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# Measuring the refractive index of double-clad fibers using an interferometric technique

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Multiple-beam Fizeau interferometry is an accurate and simple technique in the field of fiber research. In this paper, we present expressions for the fringe shift across a double-clad fiber with graded-refractive index inner cladding and we provide the layout of the measuring optical system.

## 1 Introduction

Double-clad fibers (DCFs) are used in fiber laser and in endescopy. Multiple-beam interferometry is an accurate technique that has been used in the field of fiber reasearch. Inserting the fiber in a liquid wedge with its axis perpendicular to the wedge axis causes the fringes to be shifted perpendicularly with respect to the liquid fringe. The amount of shift is a function of the fiber parameters. To the best of the authors knowlege, there is no model for the shape of the fringes pattern across a DCF with graded- index inner cladding. In this paper we provide expressions for the fringe shape across the DCF with graded-index elliptical inner cladding. In addition, we provide a simulation example.

## 2 Theory

The optical system that is required to produce Fizeau fringes is shown in Fig. 1. The ray paths through a DCF with elliptical inner-cladding is shown in Fig. (2).

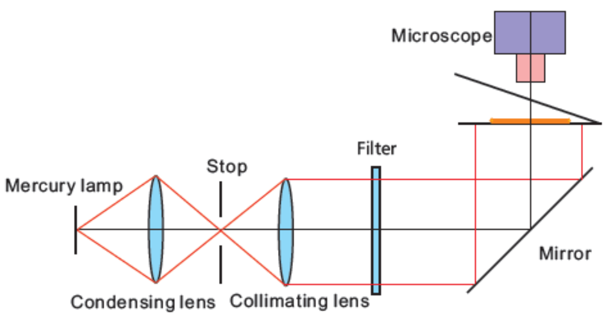


*Fig. 1 Optical setup to produce Fizeau fringes across DCF.*

The refractive index profile across the inner cladding is represented by

$$n_{CL2}(r) = n_{CL2}(0) - \Lambda\left(\frac{x^2}{A^2} + \frac{y^2}{B^2}\right)^{\alpha/2} \qquad (1)$$

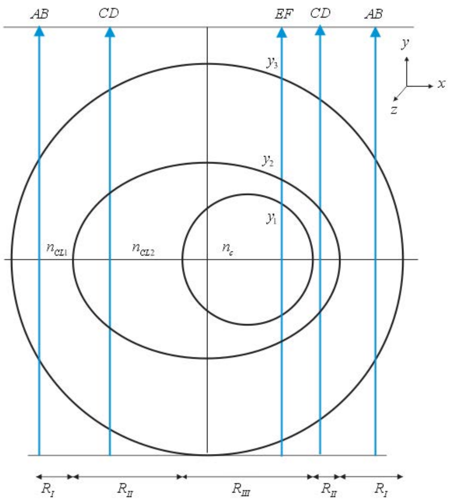


*Fig. 2 Ray paths through DCF.*

Where $n_{CL2}(0)$ is the refractive index at the center of the inner cladding, $n_{CL2}(r)$ is the refractive index across the inner cladding, $\alpha$ is the refractive index profile parameter, $\Lambda$ is the grading parameter $(\Lambda \ll 1)$, $A$ and B are the semiminor and semimajor axes of the inner cladding, respectively. The fringes across the DCF are shifted with repect to the liquid fringes. The fringe shifts are given by

$$\delta Z_I = \frac{4\Delta Z}{\lambda}\left(a_{CL1}^2 - x_I^2\right)^{1/2}(n_{CL1} - n_L) \qquad (2)$$

$$\delta Z_{II} = \frac{4\Delta Z}{\lambda}\left[\begin{array}{l} \left(a_{CL1}^2 - x_I^2\right)^{1/2}(n_{CL1} - n_L) \\ +B\left(1 - \dfrac{x_{II}^2}{A^2}\right)^{1/2}(n_{CL2}(0) - n_{CL2}) \\ -\Lambda \displaystyle\int_0^{B(1-x_{II}^2)^{1/2}} \left(\frac{x_{II}^2}{A^2} + \frac{y_{II}^2}{B^2}\right)^{\alpha/2} dy_{II} \end{array}\right] \qquad (3)$$

