

## **Modulation instability in Raman fiber lasers**

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*We present the experimental demonstration and characterization of modulation instability induced by cross-phase modulation between the pump and the Stokes waves in Raman fiber lasers. The influence of the dispersion and the Raman efficiency of the fiber are investigated in a fiber ring laser configuration. The analysis of the influence of the pumping conditions in forward and backward schemes is also provided. We support that this effect takes part in the spectral linewidth broadening of the laser.*

### **Introduction**

Because of the versatility in the choice of the output wavelength compared to other kind of lasers, Raman fiber lasers (RFL) have been thoroughly investigated. As they could potentially become a key element in future optical telecommunication systems, a deep understanding of their behavior according to complex and various working conditions is required. Among those, the spectral linewidth is one of the parameter of this kind of laser that has not yet been fully explained in a satisfactory way. In this paper, we point out that the cross-phase modulation (XPM) between the pump and the Stokes inside fiber gain medium can lead to a modulation instability (MI) phenomenon [1,2], which in turn increases the spectral linewidth of the laser. For this purpose, we developed an experimental set-up that highlights the existence of MI in RFLs.

### **Experimental Set-up**

The practical scheme used in our experiments is shown on fig 1. It is based on a fiber ring laser configuration. The direction of propagation of light is controlled by an optical circulator. Two wavelength division multiplexers (WDM) are used to couple and uncouple the pump light from the gain fiber. The feedback and wavelength selection is provided through a 20% reflectivity fiber Bragg grating (FBG) at 1550nm. An optical isolator was used in order to avoid parasitic Fresnel back reflections from the fiber end face. The pumping device was a 6W unpolarized Raman fiber laser emitting at 1460nm. In our experiment, the pump was alternatively used in co-propagating (forward) and counter-propagating (backward) scheme with respect to the stokes light by using alternatively either of the WDM.

Three type of fiber were used exhibiting different dispersion and nonlinear characteristics. Standard single mode fiber (SMF) with low Raman gain and high anomalous dispersion at both pump and Stokes wavelengths. Dispersion shifted fiber (DSF) with moderate nonlinearity, normal dispersion at pump wavelength and small anomalous dispersion at Stokes wavelength. And finally a dispersion compensating fiber (DCF) with high Raman gain and high normal dispersion at both wavelengths.

## Modulation instability in Raman fiber lasers

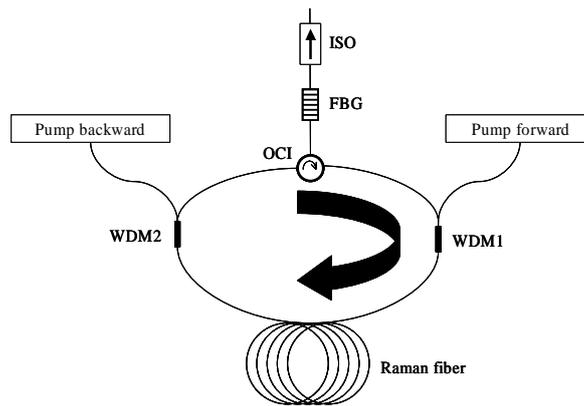


fig 1: experimental set-up

Characteristics of the fibers are summarized in table 1

Fiber	Fiber length (m)	Raman gain (1/(km*W))	Dispersion at 1460nm (ps/(nm*km))	Dispersion at 1550nm (ps/(nm*km))
SMF	1250	0.7	10.7	16.6
DSF	500	1.1	-7	0.17
DCF	200	2.2	-29.6	-18.5

Table1: characteristics of the fibers

### Discussion and results

Fig 2-4 show the output spectra of the lasers based on the three fibers: SMF , DSF and DCF respectively. Each figure presents the spectrum for co (dashed line) and counter (solid line) –propagating scheme.

