Two-dimensional refractive index profiling of optical fibers by modified refracted near-field technique RNF

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Abstract

The refracted near-field technique (RNF) is among the most widespread techniques used for measuring the refractive index profile of optical fibers and is based on illuminating the end-facet of a fiber with a focused beam whose vertex angle greatly exceeds the acceptance angle of the fiber, which is immersed in an index matching liquid. What one observes are then the refracted unguided rays rather than the guided rays. Nevertheless, the standard RNF technique cannot be applied to a wide range of optical fibers e.g. if their shapes are not axially symmetric. In this work we demonstrate a modified method which allows 2-D imaging of the refractive index profile and thereby overcoming the axial symmetric limitation of the standard RNF.

The new system is based on the same principle of the RNF, but the optical path is reversed so that the light at the fiber end-facet is collected by an objective lens and detected by a CCD camera. The method does not require scanning over the fiber end-facet. Thus the system is faster and less sensitive to vibrations and external conditions compared to the standard RNF, furthermore it allows averaging to improve the signal to noise ratio. The spatial resolution of the system is determined by the numerical aperture of the objective and by the resolution of the CCD camera. To calibrate the setup, a reference multi-step index fiber provided by National Physical Laboratory was used.

Standard RNF

- The fiber end-facet is illuminated by a focused beam whose numerical aperture greatly exceeds the acceptance angle of the fiber.
- The light will be refracted rather than being guided.
- An opaque circular stop is designed to block the guided light and the leaky modes from the fiber.
- The power that is transmitted around the opaque circular stop varies with index of refraction at the point of illumination.
- The power transmitted around the stop should vary linearly with the refractive index of the fiber at the point of illumination:

$$P(\theta_1) \cong K_1 - K_2 n(r)$$

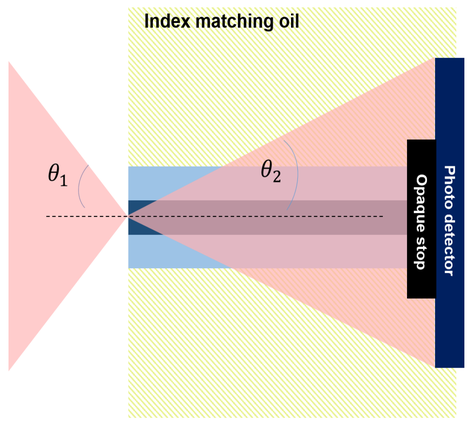
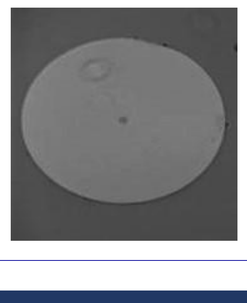


Figure 1. Schematic diagram of the standard RNF

- ✓ Direct measurement of the refractive index profile
- ✓ No theoretical corrections are required
- ✓ No specially prepared sample is required
- ✗ Measuring fibers with axially symmetrical geometry

Modified RNF

- The new system is based on the RNF technique with inversed optical path
- A homogenous light distribution is achieved using a diffuser.
- The refracted light at the end-facet of the fiber is collected using an objective lens and a CCD camera.
- Most of the rays are refracted out of the core into the cladding, resulting in intensity distribution with a lower intensity in the core.



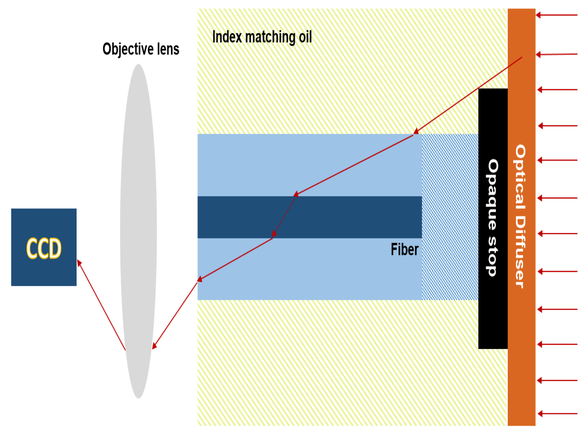


Figure 2. Schematic diagram of the modified RNF

- ✗ Measuring fibers with axially symmetrical geometry
- ✓ 2-D refractive index profile
- ✓ Simple and robust
- ✓ Fast measurements
- ✓ Accuracy $\approx 6 \times 10^{-4}$

System Calibration

- For the calibration a multi-step index optical fiber is used.
- Fig. 3 shows the image of the multi-step index fiber end-facet.
- The refractive index values and the intensity levels recorded were used to calibrate the device

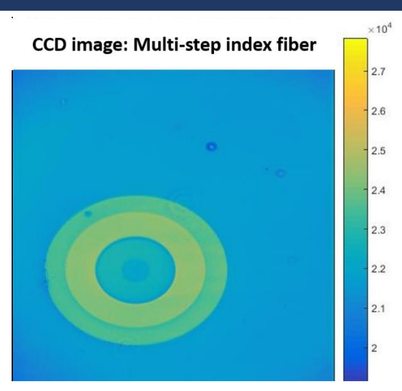


Figure 3. CCD image of the multi-step index reference fiber

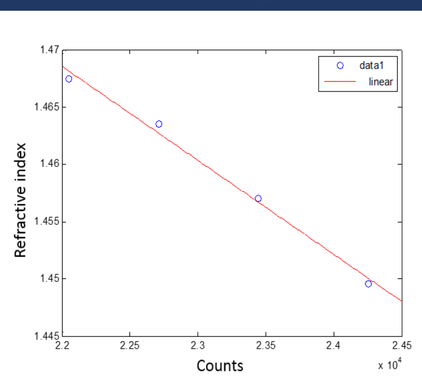


Figure 4. Calibration curve

- Fig. 5 shows the 2-D index profile of the reference fiber.
- By positioning an arbitrarily line along the fiber cross-section, the 1-D index profile is obtained in Fig. 6.
- Our measurements showed a good agreement with the NPL indices.

