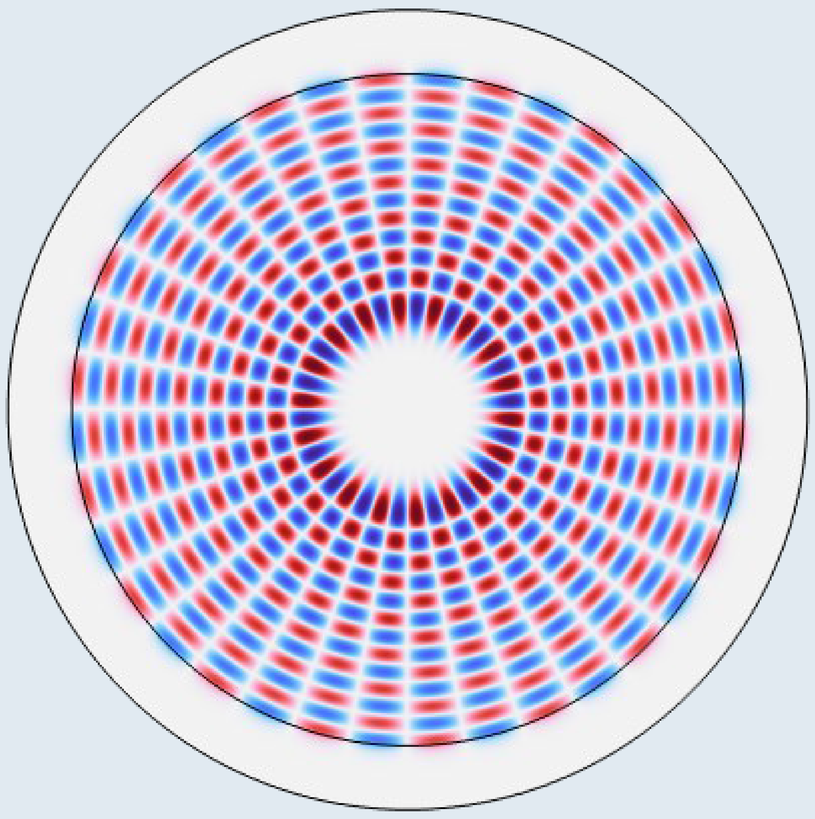


Higher-Order Mode Characteristics and Parameter Dependence in Step-Index Multimode Fibers for Fiber-Optical Tweezers

Numerical investigation of higher-order guided modes, effective index, and field confinement under wavelength and fiber-parameter variations.

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Introduction & Goals

Higher-order guided modes in multimode fibers exhibit distinct transverse field distributions and confinement characteristics, which can influence the optical field delivered for fiber-based particle manipulation. Understanding how these modes respond to fiber parameters is therefore important for controllable modal-field engineering. This work uses a full-vector eigenmode model of a step-index multimode fiber to:

- **identify representative higher-order guided modes;**
- **characterize their effective index and field confinement;**
- **evaluate their dependence on wavelength, core diameter, and refractive-index contrast.**

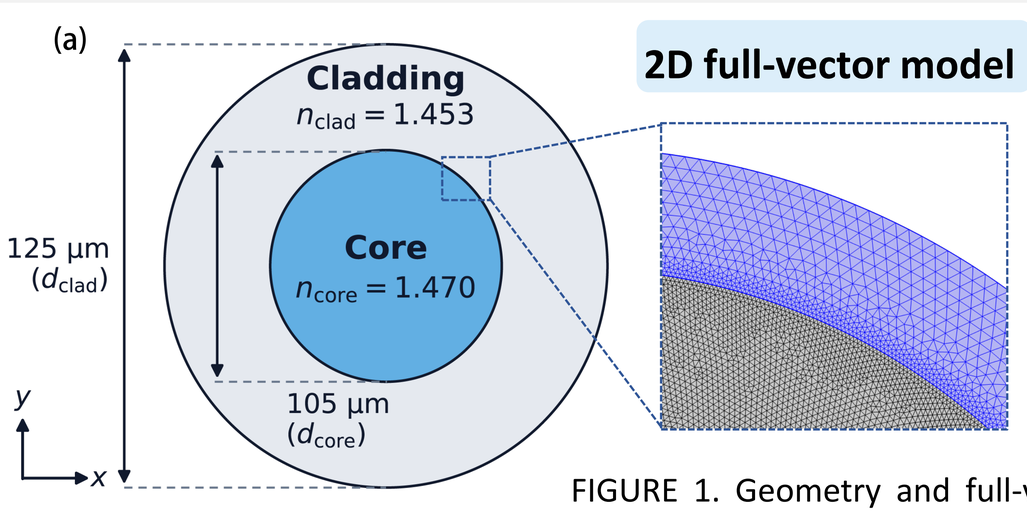


FIGURE 1. Geometry and full-vector eigenmode-analysis workflow.

