بیست و سومین کنفرانس اپتیک و فوتونیک و نهمین کنفرانس مهندسی و فناوری فوتونیک ایران
دانشگاه تربیت مدرس
۱۲-۱۴ بهمن ۱۳۹۵
23rd Iranian Conference on Optics and Photonics and 9th Conference on Photonics Engineering and Technology
Tarbiat Modares University, Tehran, Iran
January 31- February 2, 2017

تولید سالیتونهای اتلافی در نوسان ساز رامان همزمان شده

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چکیده – در این مقاله، لیزر پالسی رامان برای تولید پالس ۶ نانوژول و طول موج مرکزی ۱۱۱۵ نانومتر ارایه می شود. برای تولید پالسهای همدوس وقوی که قابلیت فشرده شدن تا چند ده فمتوثانیه را داشته باشند، پالس دمش در ۱۰۶۴ نانومتر و رامان در ۱۱۱۵ نانومتر همزمان شده اند. پالسهای رامان تولید شده توسط توری پراش تا ۲۰۰ فمتو ثانیه فشرده شده اند.در انتها مدل تحلیلی نوسان ساز رامان بر پایه ی معادله غیر خطی گینزبرگ-لانداو ارایه شده و پاسخ تحلیلی آن استخراج گردیده است. به توجه به معادله مذکور پالسهای رامان از نوع سالیتونهای اتلافی می باشند.

کلید واژه- سالیتونهای اتلافی، لیزر رامان، دمش همزمان شده

Generation of dissipative solitons in synchronously-pumped Raman laser

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Abstract- Here, we present a synchronously-pumped Raman laser, which can support dissipative solitons. The laser comprises a 37 MHZ passively mode-locked oscillator as a pump source, a pre-amplifier and Raman oscillator. After synchronizing pump and Raman pulses, we generate 6 nJ pulses at 1115 nm and compress it to 200 fs by using a pair of transmittance grating. We modeled the Raman oscillator by complex Ginzburg-Landau equation and obtained their approximate analytical solution.

Keywords: Raman laser, synchronously-pumped, ultrafast lasers.

23rd Conference on Optics and Photonics and 9th Conference on Photonics Engineering and Technology
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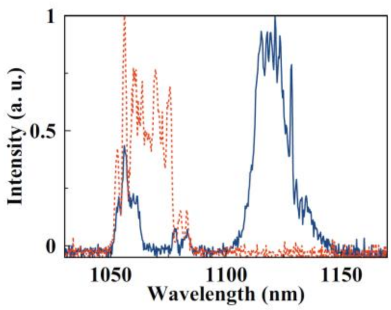
1. Introduction

Rare-earth-doped fiber lasers, based on ytterbium, erbium, and thulium, take significant advantages of high flexibility and high beam quality compare with solid-state lasers [1]. Nonlinear effects in fiber lasers, due to small core size, are more significant than solid-state lasers, and consequently, generation of a high energy and ultra short pulse is a quite challenge. On the other hand, some benefits and advantages arising from nonlinearity, such as Raman and parametric amplification, which are promising for generating of new wavelength band, which can not be covered by existing lasers. For example, Raman scattering can be used to achieve spectral regions, which are out of emission band of the current rare-earth doped fibers. Synchronously pumped Raman lasers are important for generating high-power signals, which are able to be compressed down to sub few-hundred femtoseconds. In all-normal-dispersion (ANDi) regimes, synchronously pumped Raman lasers can support high power dissipative solitons [2]. Here, we present a dispersion-managed synchronously-pumped Raman laser operating at 37 MHz, which can generate about 6 nJ pulses at 1115 nm and can be de-chirped down to 200 fs. To investigate pulse dynamics, we present a theoretical model based on complex Ginzburg-Landau equation and obtain an approximation analytical solution.

