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Power-Overlap Modal Decomposition for Predictive SMS Fiber Interference Modeling

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INTRODUCTION

The spectral response of SMS fiber sensors arises from multimode interference in the MMF. However, predictive modeling becomes computationally demanding in large-diameter MMFs due to the high number of guided modes. Here, we present a power-overlap framework to quantify modal excitation and identify the minimum modal subset required for spectrally converged, computationally efficient modeling.

METHOD

The SMS structure was numerically modeled in FIMMWAVE using the parameters of SMF-28 and a coreless MMF FGLA125.

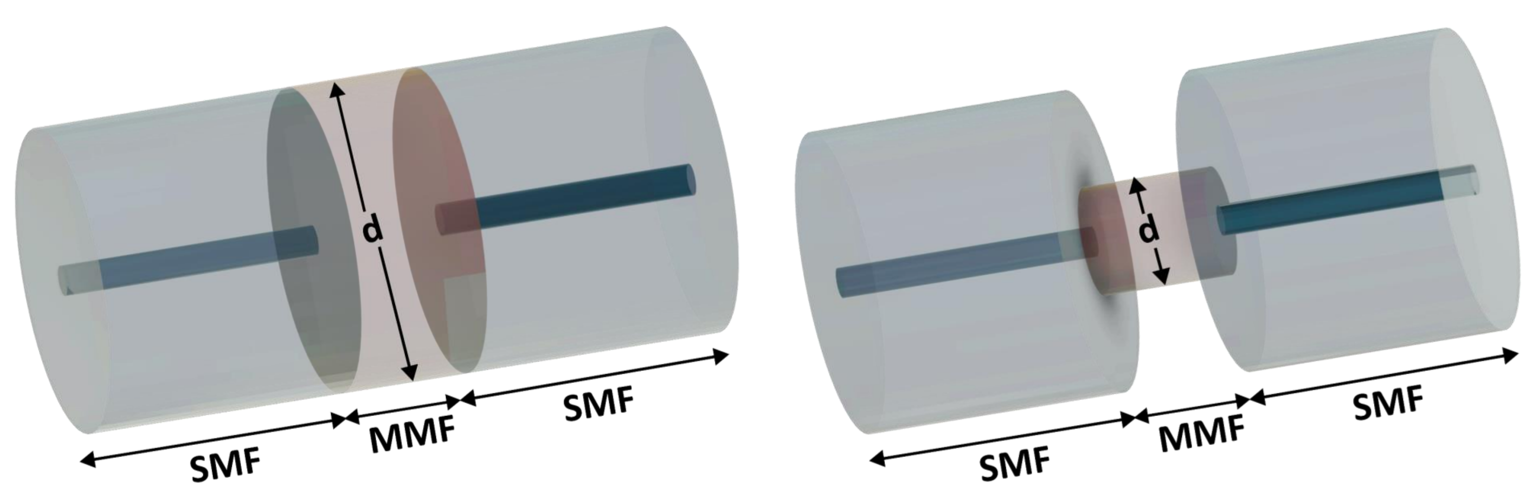

Figure 1. SMS structure used for modal analysis under etched-MMF diameter variation.

Parameter	SMF	MMF
Core diameter d_{core}	$8.2\ \mu m$	NA
Cladding diameter d_{clad}	$125\ \mu m$	$125\ \mu m$
Length L	$10\ mm$	$15\ mm$
Etched diameter d	N/A	$20-125\ \mu m$
Wavelength λ: $1550\ nm$		
Guiding region index n_g	1.450	1.444
Cladding index n_{clad}	1.444	$N/A\ (coreless)$

Table 1. Structural parameters of the SMS configuration.