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$$\delta Z_{III} = \frac{4\Delta Z}{\lambda}\left[\begin{array}{l}(a_{CL1}^2 - x_{III}^2)^{1/2}(n_{CL1} - n_L) + \\ +B\left(1 - \frac{x_{III}^2}{A^2}\right)^{1/2}(n_{CL2}(0) - n_{CL1}) \\ -\Lambda \int_0^{B\left(1 - x_{III}^2/A^2\right)^{1/2}} \left(\frac{x_{III}^2}{A^2} + \frac{y_{III}^2}{B^2}\right)^{\alpha/2} dy_{III} \\ +(a_c^2 - (x_{III} - \eta)^2)^{1/2}(n_c - n_{CL2}(0))\end{array}\right] \quad (4)$$

Where $\Delta Z$ is the fringe spacing at the liquid region, $a_c$ is the core radius, $a_{CL1}$ is the outer cladding radius, $\lambda$ is the wavelength, $n_L$ is the refractive index of the liquid, $n_{CL1}$ is the refractive index of the outer cladding, and $\eta$ is the shift of the core center. The model may be reduced to represent DCF with circular inner cladding by the substitution of $A = B = a_{CL1}$ in Eq. (1), Eq. (3), and Eq.(4) .

## 3 Simulation example

In this example we consider a DCF with circular inner cladding. The liquid that we will use has the same refractive index as that of the outer cladding (matching case). The parameters of the outer cladding are $n_{CL1} = 1.4512$ and $a_{CL1} = 62\mu m$. The parameters of the inner cladding are $A = B = a_{CL2} = 45\mu m$ . The refractive index profile of the inner cladding is charcterized by $n_{CL2}(0) = 1.46$, $n_{CL2} = 1.452$, $\alpha = 2$, and $\Lambda = 0.008$. The core parameters are $a_c = 12\mu m$, and $\eta = 15\mu m$ and $n_c = 1.4649$. The refractive index profile across the DCF is shown in Fig. 3 and the fringe shift across the fiber is shown in Fig. 4.

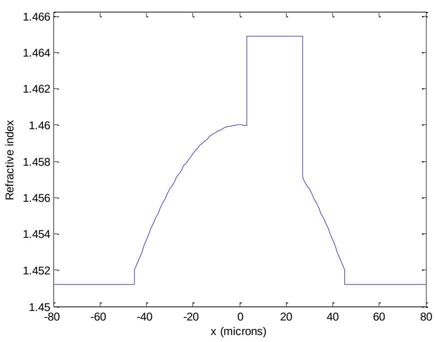


*Fig. 3 Refractive index profile across DCF with graded-index circular inner cladding*

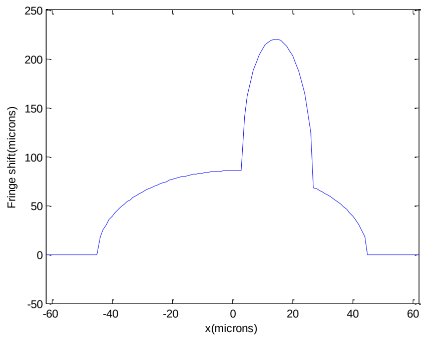


*Fig. 4 Fringe shift across DCF with graded-index circular inner cladding.*

### Conclusion

In this paper, we presented expressions for the fringe shift across DCF with elliptical graded-refractive index inner cladding. The provided expressions may be reduced to represent DCF with circular inner cladding. The simulation example shows the fringe shape across the DCF. Future work includes applying the theory to measure the refractive index profile of DCFs.

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