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# Technical Digest
# Symposium on Optical Fiber Measurements, 1992

Sponsored by the National Institute of Standards and Technology
in cooperation with the IEEE Lasers and Electro-Optics Society
and the Optical Society of America

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Fiber Cladding Diameter Measurement
by White Light Interference Microscopy

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Measurement of fiber cladding diameter with an overall uncertainty of 0.1 μm, or less, has been an ongoing project at NIST for the past three years. The main purpose of this project is to produce standard reference fibers for calibration of gray scale video microscopes. To help evaluate the systematic errors of any one technique, we have constructed three absolute measurement systems: a scanning confocal microscope, contact micrometer, and white light interference microscope.

The white light interference microscope uses a Mirau interference objective with a single surface in contact with the fiber. We chose a Mirau objective over the Michelson objective used in previous works [1,2] because of its stability, ease of operation, and higher magnification. Single-surface contact was chosen because a knowledge of the fiber index profile is not required [1] and material dispersion is avoided.

The system was constructed from commercial metallurgical microscope parts and uses bright-field illumination from a halogen lamp, a binocular eyepiece, and a CCD array video camera with 400× overall magnification. The camera is connected to a video analyzer and monitor. An optical flat is held perpendicular to the optical axis (±100 μrad) with a high quality mirror mount on a precise three-axis translation stage. The position of the flat is monitored by a commercial interferometer with 1.2 nm least count. The interferometer, translation stage, and video analyzer are all controlled by computer, and repeated measurements can be made automatically (Fig. 1).

The mirror mount has been modified to hold a standard NIST fiber holder along with a cantilevered brass weight which holds the fiber against the optical flat. The fiber holder positions the fiber on top of the flat and can be interchanged among all three NIST measurement systems. The brass weight has a semi-circular cross section and is thin enough to fit between the fiber and objective with the curved side toward the fiber. It has a 0.76 mm slot through which the fiber and flat are viewed (Fig. 2). The weight can be oriented using two precise 1/4-80 screws so that even pressure is applied to the fiber from both contact points. The weight deforms the fiber by about 0.5 μm, but the deformation is localized to a region within 20 μm of the edge of the slot. Measurements of the fiber diameter are made 380 μm from both fiber-weight contacts. Contact between fiber and flat is verified within 100 nm by viewing contact white light interference fringes analogous to Newton's rings. Surface contamination larger than 25 nm on or adjacent to the fiber can be detected using colored fringes.

The top surface of the fiber or flat is located by scanning the stage and recording white light fringes using the video analyzer while the position of the stage is monitored. The central fringe of the interferogram is then fitted to a parabola to average out random fluctuations in intensity and position tracking (Fig. 3). The region of the video image to be sampled is located using a set of cross hairs on the video monitor. Since the field of view is a few fiber diameters in extent, no lateral motion of the translation stage is required during a measurement. To measure the diameter of a fiber, the flat is located, the top of the fiber is located, and the difference is calculated. The flat is then relocated and the difference is again calculated. The average of these two measurements is one datum which has been corrected for linear drift. When this measurement is repeated without fiber replacement, the standard deviation of the measured mean diameter is about 10 nm. When the fiber is removed and replaced between measurements the uncertainty becomes 25 nm (all uncertainties are reported as $3\sigma$).

Placement of the cross hairs on top of the fiber is subject to digitizing and random errors. Slight offset of the cross hairs makes the measured fiber diameter too small. A 40× Mirau objective was used to estimate the magnitude of this effect. Six measurements on a control fiber were made alternating with measurements using the 20× objective. The 40× objective gave values 6±12 nm larger than the 20× objective. If probability distributions for placement of the cross hair are the same for both objectives, the mean offset of the measured diameter using the 40× objective is 4 times smaller than the offset for the 20× objective. Then, the correction factor is (4/3)×6 nm or 9±15 nm. All subsequent measurements include this additive correction factor, giving a total uncertainty of 30 nm.

Finally we have compared measurements on fibers using the white light interference microscope, a contact micrometer [3], and a scanning confocal microscope [4]. Measurements were made by different operators without prior knowledge of each others' results. The diameter of each fiber was measured at two specific angular orientations, thus giving a comparison of eight measured diameters (Fig. 4). Results of the interference microscope and scanning confocal microscope are plotted with respect to the contact micrometer. The mean difference between the contact micrometer and interference microscope was -1 nm and the rms difference was 15 nm. Similarly, the difference between the contact micrometer and the scanning confocal microscope was 16 nm and the rms difference was 29 nm.

Matt Young and Steven Mechels made the measurements with the contact micrometer and the scanning confocal microscope, and provided many useful insights on precise fiber measurements. 

