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Computational methodology for the analysis of SMS interferometric structures as potential biosensors.

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INTRODUCTION

Sensors are essential tools in technological progress, addressing diverse fields. Optical fiber sensors (OFS) are particularly attractive due to their high sensitivity, compactness, low weight, fast response time, etc. Among them, the single-mode–multimode–single-mode (SMS) structure stands out for its simplicity, low cost, and stability [1]. This work models a coreless-MMF SMS structure, evaluating the effects of MMF diameter and length on spectral response and overall sensing performance.

METHOD

The SMS structure was designed in FIMMWAVE using SMF-28 fiber for the SMF sections and coreless FG125LA fiber for the MMF section. In simulations, the MMF diameter was reduced from 125 µm to 20 µm to emulate etching, its length was varied, and the surrounding refractive index (1.33–1.43) was modified to evaluate spectral effects. For experimental validation, an SMS configuration was replicating the simulated design was fabricated and connected to a broadband white light source and an optical spectrum analyzer.

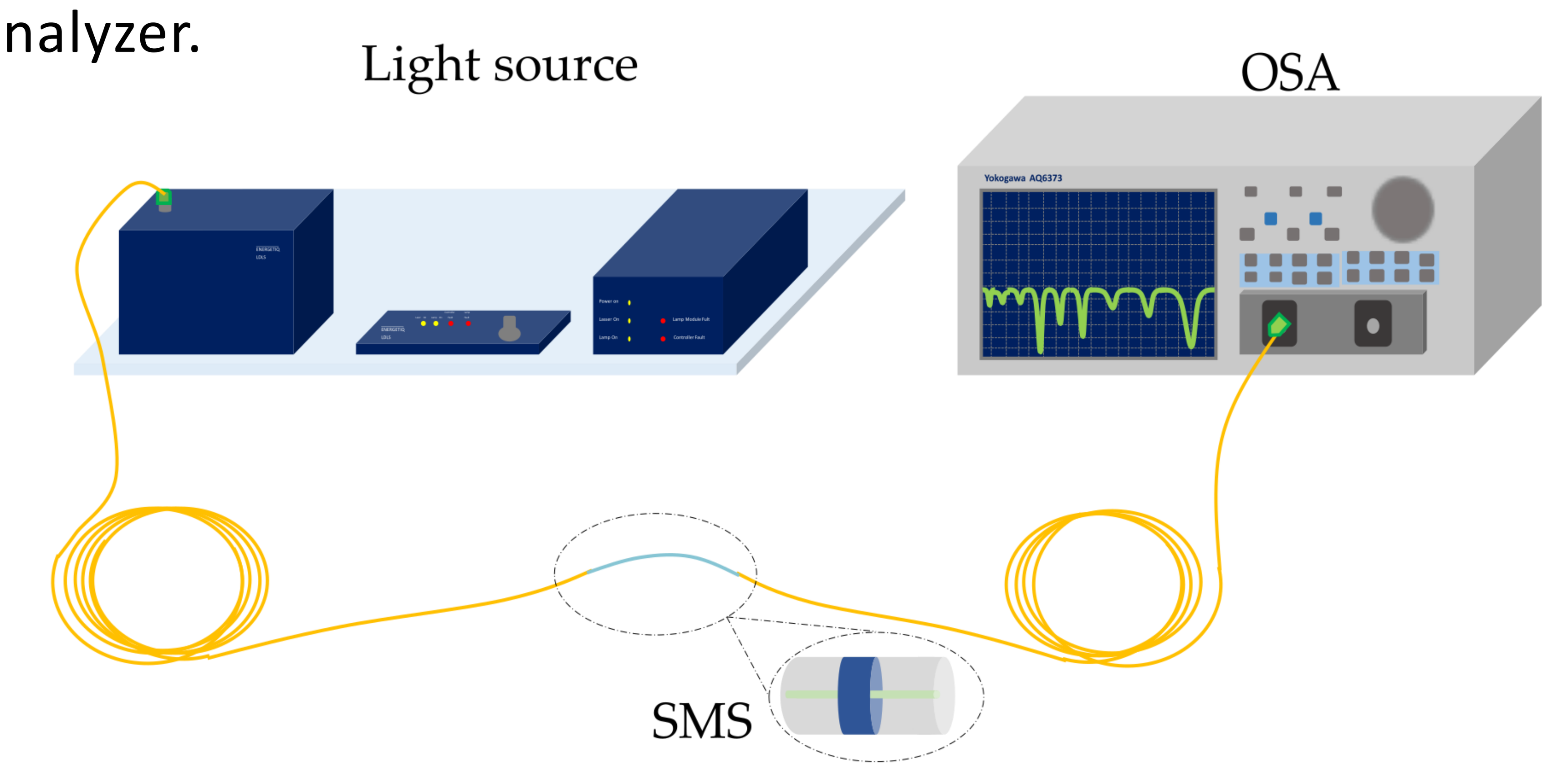

Figure 1. Schematic of the experimental setup used for the characterization of the SMS structure.

