Multi-GHz repetition-rate pulse generation by gain instability in a semiconductor-based all-fiber laser

A.V. Ivanenko[1], A.E. Bednyakova[1], S.V. Smirnov[1] and B.N. Nyushkov[2]

[1]Novosibirsk state university, Novosibirsk, Russia

[2]Novosibirsk state technical university, Novosibirsk, Russia

Abstract— We present a novel, simple and highly effective method for generating multi-GHz regular pulse trains in lasers. This method relies on self-sustaining cross-gain modulation achieved by incorporating negative optical feedback (NOF) into a cavity equipped with a semiconductor optical amplifier (SOA). Notably, this approach not only facilitates pulse formation without the need for active modulation or saturable absorption but also enables effortless multiplexing of the laser system to achieve diverse pulse repetition rates. The feasibility of the method was confirmed by the stable generation of sub-nanosecond pulses at 1.35 GHz, 1.57 GHz, and 1.79 GHz repetition rates in an SOA-based laser with a simple ring all-fiber all-PM cavity.

Keywords— fiber laser, semiconductor optical amplifier, high repetition rate pulse generation

I. Introduction

Instabilities are often associated with undesirable effects that should be avoided or suppressed. However, instabilities can play a constructive role, allowing one to achieve stable self-sustaining oscillations with a controlled frequency [1-3]. The utilization of such controlled instabilities in lasers will enable the abandonment of modulators and saturable absorbers, which are traditionally used to create and maintain stationary pulse generation. In this work, we propose and study an original method for generating multi-GHz repetition rate pulses, based on self-sustaining cross-gain modulation in a laser utilizing a semiconductor optical amplifier (SOA) with negative optical feedback (NOF).

II. Experement and Results

The all-PM laser design is based on the commercial SOA "Rayzer" and polarization-maintaining fiber-optic elements (Fig. 1a). The key components include a 40/60 main coupler and a circulator, which, being connected by fiber spans, collectively create the positive and negative optical feedback loops. For particular parameters of our experimental configuration, pulse generation started at a repetition rate of 1.567 GHz, corresponding to the 57th harmonic of the inter-mode frequency, and then could reliably switch to 1.347 GHz or 1.786 GHz (the 49th and 65th harmonics of the inter-mode frequency, respectively) by manipulating the laser gain or loss.

The stability analysis of the continuous-wave (CW) solution reveals that these frequencies correspond to the most pronounced peaks in the NOF-induced instability gain spectrum. Fig. 1b displays an upper envelope of the instability gain spectrum $\chi(\nu)$ without considering its rapid oscillations. At

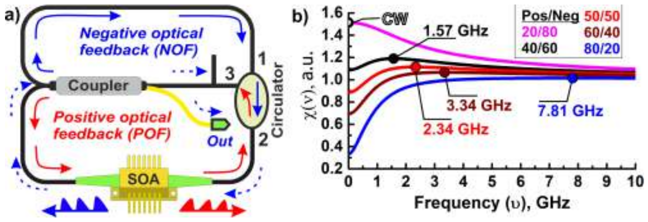

Fig. 1. a) Schematic of the laser, b) $\chi(\nu)$ - the upper envelope of the instability gain spectrum vs rapetition rate frequency (ν) at different

certain frequencies CW generation becomes unstable ($\chi > 1$), and the continuous wave breaks up into pulses with a frequency corresponding to the maximum value of $\chi(\nu)$. Notably, adjusting the coupling ratio can further augment the pulse repetition rate, as depicted in Fig. 1b. It's worth noting that the resulting modulation of the laser gain is also restricted to frequencies matching the spacing of longitudinal laser modes. These factors enable the reproducible generation of stable pulses at precisely defined repetition rates

The method offers remarkable simplicity, compactness, and energy efficiency compared to active modulation techniques commonly used for generating multi-GHz pulses in SOA-based lasers We believe that it has the potential to be implemented using various optical components in the laser cavity design to scale up to ~10 GHz pulse repetitions rates and it may be in demand in various applications in the field of optical telecommunications, e.g., for improving the “Radio over fiber” technology, used for the deployment of new generation mobile networks (5G).

Acknowledgment

This work was supported by Russian Science Foundation (24-12-00314).

References

[1] Smirnov, S., Nyushkov, B., Ivanenko, A., & Bednyakova, A. (2023). High-repetition-rate pulse generation via self-sustaining cross-gain modulation in a semiconductor-based laser. Optics Letters, 48(23), 6084-6087.

[2] Tarasov, N., Perego, A. M., Churkin, D. V., Staliunas, K., & Turitsyn, S. K. (2016). Mode-locking via dissipative Faraday instability. Nature communications, 7(1), 12441.

[3] Nyushkov, B., Ivanenko, A., Smirnov, S., & Turitsyn, S. (2023). Transient light shift register mechanism of bi-chromatic pulse generation. Optica, 10(8), 1029-1036.