionately smaller fraction of the light collected than when there is no obscuration. The loss of light from the collecting optics therefore appears the dominant effect. Clearly the blocking NA can be increased to a point where this is no longer the case as can also be seen from the Figure when the blocking NA exceeds about 0.4.

Focus Effects.

A 125um clear aperture was mounted on a hollow hemispherical profiling cell and inserted in the first RNF instrument. The numerical apertures for the launch objective, blocking disc and collecting optics were 0.85, 0.47 and 0.83 respectively. A raster scan was performed over the region of the aperture with a scan increment of 2um, and a least-squares fit to the 50% intensity-level data points was applied to obtain the average diameter.

Fig 2 shows the effect on measured diameter of varying the focus position. The diameter scale was calibrated against a fibre measured on the microscope, discussed above. The optimum focus position was taken as the edge over which the approx 20%-80% risetime was minimum. A positive focus offset indicates the objective being withdrawn from the fibre end. The approximate sensitivity to focus is +0.12um diam/um focus.

A series of RNF scans across the edge of the aperture is shown in Fig 3, where increasing optical signal is in the downwards direction. A slight asymmetry with focus can be seen along with a discontinuity in the slope of the edge. Spherical aberration effects appear to be evident since the in-focus position should correspond to a minimum or maximum if diffraction were the only difficulty.

The profiling cell was then filled with matching oil of index 1.47. This had the effect of reducing the exit NA from the cell, which thus increased the proportion of light that was blocked and reduced the sensitivity to diffraction losses at the collection NA. The measured diameter was found to be slightly larger for the wet cell, as expected from the preceeding argument; by about 0.2um. The focus sensitivity was +0.29um diam/um focus. Typical edge plots are shown in Fig 4. The marked 'knee' in the slope of the edge that occurs for positive focus offsets is not fully undestood but its asymmetry with focus position is probably due to the interaction of diffraction effects with spherical aberration in the objective. However the discontinuities in the slope were found to disappear when a large area detector was positioned immediately behind the mask in place of the normal collecting optics.

It was found that by fitting a 0.9NA objective with a coverslip correction ring the 'knee' could be made to occur for negative focus offsets by adjustment of the correction ring. The slope of the focus sensitivity was also reversed so that a positive focus offset gave a decrease in measured diameter. For a particular correction ring setting the 'knee' occured at the in-focus position, in which case the diameter showed reduced sensitivity to focus position. However, the in-focus diameter was found to be relatively insensitive to the level of coverslip correction.

Discussion.

The problems associated with the use of an aperture in chrome for calibration of the RNF profiler have been discussed. Due to diffraction effects the measured diameter of the aperture is dependent on the particular configuration of launch NA, collection NA and blocking NA, as well as focus position; in the latter case spherical aberration effects the result also. The use of an aperture for calibration is therefore only valid under strictly controlled conditions.

A chrome aperture of annular form is under development which is expected to show less sensitivity to diffraction effects. An average of the internal and external diameters of the annulus will constitute the reference dimension since this will have reduced sensitivity to axially symmetric aberrations,(2), blocking NA and focus. This is because line-spacing rather than line-width will be the measurement parameter. However, as in high resolution microscopy, the presence of an asymmetric aberration such as coma will be detrimental.

Finally, similar calibration discrepancies have been observed in the scanning beam method for fibre diameter measurement. This technique is often employed for control purposes during fibre pulling. Calibration is usually by means of a series of opaque wires of known diameter. Edge response effects in this environment are under investigation.

References.