RESULTS & DISCUSSION

Sensitivity increases as MMF diameter decreases, reaching ≈386 nm/RIU in the visible and ≈968 nm/RIU in the NIR (near-infrared) for 20 µm. Higher sensitivity in the NIR confirms this region is more favorable for detecting refractive index variations.

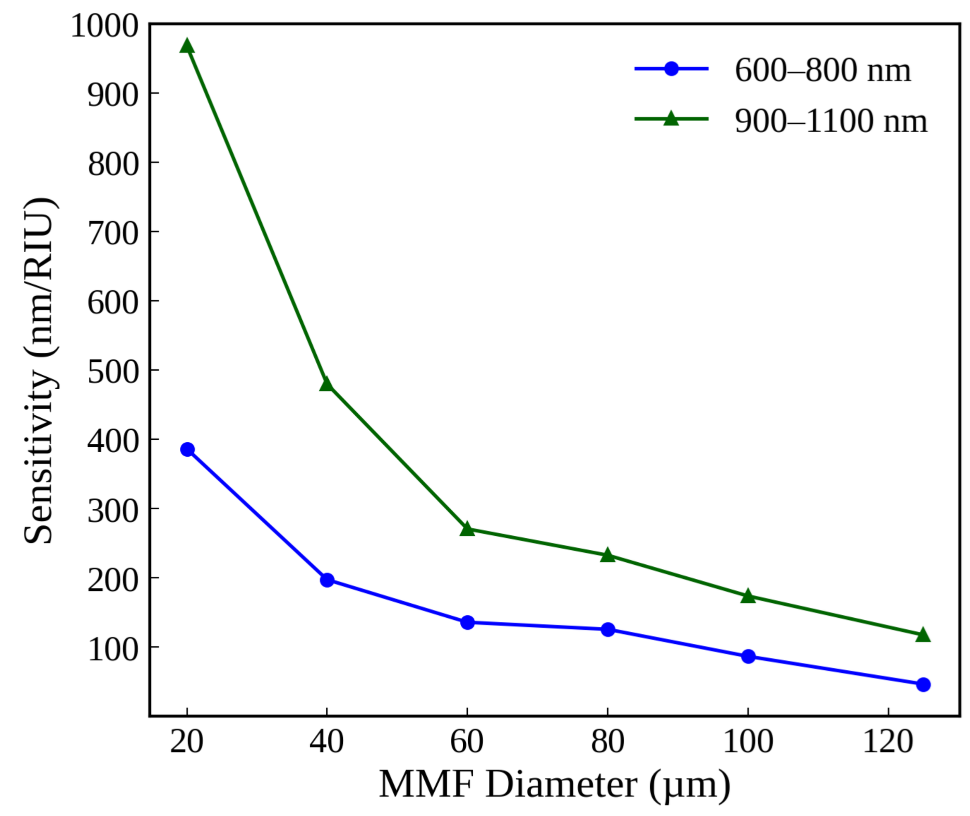

Figure 2. MMF diameter effect on SMS sensitivity in visible and NIR.

Stable FWHM (≈9–12 nm); FoM rises with smaller diameters, evidencing MMF tapering as an optimization strategy.

Table 1. FWHM and FoM values for sensor configurations with different MMF diameters, obtained from numerical simulations.

	MMF Diameter (µm)					
	125	**100**	**80**	**60**	**40**	**20**
FWHM (nm)	10	11	9	12	11	10
FoM (1/RIU)	11.76	15.79	25.85	22.55	43.60	96.79

Experimental and simulated spectra exhibited two resonance peaks, confirming model validity though slight shifts appeared from refractive index mismatches, constant NA assumption, limited mode calculation, and fiber length variations. In the 125 µm MMF, sensitivity was higher in the NIR, where imperfections, coupling and scattering losses, and noise increased discrepancies.

Moreover, longer MMF sections (11–17 mm) produced systematic linear shifts to lower resonance wavelengths.