References

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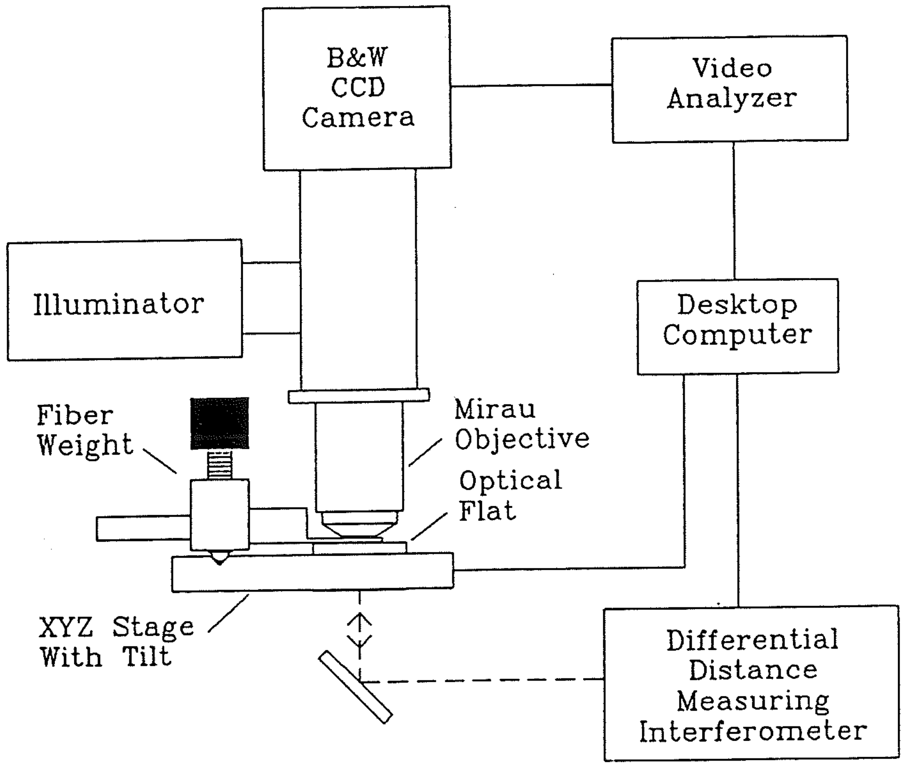


Fig. 1. White light interference microscope system based on Mirau objective.

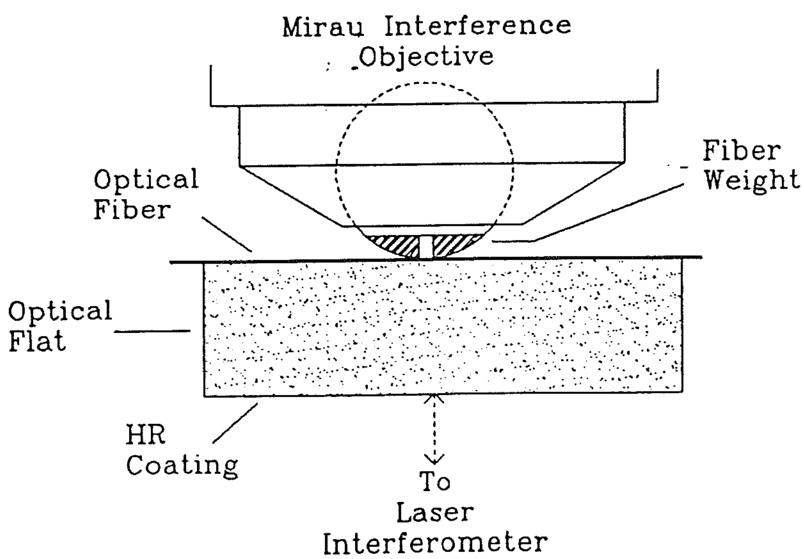


Fig. 2. Schematic of fiber held in contact with optical flat.

