Multi-scale fibre-based optical frequency combs: science, technology and applications (MEFISTA)

Deliverable D1.2 Passive cavity architecture based on a Fabry Perot resonator in a few mode fibre

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Contents

Passive cavity architecture based on a Fabry Perot resonator in a few mode fibre

Optical frequency combs are spectra composed by a cascade of coherent discrete frequencies, which can find applications in many different fields, from spectroscopy to optical-atomic clocks. Recently, researches in sources capable of producing such kind of spectra focused mostly on microresonators [], which can be manufactured in many different ways. Those devices are astonishing from a performance standpoint: they are capable of produce very wide spectra and, due to their huge quality factor, they are usually driven with very little power. One major issue with such devices is usually link to their dimension, which can be as small as micrometre scale. This makes the injection and extraction of light quite difficult, and usually require special ad-hoc solution depending on the kind of microresonator used. On the other side of the device's spectra, there are fibre ring cavities: usually fabricated by closing several tens of meters fibre with a coupler, which made the injection and extraction of light very easy. On the other hand, due to their dimension and components, losses of fibre cavities have a finesse in the order of 10 or 20, which are not really comparable with microresonators. Recently, however, new losses compensations technique has been proposed which allows to produce very wide spectra, but since the free spectral range is linked to the size of the cavity, the line-to-line spacing is not useful to application such as spectroscopy.
An interesting alternative to those approaches is the use of Fabry-Perot fibre cavities, fabricated by closing a few centimetres of fibre between two finely polished standard fibre connectors (FC/PC). This really merge the ease of use of fibre ring cavities with the spectral characteristic of microresonators.
An example of such cavities has been proposed by our team of the University of Lille [1], they were capable of observe MI spectra by means of this kind of resonator.

We propose here an overview of those first experimental result.

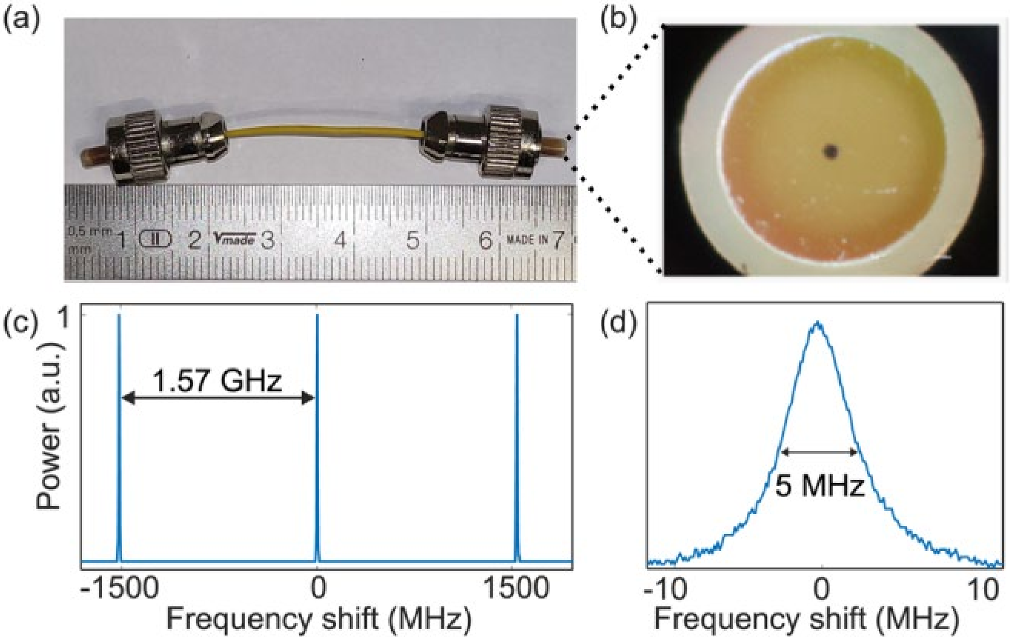

Fig. 1: (a) Picture of a Fabry-Perot resonators, (b) zoom of one of the mirrors end. (c) and (d) resonances and response of the cavity, respectively.

