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Refractive Index Profiling of Optical Waveguides
光波導折射率分析

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Outline

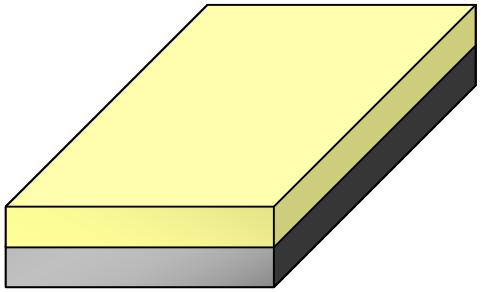
- Motivation
  - Refractive index profiles (RIP) and optical waveguides
  - Methods of RIP reconstruction
- Inverse calculation algorithm
- Differential near-field images
  - Modified end-fire coupling method
- Two-dimensional RIP reconstruction of optical waveguides

Refractive Index Profiles of Optical Waveguides

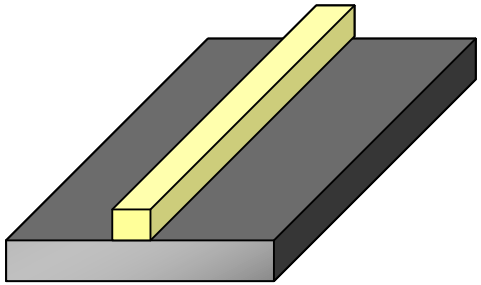
1D

2D

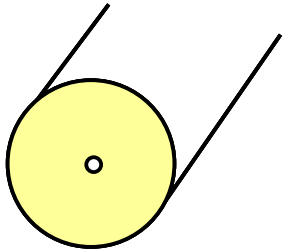
Step-index distribution



Planar waveguide

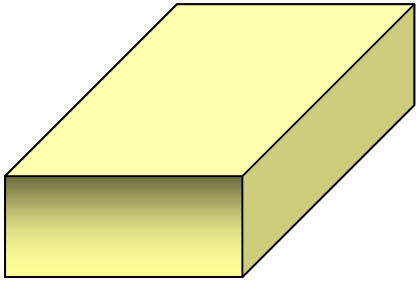


Ridge waveguide

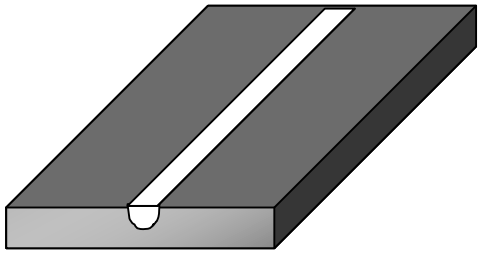


Optical fiber

Graded index distribution



Metal diffusion planar waveguide

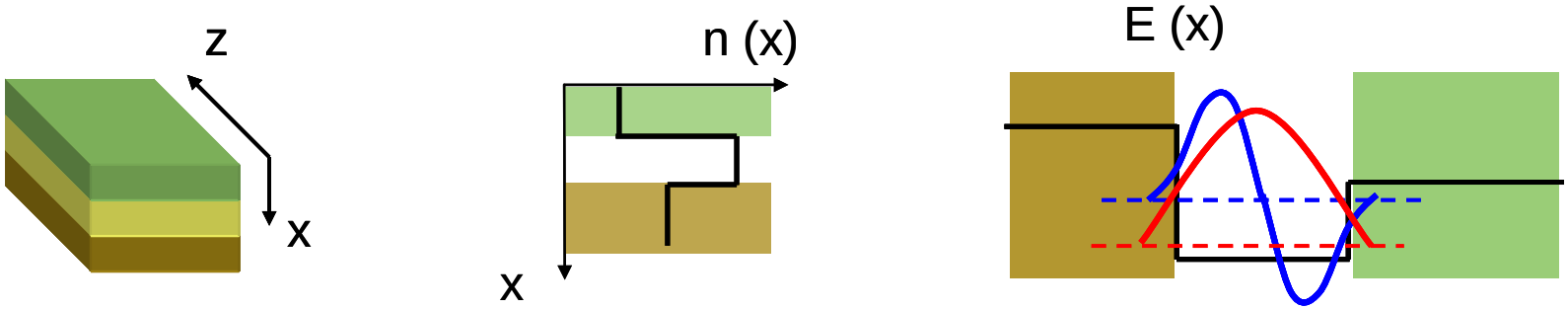


Channel waveguide

Refractive Index Profiles (RIP) of Optical Waveguides

- RIP is crucial in the determination of waveguide mode properties.
- Knowing the RIP helps complicated device design.
- RIP is decided by the fabrication parameters.
- The guiding mode can be derived from the RIP by scalar wave equation.