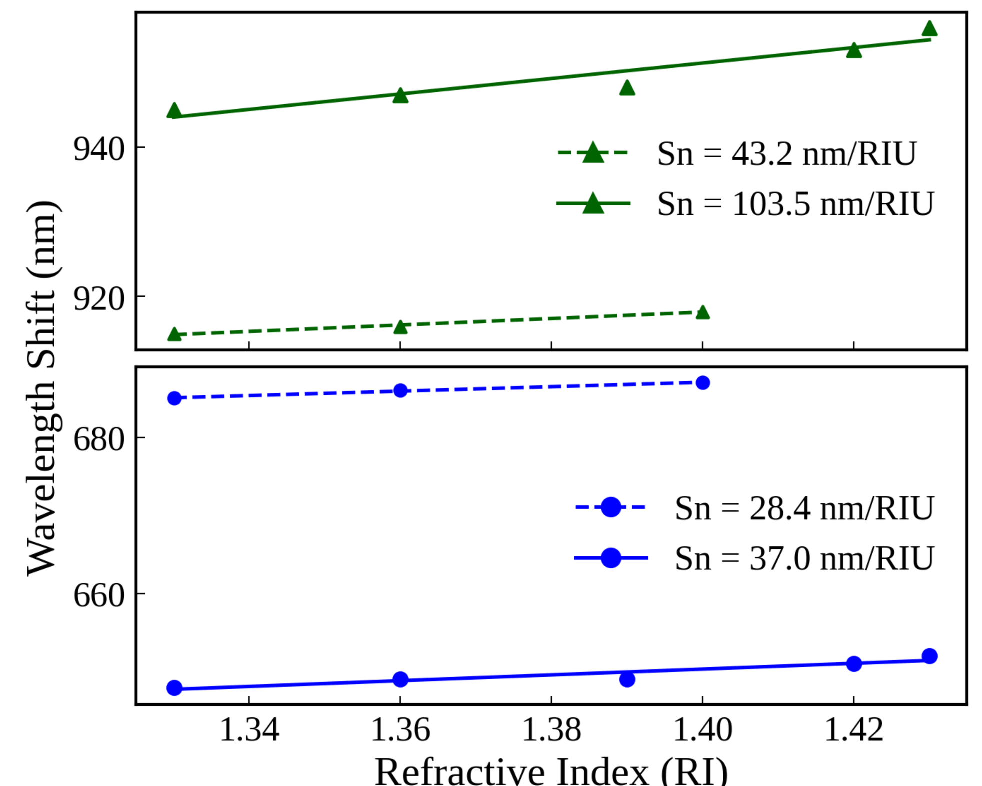

Figure 3. Resonance wavelength shift vs. refractive index for 125 µm MMF.

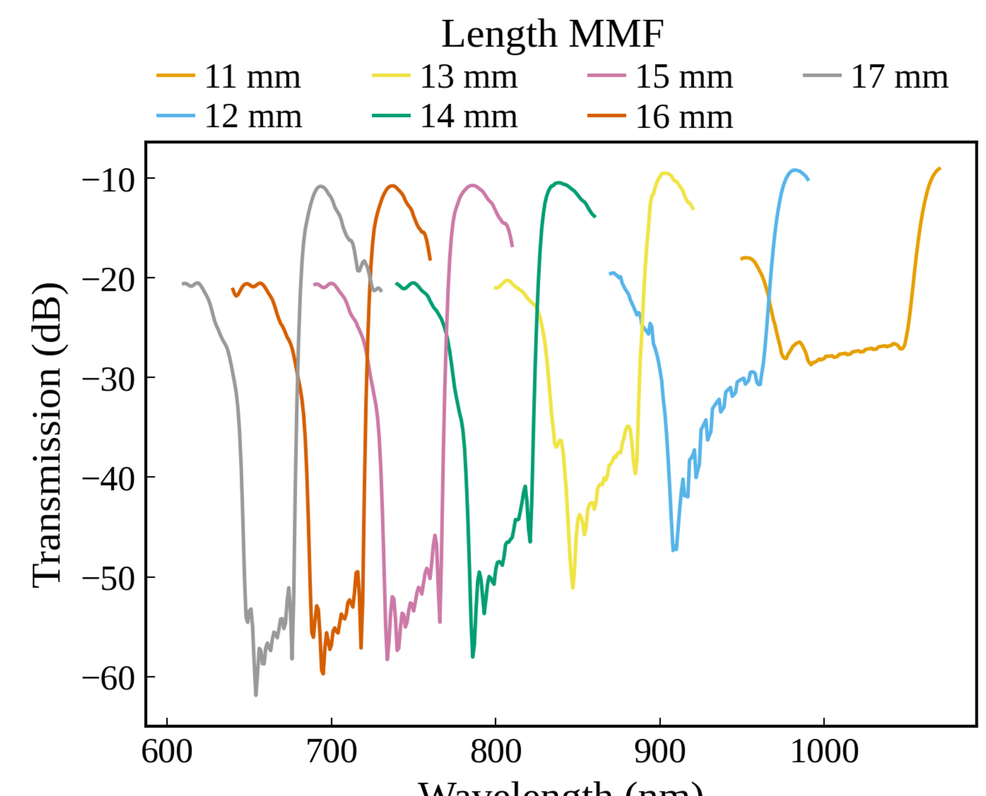

Figure 4. Wavelength shift of the main resonance in simulated SM sstructure for varying MMF lengths.

CONCLUSION

The results validate the proposed modeling methodology and demonstrate the potential of the coreless-MMF SMS structure as a basis for developing high-precision, low-cost optical biosensors. Sensitivity rises with decreasing MMF diameter, achieving ≈386 nm/RIU in the visible range and ≈968 nm/RIU in the NIR at 20 µm, with improved figure of merit and stable FWHM, confirming tapering as an optimization strategy.

REFERENCES

[1] I. Del Villar, A. B. Socorro, J. M. Corres, F. J. Arregui, and I. R. Matias, "Refractometric sensors based on multimode interference in a thin-film coated single-mode–multimode–single-mode structure with reflection configuration," Appl Opt, vol. 53, no. 18, p. 3913, Jun. 2014, doi: 10.1364/AO.53.003913.