Fabry-Perot Resonator and experimental setup:

In Fig. (1) a) and b) is depicted an example of Fabry-Perot cavity. It's possible to note the simplicity in the idea, even if the fabrication requires some specialised technique for the polishing and the deposition of the mirrors at the ends of the connectors (vapor depositions). In this case the resonators are made by $L = 6.51\ cm$ of single mode fiber (SMF-28), $\beta_2 = -22.9\ ps^2Km^{-1}$ and nonlinear Kerr coefficient $\gamma = 1.2\ W^{-1}Km^{-1}$. The total reflectivity of the mirrors obtained is 99.84% over 100nm. Fig. 1 (c) and (d) shows the resonances, with a free spectral range of 1.57 GHz, and transfer function of the cavity with a linewidth of 5 MHz. It was able to reach a finesse of about 314, correspondent to a quality factor of about 38 million.
The experimental setup used in this experiment is described in Fig. (2): once again, the strong point of this kind of resonators is the plug-and-play feature, typical of fibre ring cavities. The cavity is driven by a train of 70 ps quasi-squared pulses, which are amplified by two erbium-dope fibre amplifiers and injected in the cavity after appropriate filtration. The repetition rate of the pulses is finely tuned by means of a frequency synthesizer, so that the pulses overlap perfectly inside the cavity at each round-trip.
Using pulses it's a good trade off: it requires a perfect synchronization, but it allows to reach high peak powers with low average power, and thus avoids non wanted effect such as stimulated Brillouin scattering.
A polarization controller is used to align the polarization of the input signal to one of the axes of the cavity. At the output, the signal is split in half: 50% is analysed through a high resolution complex

optical spectrum analyser (BOSA), and 50% is used in a feed-back loop to stabilise and control the cavity detuning by means of a PID controller. If needed, a Bragg grating is used to filter out the pump and measure only the modulated spectral components of the signal.

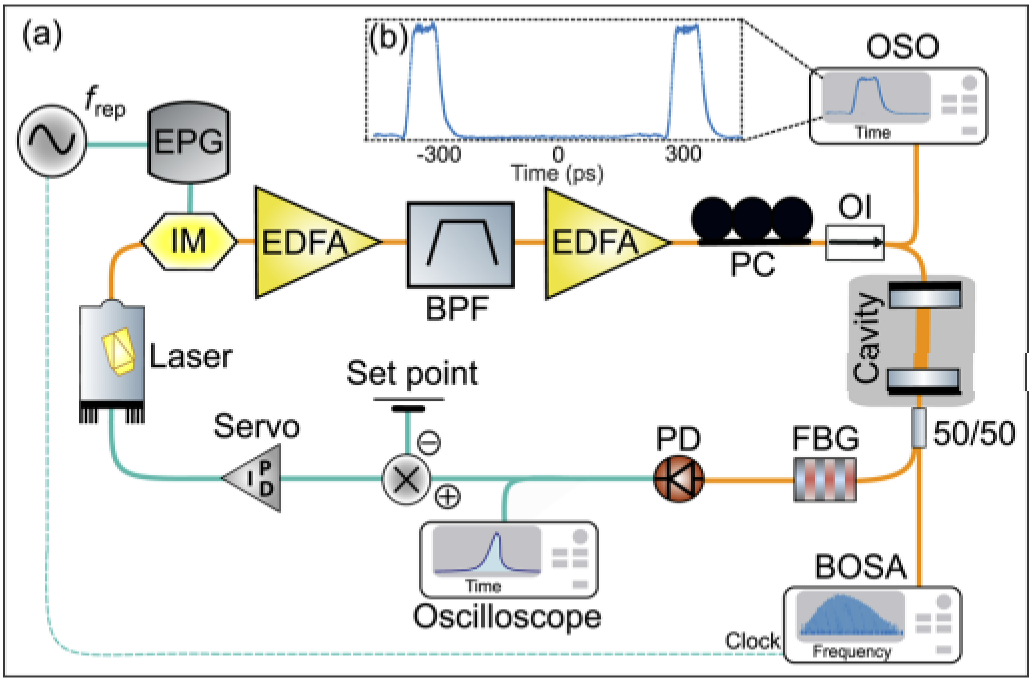

Fig. 2 (a) experimental setup. (b) example of pules taken from the OSO.

Measurements and simulations:

With the experimental setup described above, a series of measurements has been performed, in order to demonstrate the possibility of get MI spectra with this kind of device. In Fig. 3 a series of power and phase spectra measured with the BOSA is proposed. The spectrum obtained is quite interesting: we see a series of subcombs separated by the MI frequency. Furthermore, the profile of each sub-comb is not uniform but it’s characterised by the typical capital cosine profile. This shape is due to the pulsed pumping which, being periodic, gives this shape to the power spectrum. Each subcombs if formed by about 125 teeth, and their line-to-line separation corresponds to the FSR of the cavity [Fig. 3 (b)].