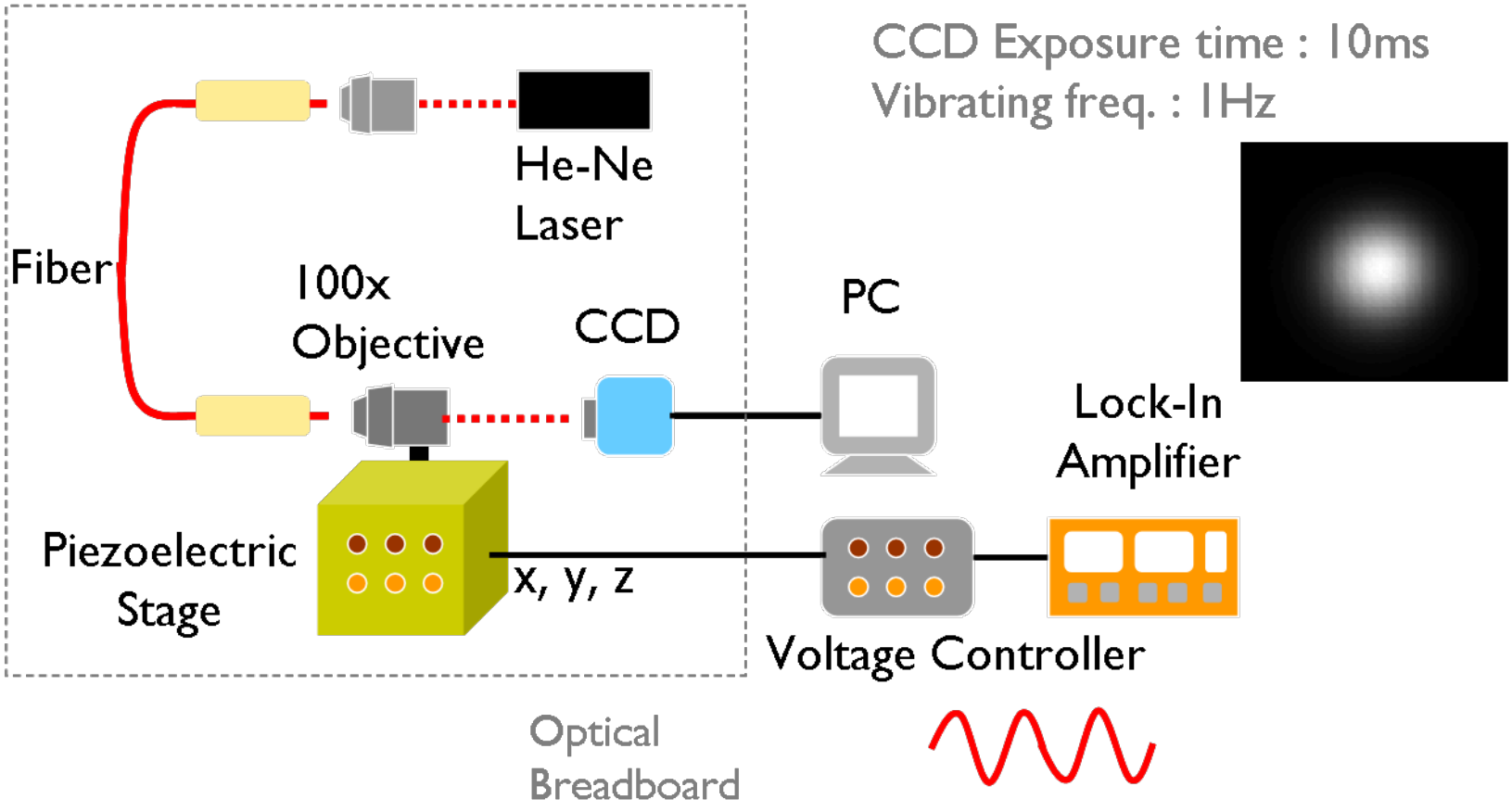
Refractive Index Difference and Eigenmodes



