Noise-characterization of an ultra-fast Raman fiber laser

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Abstract

We investigate the noise characteristics of a ultrahigh repetition rate Raman fiber laser, and show that the supermode noise can be significantly reduced by adding a subcavity to the laser.

Introduction

In the last decade a continuous effort has been made to increase the repetition rates of lasers further and further. The need to overcome the electronic bandwidth limitation of actively mode-locked lasers to continue the increase in repetition rates has spurred a great interest in various passive mode-locking techniques, using saturable absorbers or taking advantage of fiber nonlinearities.

We have recently demonstrated the combination of Raman amplification with the mode-locking technique of dissipative four-wave mixing (DFWM) to form a passively mode-locked Raman fiber laser [1]. The use of Raman amplification promises very high average output powers, while simultaneously providing a virtually wavelength independent gain mechanism overcoming the wavelength limitations of rare-earth doped gain mechanisms. The DFWM mode-locking technique allows us to achieve repetition rates in excess of 100 GHz by simply incorporating a passive filter into the laser cavity.

A fiber laser mode-locked at these repetition rates will necessarily operate at very high harmonics of the fiber resonance frequency. It is well known that harmonically mode-locked lasers suffer from a phenomenon often denoted as supermode noise, i.e. a beating between different sets of cavity modes oscillating simultaneously inside the laser [2,3]. The effect can usually be identified in the laser RF spectral density by observing peaks not only at the repetition rate of the laser, but also at multiples of the cavity resonance frequency.

Research on supermode noise has been mainly limited to actively harmonically mode-locked lasers. Given the lack of methods to measure the noise of a laser at repetition rates of over 100 GHz directly, we performed numerical simulations to get an indication of the effects of the presence of supermodes on our mode-locked Raman laser performance. The numerical simulations show a very good agreement with experiments and help to explain several observations in the experimental autocorrelation traces. In order to more quantitatively measure the noise characteristics we have then built a laser mode-locked at 10 GHz using the same technique. We show that we can greatly reduce the number of supermodes by adding a subcavity acting like a Fabry-Perot filter into the laser.

Numerical simulations

The laser is modeled by a Ginzburg-Landau type equation with gain, which is numerically simulated using the well-known split-step Fourier method. The dissipation crucial for the laser operation is provided by multiplying, once every round trip, the electric field by a spectral filter consisting of a band pass filter combined with a Fabry-Perot filter (see Reference [1] for the exact shape of the filter). To incorporate the supermode noise into our model, we take advantage of the numerical discretization. Each discretization point can be interpreted as one cavity resonance mode, thus by changing the sampling of the spectral filter, we are effectively varying the number of supermodes present in the laser. Figure 1 depicts (a) the experimental autocorrelation trace of our laser mode-locked at 160 GHz and (b) the results of simulations for similar parameters. The numerical results closely resemble the experiment. A further investigation reveals that the autocorrelation background and the non-flat envelope are both caused by fluctuations in pulse repetition rate, intensity and phase due to supermode noise.

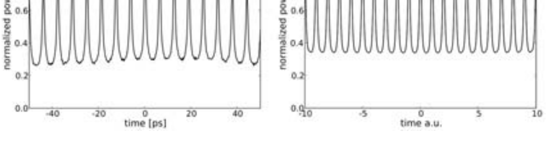

Figure 1: (a) Autocorrelation of the laser operating at 160 GHz. (b) Autocorrelation of a simulation for similar parameters

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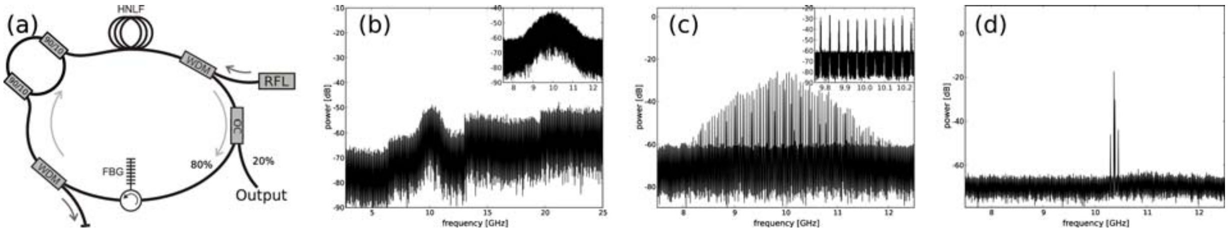

Figure 2: Experimental setup of the passively mode-locked laser with a subcavity acting as a Fabry-Perot filter (a), RF-spectrum of the 10 GHz laser without (b) and with the 440 cm subcavity (c), and RF-spectrum of the 10 GHz laser with two subcavities combined by the Vernier principle (d).

