CALIBRATION OF FIBER DIAMETER MEASUREMENTS

K.W. Raine(1), J.G.N. Baines(1), A.G. Hallam(2), N.P. Turner(1)

(1) Division of Mechanical and Optical Metrology,
National Physical Laboratory, Queens Road, Teddington,
Middlesex, UK. TW11 0LW

(2) York Technology Ltd, York House, School Lane
Chandlers Ford, Hampshire, UK. SO5 3DG

A recent study of the calibration of fiber diameter measuring instruments [1] has highlighted various problems associated with some of the more commonly used measurement techniques.

The use of a cleaved fiber end as a transfer standard was considered unsatisfactory because of the difficulty in maintaining a good quality cleave over long periods of time and the effect of cleave quality on edge fitting algorithms. In order to establish a reliable reference standard we have measured the diameter of many samples of the same pure silica fiber by three independent techniques (white light interferometry, mechanical contact and image inverting microscopy) and the results had a total spread of 0.1µm [1]. This fiber was then used as a reference for the assessment of chromium-on-glass artefacts and of other measurement techniques under various conditions. Chromium masks were studied because they are mechanically robust, can be made with sharp edges and are already used as linewidth standards in microelectronics. We investigated the use of a linewidth standard and circular chromium-on-glass patterns (apertures, stops and annuli) which are more representative of a fiber end.

Measurements using imaging microscopy showed that the mean diameter of an annulus, or the line spacing of a linewidth photomask, is insensitive to experimental conditions. Such objects are therefore suitable for calibrating the transducers and detectors of many fiber diameter measuring instruments.

When measuring fibers and masks it is common practice to use the 50% intensity level of the image as the edge setting criterion. However, the true edge position normally occurs at or close to the 25% intensity for both fibers and opaque chromium masks when using a properly set up microscope [2]. Therefore to obtain the true diameter or linewidth, it is necessary for the 25%-50% offset to be accurately known and reproducible. We found that this could be determined from measurements of calibrated circular chromium masks or linewidth standards in transmitted light. Using a grey scale digitization system the offset was larger than expected (0.8µm) and instrument dependent. This has been further investigated. We showed that it was possible to obtain agreement with the reference methods to ±0.15µm on grey scale and image shearing instruments.

USING CHROMIUM MASKS IN REFLECTED LIGHT

It is always advisable to measure opaque chromium masks in transmitted light (T) as this avoids the edge distortion due to the phase differences between the light reflected from each side of the boundary [2]. Thus when measuring with reflected light (R), the 25% intensity level which normally locates the true edge position can now lead to an error. Because some grey scale instruments are designed for use with reflected light only, we have measured a number of bright and dark chromium-on-glass lines in reflected light. Some masks were made with a single layer of chromium, others had anti-reflection coatings on the chromium. The measurements were carried out with an image shearing microscope using an objective with a numerical aperture (NA) of 0.65 (x40 magnification) and green filtered illuminating light. Additional magnification was used to make the TV scan linewidth correspond to 0.1µm in the object plane. Surprisingly, we found that with both dark and bright lines the linewidth determined at the 50% intensity level, measured in R, were in the range 0.05µm to 0.15µm smaller than the value measured in transmission (corrected for the appropriate 25%-50% offset). This was contrary to expectation since the dark line, as viewed in R, should have measured larger than the corrected value. The measurements were found to be fairly insensitive to operating conditions. For example, a change in condenser NA of 0.6 to 0.1, or of the center wavelength of the illumination from 550nm to 633nm changed the value by no more than 0.05µm. The introduction of several wavelengths of spherical aberration (by placing a 170µm thick cover-slip between the objective and the mask) only led to small increases in linewidths of between 0.05µm and 0.1µm, in fact resulting in measurements closer to the correct value.

Thus whereas fibers, and chromium masks measured in T, have the same offset [1], the results show that the difference in the offset between fibers, and chromium masks measured in R, would be up to 0.15µm with this instrument. However, the 50% intensity level was found to be insensitive to experimental conditions, for example focus, when the ratio of the condenser NA to the objective NA (S) was about 0.7, thus it should be possible with good characterization to use chromium masks for calibration using reflected light.

THE 25%-50% OFFSET

In the earlier work [1] we noted that the 25%-50% offset seemed to be the appropriate correction, for a fiber in R, even if the value was increased by inadequate TV resolution. We have investigated this unexpected result further by measuring in T a calibrated clear linewidth under different conditions. We have found that the 25%-50% offset determined from photometric measurements can lead to errors. When this value was increased from the theoretical value of 0.2µm to 0.35µm (NA 0.65) by reducing the image size on the TV, repeated measurements showed an error of 0.1µm in the linewidth. The photometrically determined value of the 25%-50% offset also led to errors in the presence of spherical aberration or when the green filter was removed. However, if the offset was determined from the difference between the measured value and the calibrated linewidth, the correct value of the offset was obtained under a wide range of conditions. Measurements of fiber using this value then led to agreement with the diameter determined from other methods to 0.1µm. Applying the offset obtained in this way to our earlier measurements with inadequate TV resolution [1] led to a reduction in diameter of 0.1µm but we found the results to be still within the ±0.15µm of the reference value.