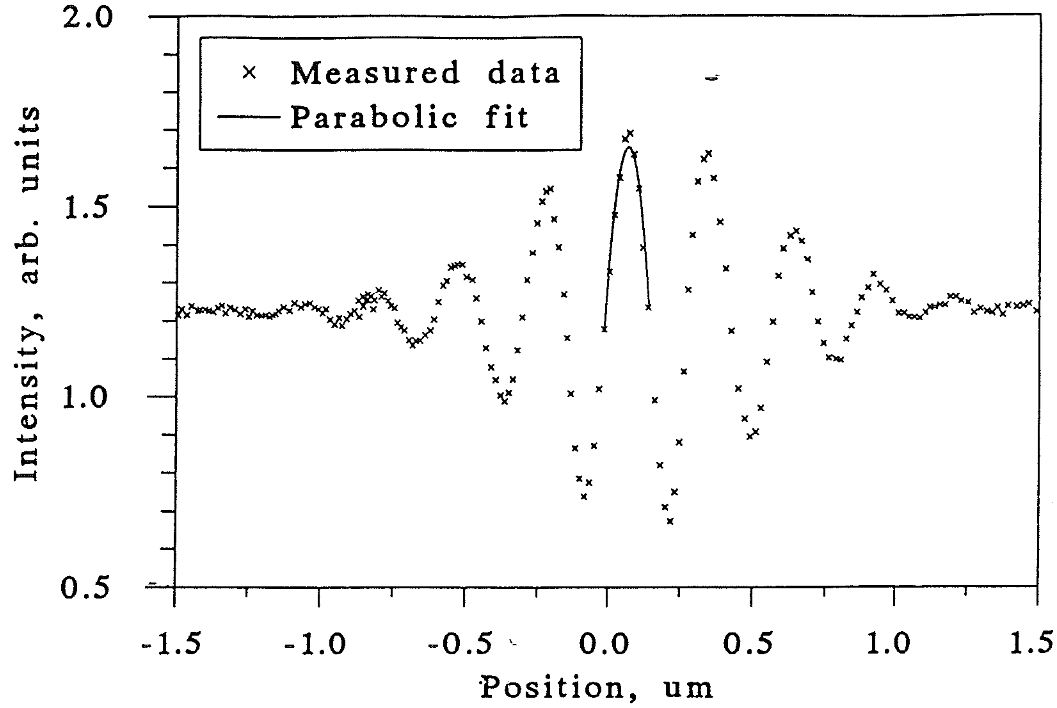


Fig. 3. White light interferogram with parabolic best fit to central fringe.

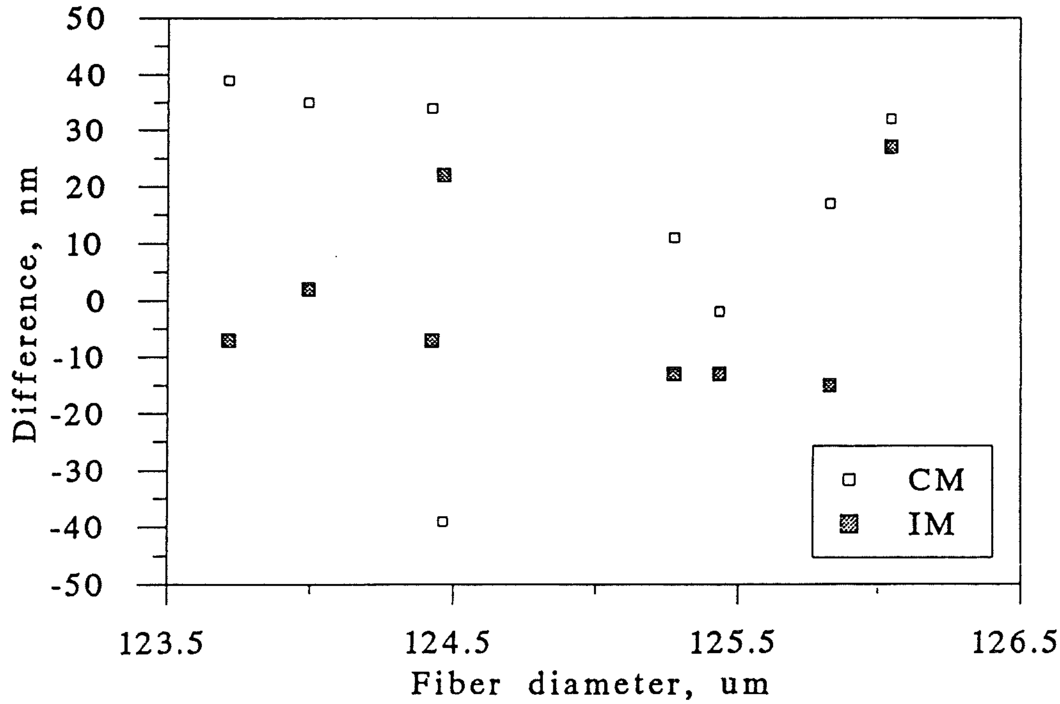


Fig. 4. Comparison of interference microscope (IM) and scanning confocal microscope (CM) with respect to contact micrometer. Measurements of fiber diameter were made at two angular orientations on four fibers.