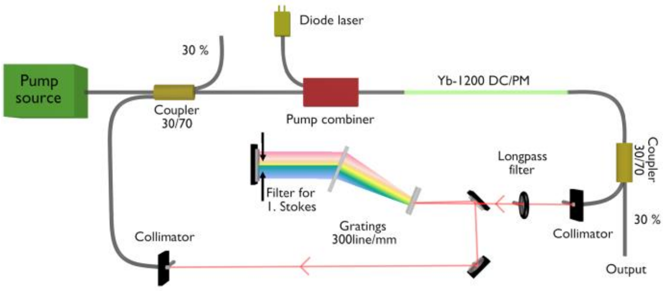
2. Experimental setup

The schematic of experimental setup is shown in Fig. 1 and comprises a mode-locked oscillator, amplifier, and Raman oscillator (Fig. 1(a)). The oscillator is a home-built passively mode locked all-normal-dispersion (ANDi) laser with a repetition frequency of 37 MHz, generating a 6-ps long chirped pulse centered at 1065 nm. The output power from oscillator is about 6 mW. The all-polarization-maintaining amplifier (PM) amplifier comprises 85-cm long Yb 401-PM pumped by a single mode diode through a PM wavelength division multiplexer (WDM). The maximum output from amplifier is 250 mW. To characterize generated Raman in the Raman oscillator, we first built a high power all-PM Yb-doped amplifier (Fig. 1(b)). The amplifier consists of a 3.5-m long Yb 1200-DC-PM with 6 µm core diameter and 125 µm cladding diameter pumped by a temperature stabilized, high power multimode diode laser via a multimode pump-signal combiner (MPC). The output from first stage amplifier, after passing through a high power isolator, is used as seed for power amplifier. Measured input power, spectral width and pulse duration are 210 mW, 18 nm, and 6 ps, respectively. To measure output power and prevent any back reflection, tip of gain fiber is angle cleaved. In the experiment, we observed first Stokes generated about 850 mW pump power. The first Stokes Raman shift in the silica is about 13 THZ corresponds to 50 nm shift at 1065. The generated Raman signal after the gain fiber is very weak and partially coherent. To generate coherent Raman signal, a portion of generated Raman signal is fed to the amplifier. Since 1065/1120 combiner is not commercially available, pump and Raman signal are coupled by



a 30/70 coupler. The diode pump in this experiment is a 10 W fiber-pigtailed diode laser (IPG), mounted on a heat sink to control temperature and stabilize operating wavelength at 976 nm. Though the optimum length for the gain fiber is about 8 m, we used 3.5-m long due to cavity length limitation. Another 30/70 coupler is used after the gain fiber as output coupler. To control the total dispersion of the cavity and reduce walk-off length for pump and Raman signals, a delay line comprises a pair of transmittance grating (300 line/mm) is inserted inside the cavity. The total group dispersion delay is positive. Pump is filtered by a band pass filter and only Raman signal is fed into the laser cavity by using of a single mode collimator as shown in Fig. 1(a).

(a)



(b)

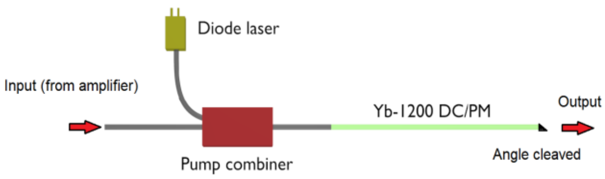


Figure 1: (a) Schematic setup of the Raman oscillator. (b) The comprised power amplifier in the Raman oscillator

3. Experimental results

Fig. 2 shows measured optical spectra with and without feedback. As shown in this figure, re-launching a portion of Raman signal to the cavity amplifies Raman signal significantly.

To achieve strong and coherence Raman pulse, the repetition rate of the Raman oscillator and pump oscillator have to be synchronized. The synchronization is done by changing the distance. of free space by using a very precise translation stage. Fig. 3 (a) shows output optical spectra after synchronization. Pump depletion is manifested in this figure. Fig. 3(b) shows Raman spectrum measured after long pass filter.

Figure 2: Measured optical spectrum of Raman oscillator with (blue) and without (red) feedback.