Guided modes $E_m(x,y)$ and propagated field $E_p(x,y,z)$ were obtained from the SMS configuration. Modal excitation was computed through the normalized power-overlap integral, where $a_m(z)$ is the modal amplitude and $P_m(z) = |a_m(z)|^2$. Since the MMF is longitudinally uniform, modal power remains nearly invariant along z.

$$a_m(z) = \frac{\iint_A E_{p,t}(x,y;z) \times H^*_{m,t}(x,y) \cdot \hat{z} dA}{\iint_A E_{m,t}(x,y) \times H^*_{m,t}(x,y) \cdot \hat{z} dA}$$

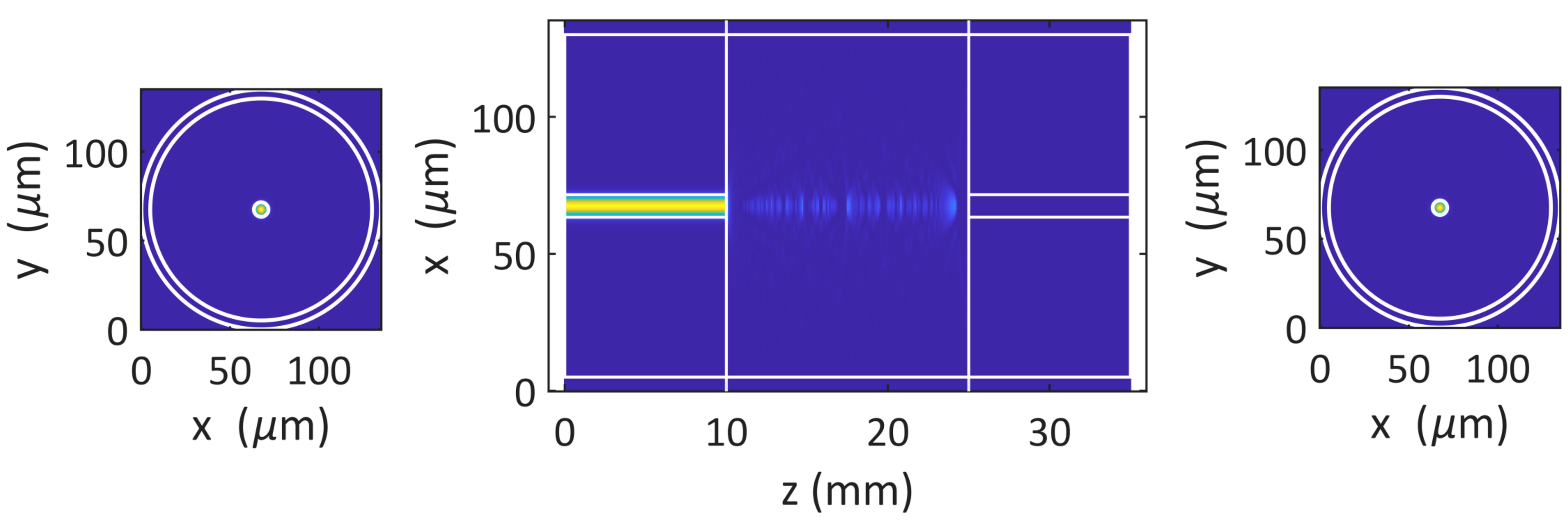

Figure 2. Field distribution at the SMS input, along the MMF, and at the output SMF.

Thus, for each etched diameter d, the modal content is represented by the longitudinally averaged and normalized modal power $\tilde{P}_m(d)$, highlighting the dominant mode orders.

$$\tilde{P}_m(d) = \frac{\frac{1}{N_z}\sum_{k=1}^{N_z} |a_m(z_k;d)|^2}{\sum_{n=1}^{M}\left(\frac{1}{N_z}\sum_{k=1}^{N_z} |a_m(z_k;d)|^2\right)}$$

RESULTS & DISCUSSION

The colormap shows how etched diameter d redistributes $\tilde{P}_m(d)$ across mode orders, shifting the distribution toward higher-order modes as d increases.