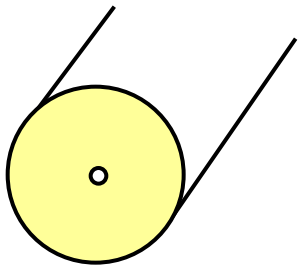
Waveguide Structure ⇒ Index Difference, n ⇔ Guiding Eigenmodes, E

$$\left[\nabla^2 + k_0{}^2 n(x,y)^2\right] E(x,y) = k_0{}^2 n_{eff}{}^2 E(x,y)$$

Modified End-Fire Coupling Measurement



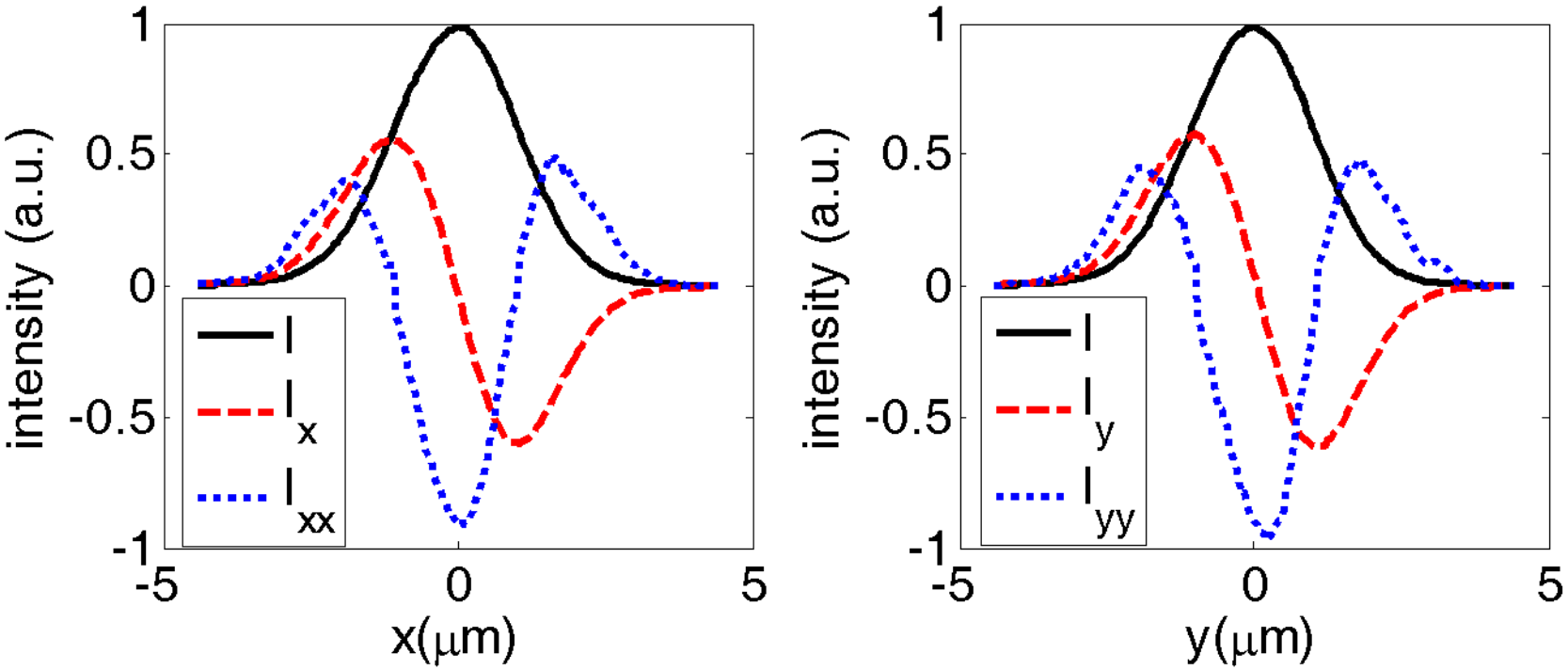
Fiber Spec.



- Thorlabs, SM600
- Operating Wavelength : 633nm
- Mode Field Diameter (MFD) : 4.3 μm
- Numerical Aperture (NA): 0.12
  (0.10 ≤ NA ≤ 0.14)
  - Step-Index Profile
  - Estimated index difference : $\Delta n \approx 0.005$