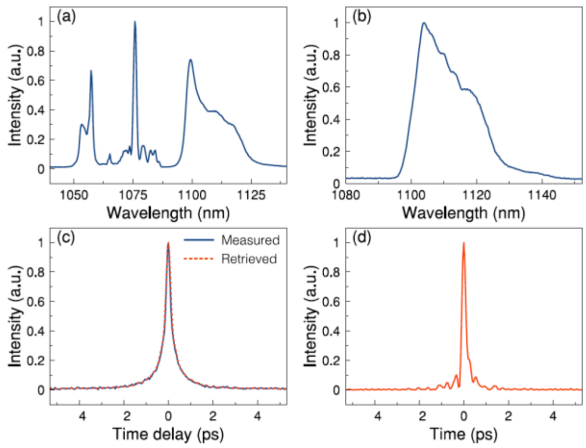


Figure 3: Measured optical spectra of a synchronously pumped Raman laser from 70/30 coupler, (a) before pump signal filtering, (b) after pump signal filtering. Measured autocorrelation of the first Stokes (blue) and retrieved autocorrelation trace by PICASO (red) (c) and retrieved pulse shape from PICASO (d).

A pair of transmittance grating (600 line/mm) is used for compressing output signal at 1120 nm. Fig. 3(a) shows measured intensity autocorration of signal after compressing. The masured pulse width is 200 fs. The pulse retieved by PICASO is shown in Fig. 3(d)

4. Analytical model

The pulse propagation in a medium in the presence of Kerr nonlinearity, group velocity dispersion, Raman gain, quantic saturable absorber and cross phase modulation can be modelled by the following set of equations [3]

$$\frac{du_s}{dz} = \left(\frac{1}{\Omega_s} - i\frac{\beta_{2s}}{2}\right)\frac{d^2u_s}{dt^2} + g_s u_s + i\gamma_s\left[|u_s|^2 + c\,|u_p|^2\right] + \frac{\mu_s}{2}|u_p|^2 u_s - d_s|u_p|^4 u_s,$$

$$\frac{du_p}{dz} = \left(\frac{1}{\Omega_p} - i\frac{\beta_{2p}}{2}\right)\frac{d^2u_p}{dt^2} + g_p u_p + i\gamma_p\left[|u_p|^2 + c\,|u_s|^2\right] + \frac{\mu_p}{2}|u_s|^2 u_p - d_p|u_s|^4 u_p, \quad (1)$$

Where $u_{p(s)}$ is pump (signal) electric field envelope,
$\Omega_{p(s)}$ describes pump (signal) bandwidth of filter, $\beta_{2p(s)}$ is group velocity dispersion at pump (signal) wavelength, $g_{p(s)}$ is linear gain, $\gamma_{p(s)}$ nonlinear coefficient for pump (signal), and $d_{p(s)}$ is quantic saturable absorber. To find analytical solution, we use the following Ansatz, which presents relation between pump and signal

$$|u_p|^2 = a|u_s|^2 + b|u_s|^4, \qquad (2)$$

Where a and b are constants. By substituting (2) into (1), the following equation is obtained

$$\frac{du}{dz} = gu + \left(\frac{1}{\Omega_s} - i\frac{\beta_{2s}}{2}\right)\frac{d^2u}{dt^2} + (m + iM)u\,|u|^2 + (\delta + i\Delta)u\,|u|^4, \qquad (3)$$

The exact solution of Eq. (3) is considered as [4]

$$u = \sqrt{\frac{A}{cosh(\frac{t}{\tau}) + B}}\, e^{\frac{-i\beta}{2} ln[cosh(\frac{t}{\tau})+B] + i\theta z} \qquad (4)$$

Where A, B, τ, β and θ are real constant. Inserting (4) into (3) and separating real and imaginary parts, gives six equations. Fig. 4 shows calculated pulse shape and optical from the analytical model

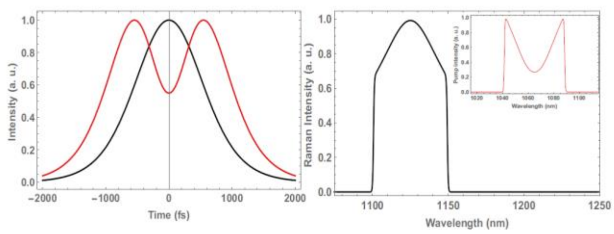


Figure 4: Calculated pulse shape (left) and corresponding optical spectra (right) from theoretical model.

5. Conclusion

We presented a synchronously-pumped Raman laser system and generated 6 nJ coherence pulses cantered at 1120 nm. By using a compressor grating, we de-chirped pulses to 200 fs. We modelled the Raman oscillator by complex Ginzburg-Landau equation and showed the oscillator can support dissipative solitons.

Acknowledgement

This work is supported by TÜBITAK under project number 115F098.

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