A 2D full-vector eigenmode model of a step-index multimode fiber was developed in COMSOL [1]. Guided modes were solved using the Electromagnetic Waves, Frequency Domain interface with local mesh refinement. Parameter sweeps of wavelength, core diameter, and index contrast were performed to evaluate effective index and field confinement.

Results

At 800 nm, the selected higher-order modes exhibit distinct transverse field distributions and span different regions of the effective-index spectrum. The R1–R8 representatives capture characteristic modal states from higher to lower n_{eff}. Their spectral positions provide a direct basis for comparing how different modal groups respond to changes in the fiber parameters. Increasing the refractive-index contrast Δn produces a clear increase in n_{eff}, with the strongest response observed for the high-n_{eff} representative modes. Field confinement also depends on Δn: strongly confined modes remain nearly unchanged, whereas intermediate and weakly confined modes show greater sensitivity. These results demonstrate that index contrast provides an effective parameter for tuning higher-order modal properties.

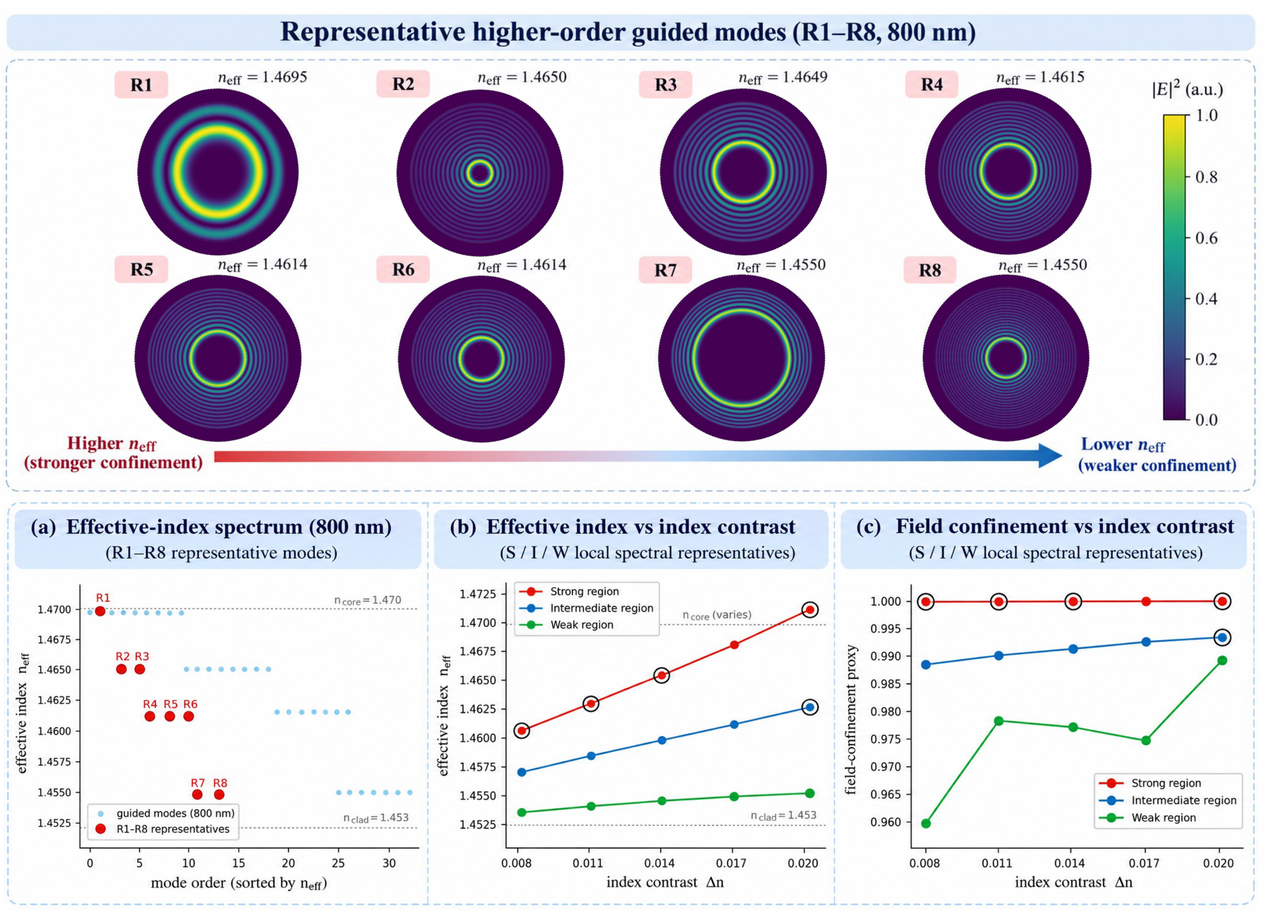


Figure 2. Representative higher-order modes, effective-index spectrum, and index-contrast-dependent modal characteristics.

REFERENCES

1. Love, J. D. & Snyder, A. W. Optical fiber eigenvalue equation: plane wave derivation. Appl. Opt. 15, 2121–2125 (1976). https://doi.org/10.1364/AO.15.002121

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