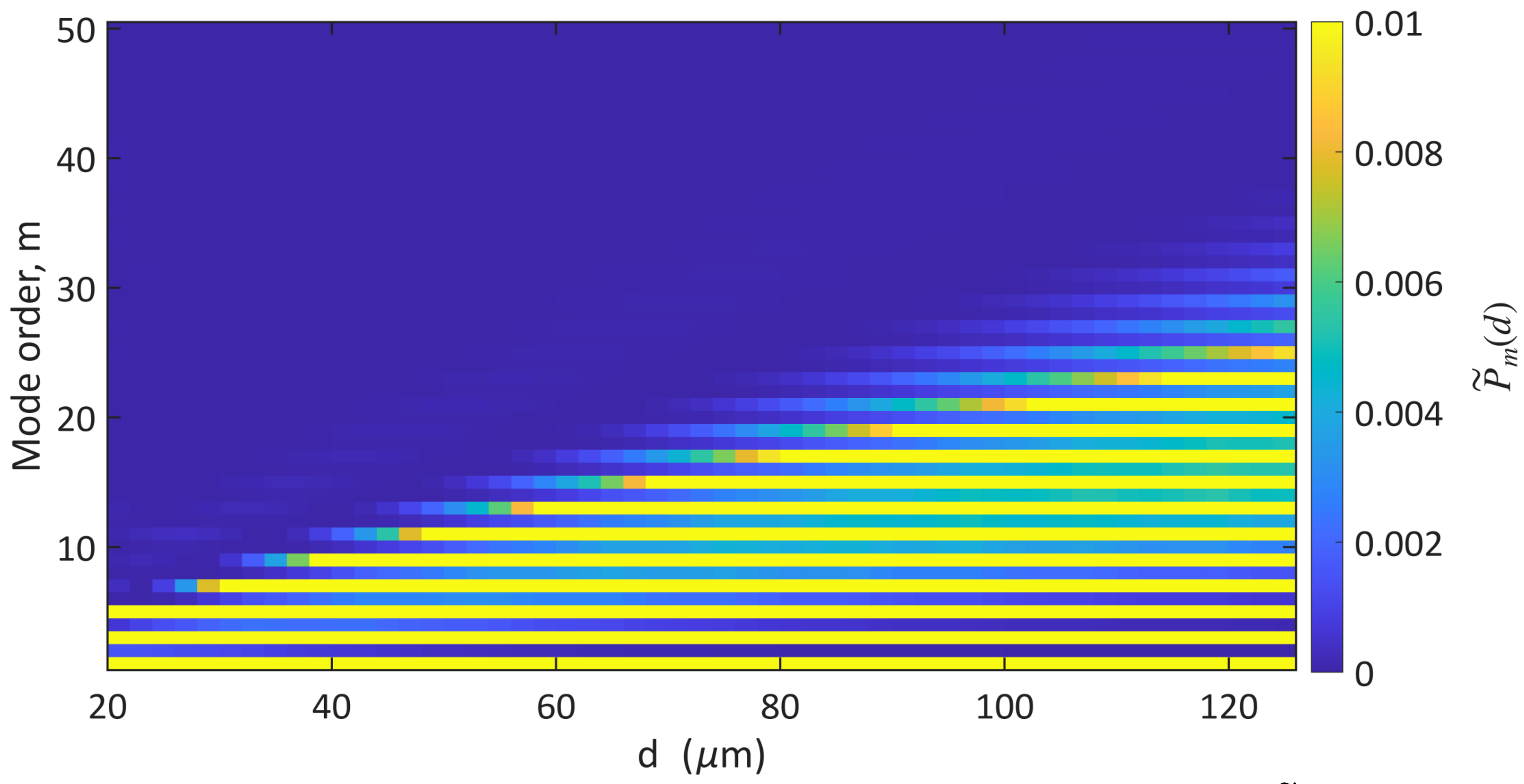

Figure 3. Longitudinally averaged and normalized modal power $\tilde{P}_m(d)$ as a function of etched diameter.

For each etched diameter, output power was computed while increasing the included modes from $N = 1$ to 50. The reference transmitted power, $T_{ref}(d)$, was defined as the output power computed using the complete modal basis ($N = 50$).

$$\varepsilon_N(d) = \frac{|T_N(d) - T_{ref}(d)|}{|T_{ref}(d)|}$$

$N_{req}(d)$, was defined as the smallest N such that $\varepsilon_N(d)$ falls below the prescribed threshold.

