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Far-detuned intramodal FWM in optical micro-fiber tunable with the micro-fiber diameter

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Abstract. We report a theoretical and experimental investigation of far-detuned intramodal four wave mixing (FWM) in the fundamental mode of optical microfibers (OMF) depending on their diameter. We demonstrate that the signal wavelength can be tuned over a wide spectral range simply by varying the OMF diameter. Using a pump at 1064 nm, signal wavelengths ranging from around 750 to 950 nm are generating by adjusting the OMF diameter from approximately 8.5 to 6.5 µm.

1 Introduction

Optical microfibers (OMFs), corresponding to the homogeneous diameter part of a stretched standard fiber, exhibit unique properties, such as strong field confinement that enhances nonlinear effects, and the presence of an evanescent field that interacts with the surrounding medium [1,2]. These stretched fibers also show a strong dependence of chromatic dispersion on their diameter. This latter characteristic is particularly relevant, as some nonlinear processes - such as four-wave mixing (FWM) - are highly sensitive to dispersion. Therefore, simply changing the diameter of the microfiber allows one to select and/or enhance specific nonlinear phenomena. In the case of intramodal FWM, the wavelength of the generated waves can thus be precisely tailored by adjusting the OMF diameter. This is the objective of the present work.

2 Theory and experiments

The FWM process requires phase-matching between the interacting waves, i.e., $\Delta\beta = 0$. This condition accounts both the linear phase mismatch due to dispersion and the nonlinear phase contribution arising from the Kerr effect, and is thus expressed as $\Delta\beta = \beta(\omega_s) + \beta(\omega_i) - 2\beta(\omega_p) + 2\gamma P_p$, with β the wavevector of the signal, pump, and idler waves at angular frequencies $\omega_s, \omega_i, \omega_p$ respectively, γ the nonlinear parameter, and P_p the pump peak power. To generate far-detuned FWM sidebands, the pump wavelength should lie close to the zero-dispersion wavelength (ZDW) of the waveguide, corresponding to a very low group-velocity dispersion (GVD) parameter β_2. The nonlinear phase-matching condition can nevertheless be satisfied due to the fourth-order dispersion term, β_4. Consequently, we first model the

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evolution of the dispersion as a function of the microfiber diameter. Figure 1(a) shows a map of the GVD parameter, β_2, as a function of both the wavelength and the external diameter of the stretched fiber, from standard fiber (125 µm in diameter) to microfiber (500 nm in diameter). The ZDWs are indicated by dashed white curves. Two diameters, 0.86 µm and 6.57 µm, clearly exhibit a ZDW at the pump wavelength $\lambda_p = 1064\,nm$. To ensure the mechanical robustness of the microfiber, we favor the larger diameter in this work, around 7 µm. Figure 1(b) presents the evolution of the parametric gain curves given by $g = \left((\gamma P_p)^2 - (\Delta\beta/2)^2\right)^{1/2}$, with $P_p = 7\,kW$ and OMF diameters ranging from 6.0 to 8.9 µm for these simulations. It is evident that the anti-Stokes signal spans the theoretical spectral range 715-960 nm.

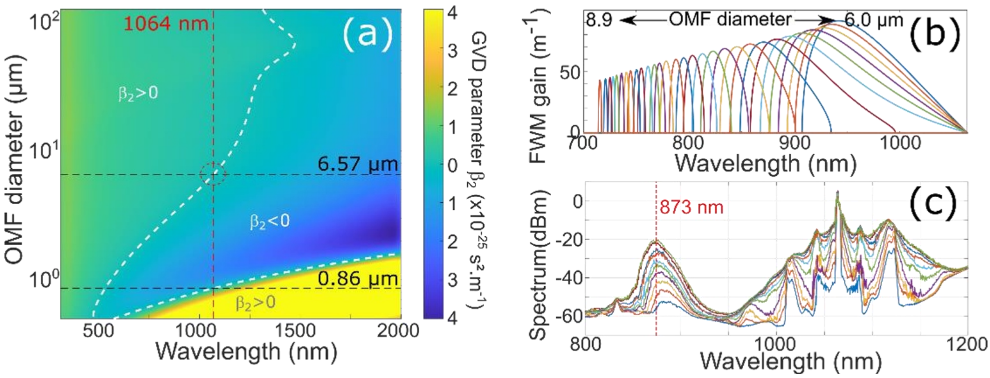

Figure 1. numerical simulation and experimental results. (a) evolution of the GVD parameter β_2 and ZDWs of the OMF with the wavelength and the OMF diameter; (b) evolution of the parametric gain with the OMF diameter; (c) experimental spectra for a pump wavelength of 1064 nm, an OMF with a diameter of 6.9 µm and a length of 13.8 cm. Pump peak power increases from 15 kW to 30 kW.

Regarding the experimental studies, OMFs are fabricated by stretching and tapering a standard SMF28 silica fiber using the heat-brush technique. Figure 1(c) shows the evolution of the output spectrum of an OMF of 6.9 µm diameter, 13.8 cm long, as a function of peak pump power ranging from 15 kW to 30 kW. A distinct FWM peak is clearly observed around 873 nm confirming the theoretical predictions and proving the feasibility of the concept.

3 Conclusion

We have numerically demonstrated that intramodal FWM signals in the fundamental mode of optical microfibers (OMF) can be generated and tuned over a spectral range exceeding 200 nm by varying the OMF diameter by only 2 µm around 7 µm. Preliminary experimental results confirm the generation of a spectral peak far from the pump.
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