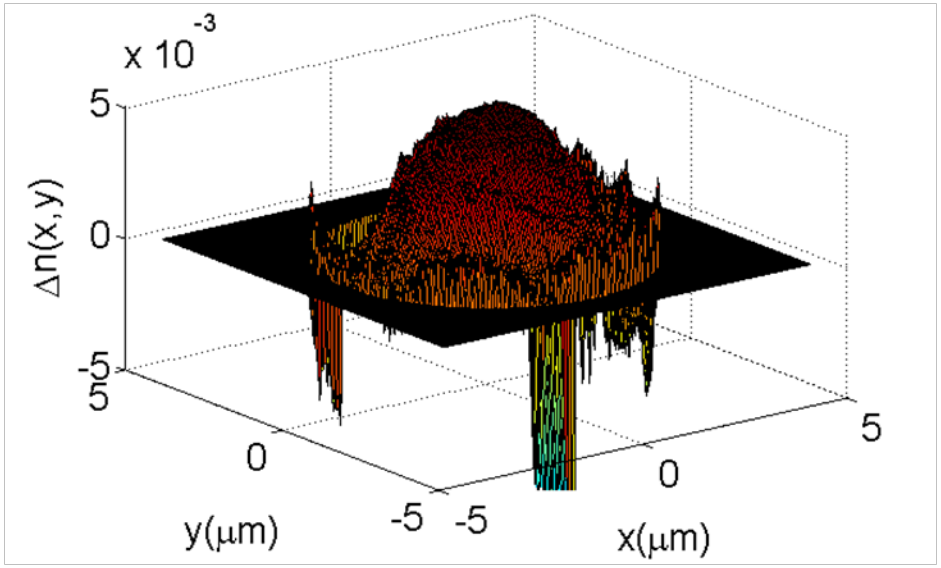
Measured Intensity and its Derivates of Single Mode Fiber

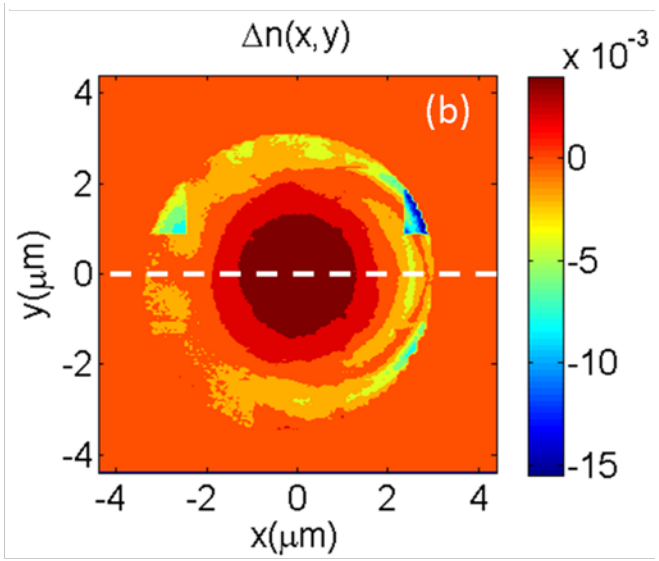
$$\Delta n(x,y) \cong -\frac{1}{4n_s {k_0}^2}\left[\frac{I_{xx}}{I}+\frac{I_{yy}}{I}-\frac{1}{2}\frac{\left({I_x}^2+{I_y}^2\right)}{I^2}\right]+\Delta n_{eff}$$

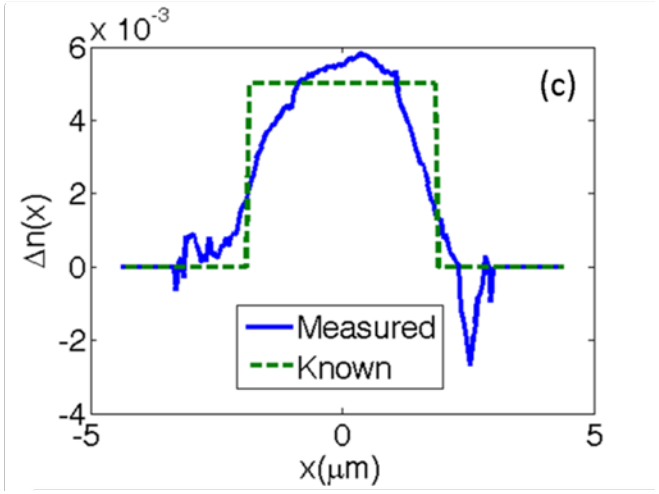


Reconstructed Refractive Index Profile of an Optical Fiber

$$\Delta n(x,y) \approx -\frac{1}{4n_s k^2}\left[\frac{I_{xx}}{I}+\frac{I_{yy}}{I}-\frac{1}{2}\frac{(I_x^2+I_y^2)}{I^2}\right]+\Delta n_{\text{eff}}$$







Wan-Shao Tsai, Sheng-Chieh Piao, and Pei-Kuen Wei, *Opt. Lett.* **36**, (2011)

Conclusion

- The differential fields of optical waveguides were measured by the proposed modified end-fire coupling measurement.
- The modified end-fire coupling measurement was successfully applied in the 2D index reconstruction of a symmetric single-mode fiber and an asymmetric Ti:$LiNbO_3$ channel waveguide.
- The reconstructed index profiles agreed quite well with the known distributions.