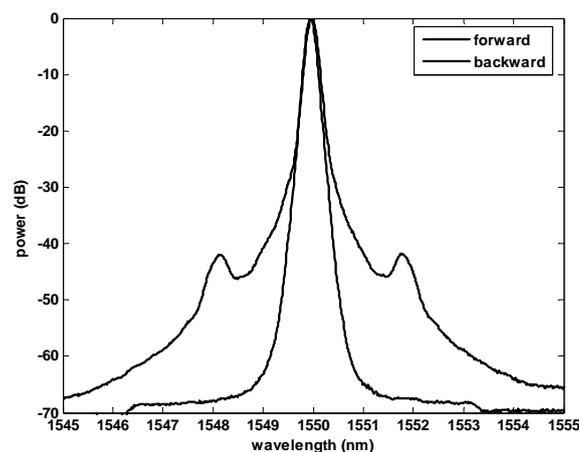


fig 2: output spectra for SMF fiber

Under the low gain conditions of the experiment, we see the appearance of sidebands on each side of the central emitting wavelength when the co-propagating scheme is considered. Those two lobes are the results of the modulation instability that arise from

the cross-phase modulation (XPM) between the high power pump and the generated Stokes wave.

The low gain is required in order to have a higher threshold. If threshold is low, pump will not be powerful enough to generate MI on the Stokes and even if one increases the power, the pump depletion will prevent the power to raise at a sufficient level.

When the two waves counter-propagate, the four-wave mixing process lying beneath MI is no more phase-matched and the side lobes disappear.

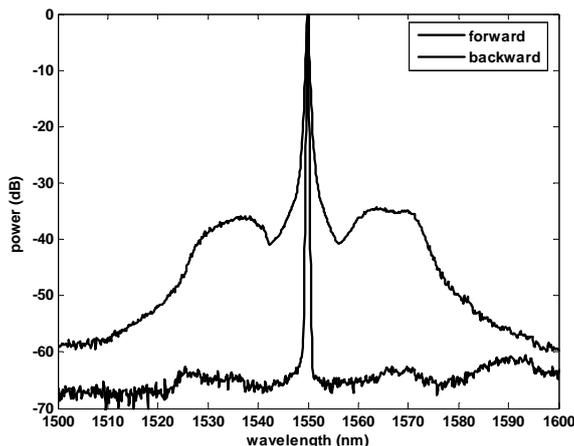


fig 3: output spectra for DSF fiber

The frequency of the maximum of the side lobes depends on both nonlinearity and dispersion of the fiber. As we can see on fig 3 the side lobes have a much more important extent for the DSF that exhibits the smaller anomalous dispersion at the Stokes wavelength

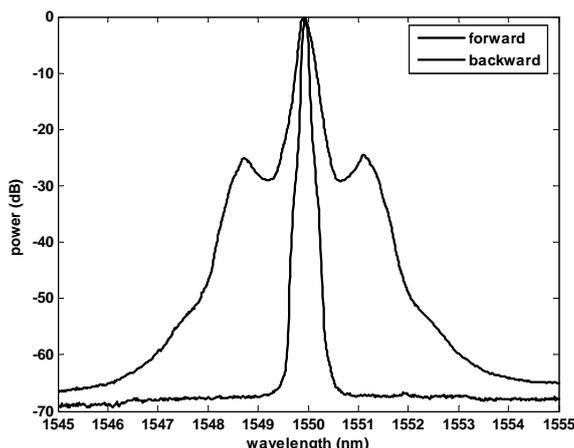


fig 4: output spectra for DCF fiber

Fig 4 shows the DCF based RFL spectrum. The existence of MI in this fiber that however exhibits normal dispersion at both pump and Stokes wavelength can be explained by the presence of XPM between those two waves as demonstrated in [1].

As one can see on all these figures, the central line of the spectra is broader when the pump and the Stokes waves co-propagate. When the two waves counter-propagate the XPM is averaged on the whole fiber length making the broadening ineffective. This broadening increases with the nonlinearity of the fiber.

Table 2 summarizes the central frequency  $f_{\max}$  of the MI side lobes and the percentage of broadening D of the central line.

Fiber	$f_{\max}$	D
SMF :	227 GHz	9%
DSF :	1.81 THz	24%
DCF :	150 GHz	58%

Table 2: maximum frequency of MI gain and spectral broadening

## Conclusion

In this paper, we experimentally demonstrated the existence of MI in RFLs. We also show that this phenomenon induces a spectral broadening of the laser line. A comparison between several type of fibers demonstrate that XPM between pump and stokes is involved in the process.

## Acknowledgement

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