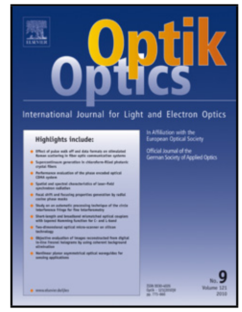

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Authors: Hanyuan Ying, Jianqiu Cao, Yu Yu, Meng Wang, Zefeng Wang, Jinbao Chen

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Raman-noise enhanced stimulated Raman scattering in high-power continuous-wave fiber amplifier

HanyuanYing, [1, 2, 3] Jianqiu Cao, [1, 2, 3*] Yu Yu,[1, 2, 3] Meng Wang, [1, 2, 3] Zefeng Wang, [1, 2, 3] and Jinbao Chen[1, 2, 3]**

[1] *College of Optoelectronic Science and Engineering, National University of Defense Technology, Changsha, Hunan, 410073, China*
[2] *Hunan Provincial Key Laboratory of High Energy Laser Technology, Changsha, Hunan, 410073, China*
[3] *Hunan Provincial Collaborative Innovation Center of High Power Fiber Laser, Changsha, Hunan, 410073, China*
*Corresponding authors: * jq_cao@126.com*
*** kdchenjinbao@aliyun.com*

ABSTRACT:
The stimulated Raman scattering (SRS) in high-power continuous-wave (CW) fiber amplifier is investigated with the seeded Raman noise taken into account. It is revealed that the seeded Raman noise, as a portion of seed light, should enhance SRS in high-power CW fiber amplifier even when it is much weaker than the seeded signal light. The analytic formula for predicting the Raman threshold of bi-directional pumping fiber amplifier is given with the seeded Raman noise taken into account, and the predictions agree well with the numerical results. It is also revealed that the co-pumping amplifier suffer from the lowest Raman threshold, and the counter-pumping one is more beneficial to the SRS suppression than the bi-directional pumping one when the pump absorption of active fiber is larger than 8.7 dB. These results will provide guidance for the design of high-power CW fiber amplifier.

KeyWords: Fiber amplifiers; Stimulated Raman scattering; Pumping.

1. Introduction

High-power fiber lasers have attracted much attention because of their advantages such as compactness, reliability, high efficiency, good beam quality, etc. Particularly with the rapidly power up-scaling in recent years, they can meet various requirements of academic and industrial applications [1-3]. In 2009, a 10-kW single-mode fiber laser was demonstrated with the master oscillator power amplification (MOPA) configuration [4]. Nowadays, the MOPA configuration consisting of a seed fiber oscillator and a fiber amplifier is most-widely used in high-power fiber laser system, where the fiber amplifier plays the most important role for the power scalability of MOPA fiber laser system.

One fundamental issue limiting the power scalability of MOPA fiber laser system is the stimulated Raman scattering (SRS) in the high-power fiber amplifier [2, 5, 6]. It has been revealed that when the signal power is beyond some threshold (generally named as the Raman threshold), SRS should be present and preventing the further increment of signal power. A number of studies were carried out with the purpose of estimating the threshold. At present, two typical formulas given by J. R. Smith [7] and C. Jauregui et al [8] are most widely used, which are induced with the case of passive fiber and show that the threshold is mainly determined by the mode area, effective fiber length and Raman gain. The Raman threshold of fiber amplifier (also defined as the pump power threshold corresponding to the presence of SRS effect [9]) was also investigated in Ref. [5, 9] with the gain of active fiber taken into account. All these studies were carried out based on an assumption that the SRS light be induced by the spontaneous Raman noise with a constant small power [7-9].

However, such an assumption may not be so coincident to the practical case of fiber amplifier in the high-power MOPA fiber laser system. The reason is that seeded Raman noise, as a portion of the seed light output from the seed fiber oscillator of MOPA fiber laser system, was not taken into account in these studies. It should be noted that because of the high-power (hundreds-of- to kilo-Watt) of seed fiber oscillator, the seeded Raman noise may be mainly induced by SRS rather than uniquely by the spontaneous Raman scattering in the seed fiber oscillator. However, because it is generally much smaller than the seeded signal light, we still call it as the “seeded Raman noise” here. Such a seeded Raman noise may be too weak to be observed with the spectrum measurement, especially when the signal-to-noise ratio of the spectrum measurement is not high enough (e.g., around 30 dB [10, 11, 13-15]), but may be much larger than the initial power of Raman noise used in these studies of Ref. [7-9]. Taking a 200-W seed fiber oscillator for example, the seeded Raman noise will be 0.2 mW with a 60-dB Raman suppression of seed fiber oscillator, which can be much larger than the value (estimated to be around 10^{-7} W with the Eq. (15) of Ref. [9]) used in Ref. [7-9]. Then, such a large seeded Raman noise will make the Raman threshold predictions of formulas given in Ref. [7-9] not effective.

Actually, some recent experimental studies also implied that the effect of seeded Raman noise should not be neglected. For example, the 3-kW Raman fiber laser reported in Ref. [10] demonstrated that the seeded Raman noise can be strong enough as the Raman seed of the multi-kW Raman fiber amplifier, which suggests that the effect of seeded Raman noise on SRS in the fiber amplifier should be considerate. Besides, the experimental study in Ref. [11] also revealed that the Raman threshold of fiber amplifier should be varied with the seed light power. It should be noted that the seeded Raman noise output from the seed fiber oscillator may increase monotonously with the seed light power [10, 12]. Then, besides the seeded signal light, the seeded Raman power (i.e., the power of seeded Raman noise) may still be a factor affecting the Raman threshold of fiber amplifier. Now, how seriously will the seeded Raman power affect the SRS effect in the fiber amplifier? What is the relationship between the seeded Raman power and the Raman threshold of