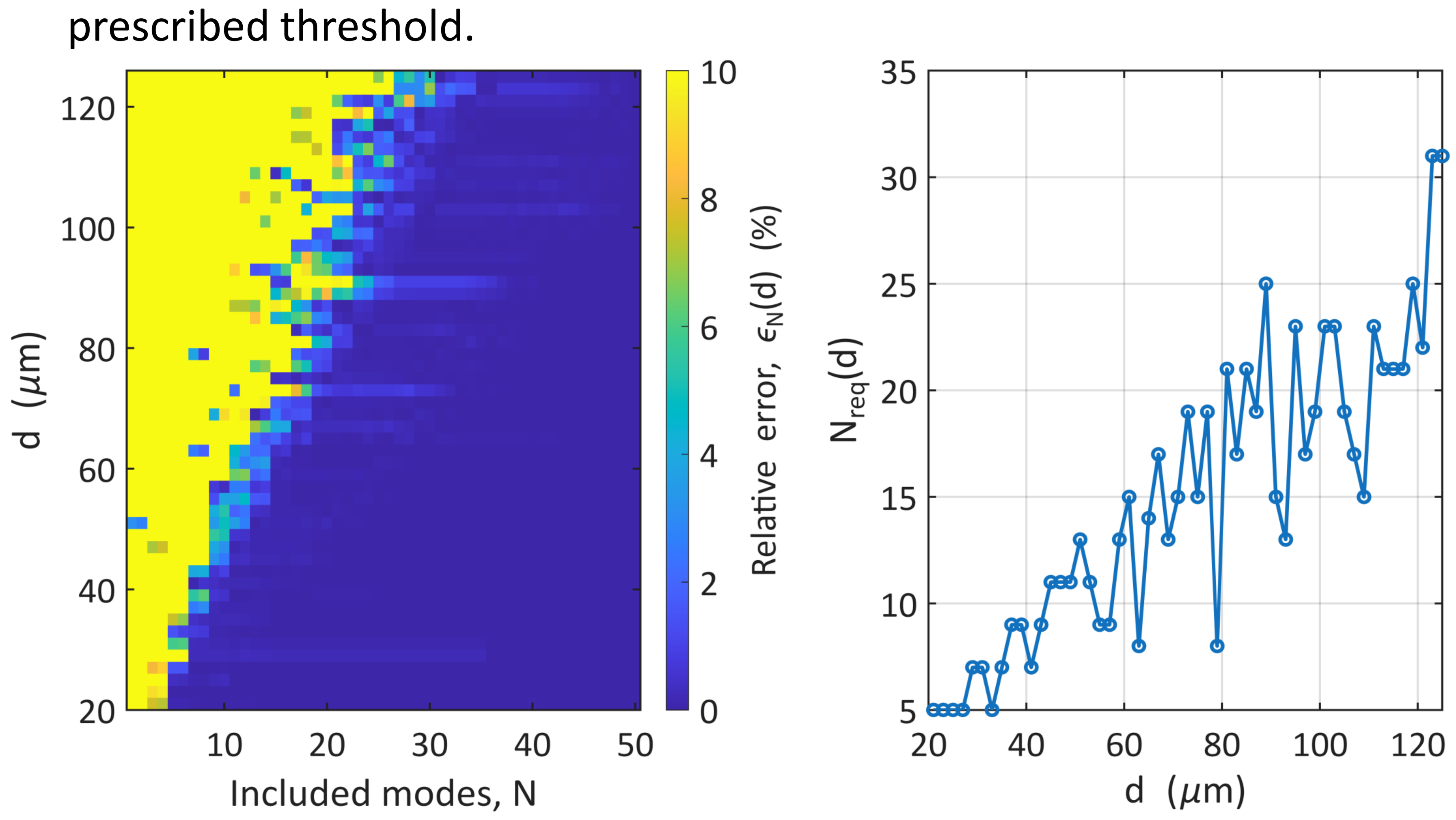

Figure 4. Output-power convergence versus etched diameter. Left: relative error versus included modes and etched diameter. Right: minimum required modes for δ=2%.

CONCLUSION

Etched MMF diameter drives modal power redistribution and reveals the dominant modes governing the SMS response. As the diameter increases, the modal distribution shifts toward higher-order modes and the number of required modes rises from about 5 to roughly 30, yet spectral convergence is still achieved with a reduced modal subset well below the full basis, fulfilling the objective of efficient model reduction.

REFERENCES

[1] Snyder, A.W.; Love, J.D. Optical Waveguide Theory; Chapman and Hall, 1983.
[2] Okamoto, K. Fundamentals of Optical Waveguides, 2nd ed.; Elsevier, 2006.
[3] Lara-Davila, N.C.; Montoya-Cardona, J.A.; Gonzalez-Valencia, E. Eng. Proc. 2025, 118, 32.