Supermode noise reduction with a subcavity

The experimental setup is depicted in Figure 2(a) (see Reference [1] for a detailed description). By incorporating a subcavity into our ring laser, we effectively introduce an additional Fabry-Perot filter into the cavity to filter out the supermodes. Due to the all-fiber nature of the subcavity, its influence on cavity losses is comparatively small. We note that the very high average intracavity power of our laser is easily handled by our all-fiber subcavity but that this power level prevents the use of more traditional bulk micro-optics fiber-coupled Fabry-Perot filters.

In order to be able to do quantitative measurements of the laser noise, we constructed another laser setup operating at 10 GHz and measured its output using a RF-spectrum analyzer. The RF-spectrum shows a broad peak centered at the expected 10 GHz with a width of around 2 GHz similar to the width of the individual reflection peaks of the spectral filter [see Figure 2(b)]. Once a subcavity with a length of approx. 4.4 m is introduced into the laser cavity, the broad peak is replaced by individual peaks spaced at about 45 MHz, corresponding to the free spectral range (FSR) of the subcavity. However the 2 GHz envelope still remains [Figure 2(c)]. For a further reduction in the supermode noise, we have used two subcavities with a length ratio of 20/21. The two subcavities superimpose according to the Vernier principle to form a filter with an FSR of around 900 MHz. The result is depicted in Figure 2(d). We see a significant improvement of the signal to noise ratio by more than 20 dB. However there are some drawbacks to this method, in particular the length fluctuations between the two subcavities cause temporal instabilities. Nevertheless we are confident that these can be overcome by actively adjusting the length of one subcavity with a feedback mechanism.

Output power

Finally we would like to present a further twofold increase of the average output power on our previously reported results. By changing the output coupler of the laser we are able change the slope efficiency of the laser. Although the lasing threshold increases with increased coupling ratio, we are still able to demonstrate a maximum output power of 926 mW at 3.9 W of pump power. Figure 3 depicts the average output power of the laser as a function of pump power for 3 different output couplers. Apart from a slight nonlinearity induced by the detector, all graphs show a linear dependency and no saturation.

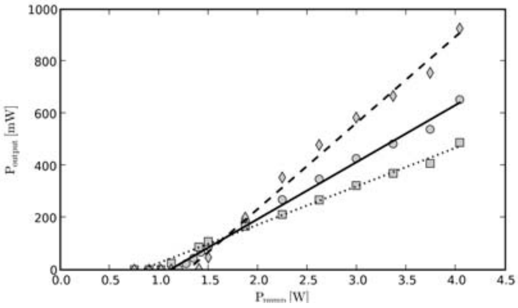

Figure 3: Output power of a 160 GHz laser with (bottom to top) 30%, 50%, and 70% output coupling.

Conclusions

We have demonstrated a novel technique for simulating the noise characteristics of a laser mode-locked by dissipative four-wave mixing. Numerical and experimental results agree very well and show that supermode noise causes a background in the autocorrelation traces. Further experiments using a 10 GHz laser give a quantitative measurement of the supermode noise. Finally we showed that the amount of supermode noise can be significantly reduced using a set of fiber subcavities. Additionally we are able to further increase the maximum average output power to almost 1 W.

References

1. J. Schröder, S. Coen, F. Vanholsbeeck, and T. Sylvestre, Opt. Lett. 31 (2006) 3489.
2. L. Yuhua, L. Caiyun, W. jian, W. Boyu, and G. Yizhi, IEEE Photon. Tech. Lett. 10 (1998) 1250.
3. M. Nakazawa, K. Tamura, and E. Yoshida, Electron. Lett. 10 (1996) 461.