Alternatively, the offset may be determined from measurements of a calibrated chromium aperture or incorporated into the calibration by setting the true diameter at the 50% intensity level. For this to be accurate the diameter of the chromium aperture must be close to the fiber diameter (125µm). Following a calibration by this method, diameter measurements made on the fiber agreed to ±0.1µm with measurements made by other techniques. This affect would appear to be due to interaction of the curvature of the image with the TV resolution.

One of the reasons for measuring at the 50% level has often been its convenience and the insensitivity of this level to experimental conditions. However, if the condenser NA is reduced so that S is less than 0.2, leading to coherent illumination, we have found that the 25% intensity level is similarly insensitive to focus errors and the presence of large amounts of spherical aberration [3]. These conditions typically lead to errors of less than 0.05µm in linewidth values. Unfortunately we have not been able to try this with fiber measurements because low light levels caused signal to noise problems.

EFFECT OF CCD PIXEL SIZE AND PITCH IN GREY SCALE MEASUREMENTS

For the grey scale digitizer it was found that the 25%-50% offset depended on the pixel element size of the CCD camera. Offsets were determined by calculating the diameter of the reference fiber at different intensity levels. Previous work [4] showed the existence of an offset of approximately 0.8µm for a 0.4 NA (x20) objective operating at a wavelength of 550nm. In this case the pixel pitch was 15.7µm x 11.3µm. However, using a different camera having a pixel pitch of 11.6µm x 11.4µm resulted in an offset of 0.55µm under the same experimental conditions. This improvement was due the improved spatial sampling where the pixel pitch was about 0.5µm referred to the object plane.

It was found that when measuring a fiber edge a 0.65 NA (x40) objective gave an offset of 0.39µm (theoretical value about 0.25µm) when the value of S was 0.7. The corresponding pixel size was 0.25µm in the object plane. The difference between the measured and theoretical offset was similar to that obtained with the image shearing microscope when the TV linewidth was also about 0.25µm in the object plane. It has been shown [1] that additional empty magnification leads to agreement between the theoretical and measured offsets and could be applied to this instrument with possible advantage. However this would require a camera with smaller pixel size.

To minimise processing time in grey scale analysis it is preferrable not to use all the available pixels. To investigate the effect on the measured diameter of a fiber a series of measurements was made using different grid spacings. The smallest grid spacing corresponded to the pixel size of about 0.5µm in the object plane using a x20 objective. Larger grid spacings were generated by omitting pixels and were integer multiples of the pixel size. It was found that the fiber diameter was constant to within 0.1µm for grid spacings up to 1.5µm. For larger grid spacing the computed fiber diameter was reduced. The 25%-50% offset was also found to be independent of grid spacing up to a value of 1.5µm.

The insensitivity of the measurements to the grid spacing was a little surprising. It is probably due to the interaction of the image of the curved fiber edge with the square format of the CCD array, such that each part of the edge slope of the fiber is sampled at some point on the circumference.

In order to determine the offset by calibrating with a reference fiber, care must be taken to understand the interaction of the curve fitting algorithm with the actual form of the fiber edge. We have found that the presence of blade impact damage and hackle on the end of the fiber can result in an underestimation of the fiber diameter. Also, the effect of cleave damage on the fiber edge reduces the average edge slope. Thus for an imperfect edge the offset will be larger than the value expected from diffraction considerations. The use of a chromium artefact should therefore provide a more reliable means of determining the offset for grey scale instruments. If used in transmitted light, as in the image shearing measurements described above, a direct calibration incorporating the offset would also be possible.

CONCLUSIONS

We have shown that chromium-on-glass masks used with transmitted light are capable of calibrating transducers and determining offsets for imaging instruments designed for measuring the cladding diameter of optical fibers. Alternatively, they can be used to provide a calibration which includes the offset when the width of the chromium pattern has the same dimensions of the fiber. If the TV linewidth is less than 0.1µm in the object plane, the measured offsets have been found to agree with those evaluated from theory. Before reflected illumination is employed for calibration the characteristics of edge setting criteria need further investigation and characterization. If measurements are made at the 50% intensity level then the value of S should be about 0.7 but if direct measurement is made at the 25% intensity levels S should be less than 0.2. In each case the measurements are insensitive to experimental conditions and therefore more reproducible. Although we have only discussed the application of chromium masks for calibration and determining edge setting offsets, circular masks also have applications in calibrating for circularity, concentricity and assessing form fitting software and can be used to assess the orthogonality of scanning x-y stages.

REFERENCES

[1] Baines, J.G.N., Raine, K.W., Hallam, A.G., Turner,N.P.,"Fiber diameter measurements and their calibration," Accepted for publication by J. Lightwave Tech.

[2] Reynolds, G.O., DeVellis, J.B., Parrent Jr., G.B., Thompson, B.J.,"The new physical optics notebook: Tutorials in Fourier Optics," SPIE Optical Engineering Press, p 147, 1989.

[3] Kirk, C.P., "Aberration effects in an optical measuring microscope,"Appl. Optics, vol. 26, no. 16, pp 3417-3424, August 1987.

[4] Hallam, A.G., Baines, J.G.N., Raine, K.W., Turner, N.P.,"Towards a calibration standard for fiber geometry measurement", Optical Fiber Communication Conf. (OFC '90), Tech. Digest, 1990.