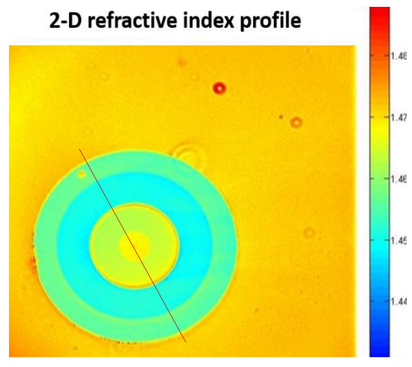


Figure 5. 2-D refractive index profile of the multi-step index reference fiber

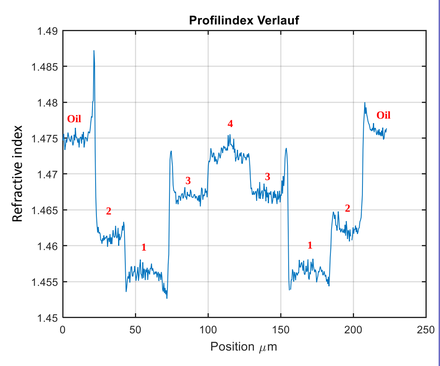


Figure 6. 1-D refractive index profile of the multi-step index reference fiber

Measurements

- Fig. 7 shows the 2-D index profile of a step-index optical fiber.
- Fig. 8 shows the 1-D index profiles.
- An index step of 0.00676 ± 0.00051 was obtained.

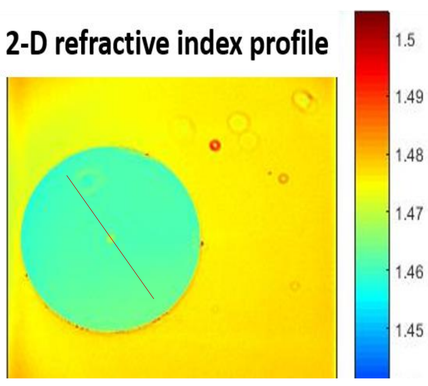


Figure 7. 2-D refractive index profile of a single mode step index fiber

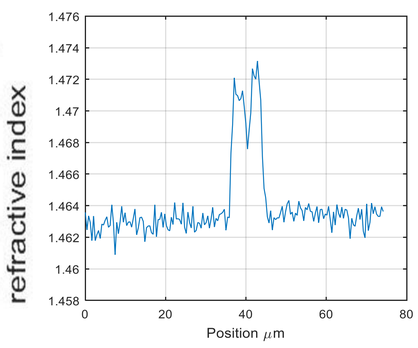


Figure 8. 1-D refractive index profile of a single mode step index fiber

- Fig. 9 and Fig. 10 show the 2-D and the 1-D index profile of a multi-core fiber.
- The refractive index dip at the very center of the core is resolved by our system (see Fig. 10).
- An index step of 0.010391 ± 0.00064195 was determined.

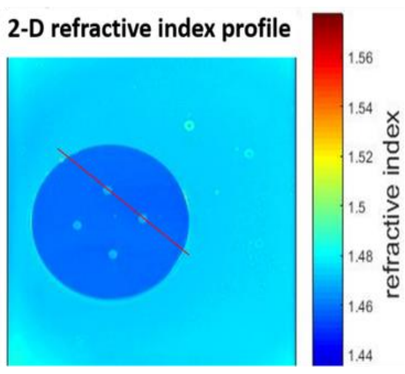


Figure 9. 2-D refractive index profile of a multi-core fiber with 4 cores. The line vector (in red) is used to obtain the 1-D index profile.

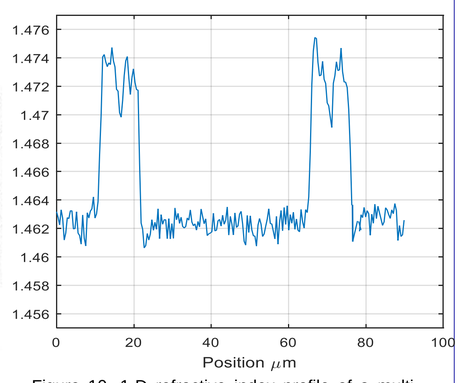


Figure 10. 1-D refractive index profile of a multi-core fiber.

Conclusion

Refractive index profiling and geometry characterization of optical fibers have been obtained by a modification of the standard refracted near field technique. Our modification resulted in a system that doesn't require scanning over the fiber end-facet. Therefore limitations due to none axially symmetrical optical fibers have been overcome by obtaining a 2-D index profile. Thus our device is faster and less sensitive to vibrations and external conditions compared to the standard refracted near field technique. The estimated accuracy of the system is similar to that obtained for optical fibers which is approximately 6×10−4.

References

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