Polarisation Effects in Nonlinear Microcoils

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Optical microcoil resonators (OMRs) fabricated by wrapping a microfibre around a rod to allow evanescent coupling between adjacent turns as in Fig 1. (a) have recently attracted much interest due to their high Q-factor and large extinction ratios resonances, low input and output coupling losses, large evanescent field and compactness [1,2], with applications such as sensing [3] and signal processing [4]. However, theoretical models published so far have neglected polarisation effects, and hence in order to develop a more detailed understanding we have modelled the OMR with polarisation-dependent coupled mode equations in the linear [5] and nonlinear regimes.

The fibre is assumed to be birefringent as well as slightly twisted, and we define a local reference frame (x, y) aligned with the fibre's slow/fast axes which rotates with the twisting of the fibre. In the j^{th} turn of the coil, the corresponding field amplitudes A_j^x and A_j^y are governed by the differential equations:

$$\begin{aligned}\frac{dA_j^x}{ds} =& i\kappa\left[A_{j-1}^x\cos(\theta^-) + A_{j-1}^y\sin(\theta^-) + A_{j+1}^x\cos(\theta^+) - A_{j+1}^y\sin(\theta^+)\right] \\ & - i\alpha A_j^x + i\gamma(|A_j^x|^2 + \frac{2}{3}|A_j^y|^2)A_j^x + i\kappa_{xy}A_j^y\end{aligned} \tag{1}$$

(the equation for A_j^y is similar and includes a propagation constant mismatch term). Here, κ is the coupling coefficient between adjacent turns, α is the loss coefficient, and θ^-, θ^+ are the twist angles between the lower and upper turns respectively. The sine and cosine terms describe the twist dependent coupling between the neighbouring x and y polarisations and the nonlinear γ term models the self and cross phase modulation. Only the Kerr nonlinearity is simulated and higher order nonlinear interactions are ignored. Polarisation rotation from twist induced elasto-optic effects is accounted for by the κ_{yx} and κ_{xy} terms. The pitch between turns is assumed to be much smaller than the rod diameter, so geometric phase effects are not considered here.

Note that twisting the fibre couples the two orthogonal polarisations which would otherwise have propagated independently. This is clear from Fig. 1(b) which shows the x resonances are detectable in the y polarised output and vice versa. When red-detuned from resonance, the transmission shows bistability as in Fig. 1(c), with nonlinear switching powers typically in the range 10-100W. However, the hysteresis characteristics strongly depend on whether the wavelength is detuned from an x or y resonance. With the former, the contrast between the high and low transmission states is larger and the switching threshold power is lower, since coupling from the y to x polarisation state is favoured due to the choice of left-handed twist in this example. For similar reasons, the input polarisation angle also affects the switching power and contrast. The bistability can be exploited for memory applications, whilst the nonlinear switching is useful for performing polarisation sensitive Boolean logic functions.

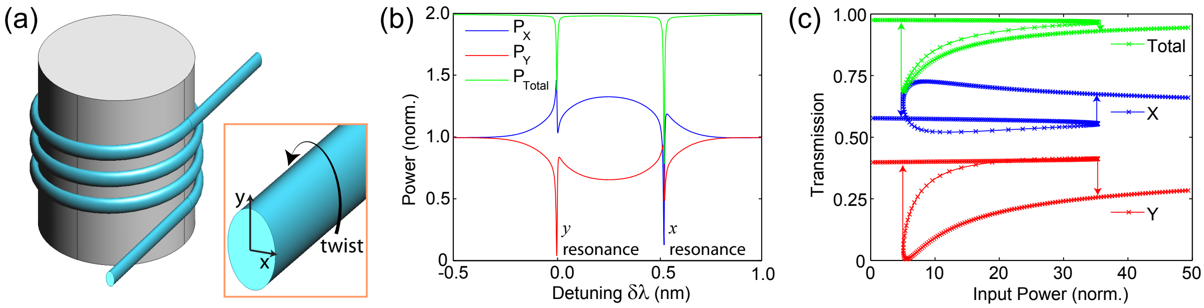

Fig. 1. (a) Microcoil structure showing the local (x, y) axes and fibre twist. (b) Typical linear output spectrum over one FSR for a 3 turn OMR with an input polarised at $\pi/4$ rad and fibre twist of $\tau = 30$ rad/m. (c) Bistability when detuned 25pm from the y resonance, showing hysteresis in the transmission and x and y components. Power is normalised for $\gamma = 1$/W/m.

References

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