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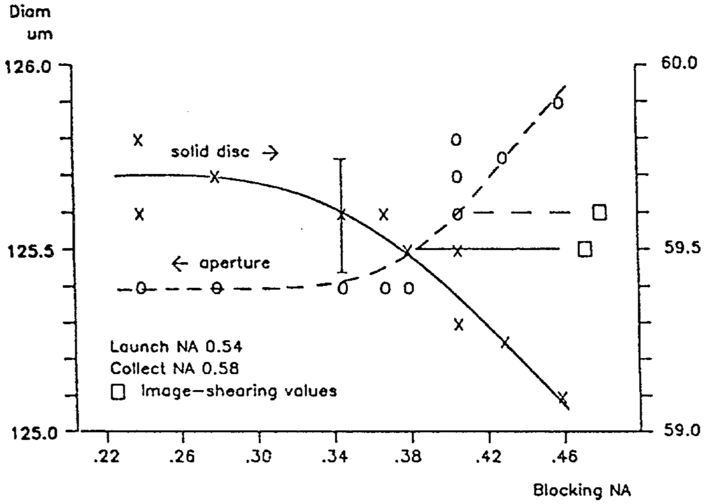
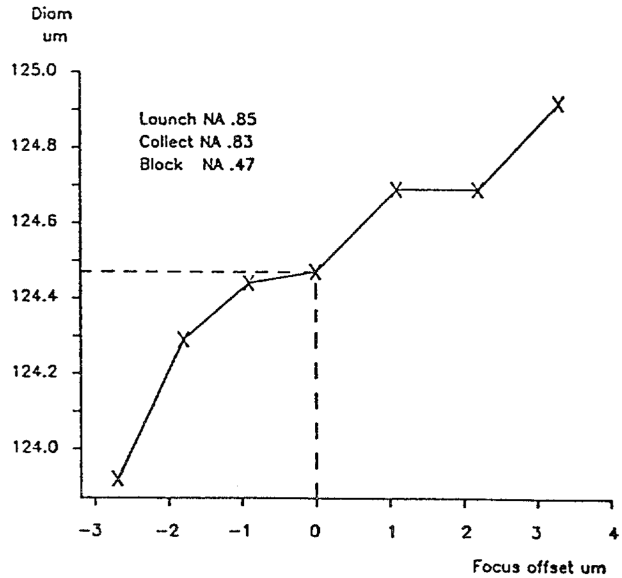


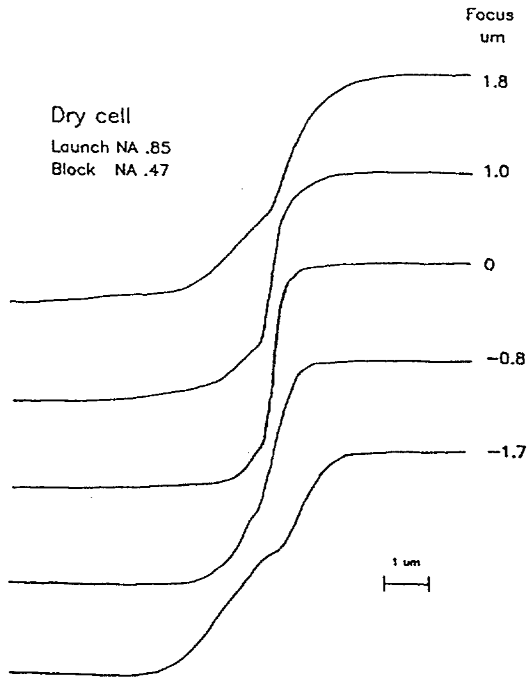
Diameter vs Blocking NA

Fig 1



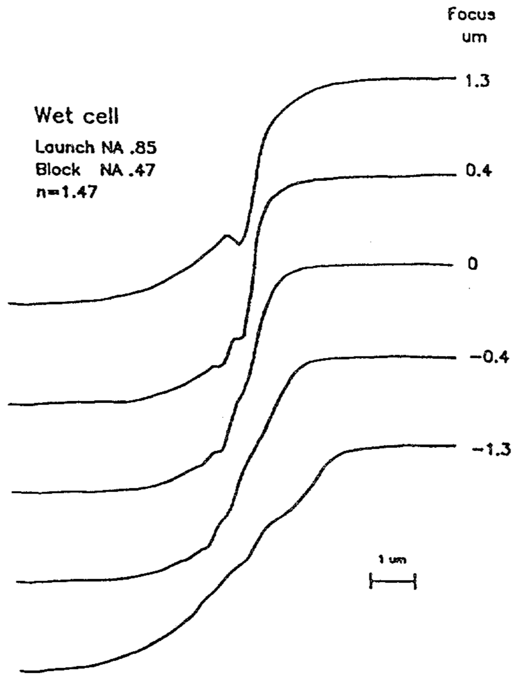
Aperture diameter vs Focus Offset

Fig 2



Aperture edge response

Fig 3



Aperture edge response

Fig 4