The resonator can be modelled with a system of two coupled nonlinear Shrodinger equations:

$$\frac{\partial F}{\partial z} + \beta_1 \frac{\partial F}{\partial t} + i \frac{\beta_2}{2} \frac{\partial^2 F}{\partial t^2} = i\, \gamma (|F|^2 + G\, |B|^2) F, \qquad (1)$$

$$-\frac{\partial B}{\partial z} + \beta_1 \frac{\partial B}{\partial t} + i \frac{\beta_2}{2} \frac{\partial^2 B}{\partial t^2} = i\, \gamma (|B|^2 + G\, |F|^2) B, \qquad (2)$$

Where $F(z,t)$ and $B(z,t)$ are the forward and backward fields propagating inside the cavity, $\beta_1^{-1} = c/n$ is the group velocity, (c is the speed of light and n the refractive index of the fibre); β_2 is the group velocity dispersion, γ is the Kerr nonlinearity term, and G=2 the coupling parameter for the cross phase modulation.
The boundary condition of the cavity can written in the following:

$$F(0,t) = \theta E_{IN} + \rho B(0,t), \quad (3)$$

$$B(L,t) = \rho e_0^{i\phi} F(L,t), \qquad (4)$$

Where θ and ρ are the transmission and reflection coefficient, respectively; ϕ_0 accounts for the total phase accumulated by the signal inside the cavity $\frac{4\pi nL}{\lambda}$ (λ being the pump wavelength) plus any possible contribution from the mirrors.
By integrating the model with a numerical method, it was passible to get good agreement with the measurements. For the simulations the parameters of the cavity are: $\rho = 0.995$, $\theta = 0.0396$, $\gamma = 1.2\ W^{-1}Km^{-1}$, $\beta_2 = -22.9\ ps^2Km^{-1}$, $L = 6.51\ cm$, $n = 1.4582$ and $\gamma = 1550\ nm$.

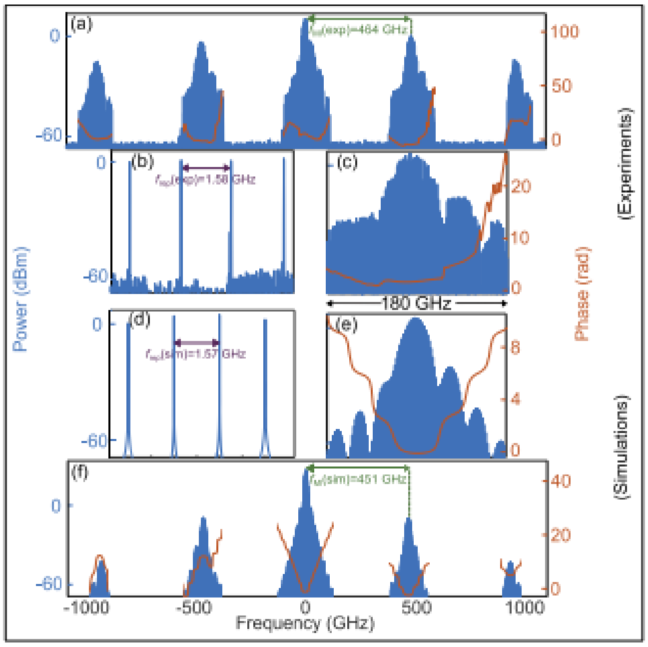

Fig. 3: examples of the measured power spectrum and phase: (a) overall spectrum, (b) zoom on the single lines of a sub spectrum (c). Note the sinc profile of the subspectrum and the good agreement with the numerical simulations (d), (e) and the full spectrum (f).

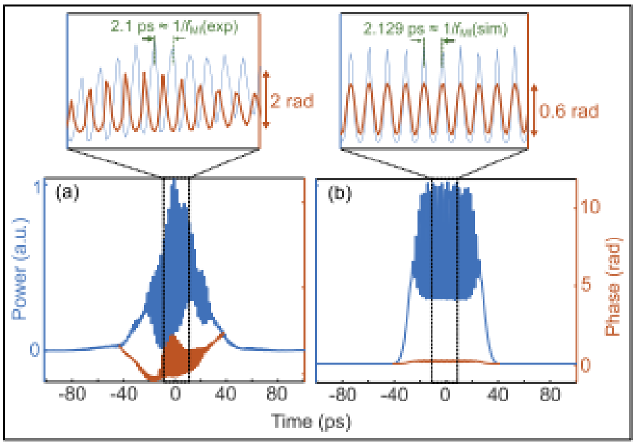

Fig. 4: comparison between measured time domain modulated pulse, blue trace, and phase, orange traces, (a) and numerical simulations (b).

Conclusion and next step

In conclusion, this preliminary work demonstrated the use of a Fabry-Perot cavity as micro resonator. In the future the aim is to fabricate and characterize different kind of Fabry-Perot cavity, which has still to be manufactured.

References:

[1]

T. Bunel *et al.*, ‘Observation of modulation instability Kerr frequency combs in a fiber Fabry–Pérot resonator’, *Opt. Lett.*, vol. 48, no. 2, p. 275, Jan. 2023, doi: 10.1364/OL.479466.

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