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LETTER

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Letter

Low temporal radiation coherence of noise-like pulses

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Abstract

It is quite well-known that coherence is an intrinsic property of laser radiation. However, after the advent of noise-like pulses, it turns out that the temporal coherence of their radiation is low and the electromagnetic field oscillations in adjacent noise-like pulses are not correlated. This work experimentally studies for the first time the degree of coherence of electromagnetic field oscillations inside a noise-like pulse. We measure the visibility of interference fringes at the exit from a Michelson interferometer when its optical path difference is scanned around zero up to and exceeding the length of the noise-like pulse. The experimental data indicate close to zero temporal coherence of radiation within noise-like pulses.

Keywords: mode-lock fibre laser, intra-pulse radiation, noise-like pulses

1. Introduction

The temporal coherence of laser radiation is usually assumed to be high due to a fixed (or practically fixed) relationship between electro-magnetic field phases at various times within a limited period. The correlated course of the wave processes at different points in time has both advantages and disadvantages. One of the disadvantages consists in the formation of random interference patterns (speckle structures) as a result of illumination with coherent radiation of randomly inhomogeneous objects (e.g. rough surface) or when such radiation passes through a transparent (or partially transparent) medium with random spatial distribution of refractive index.

The reduction of temporal coherence of radiation is important in many applications where speckle structures are an unwanted phenomenon. Various measures are taken for contrast reduction of speckle structures or their elimination, both inside the laser cavity and outside [1]. The basic idea used in most of these methods is weakening (or disruption) of phase relationships of electro-magnetic fields at different time points.

However, there exists at least one more approach relying on the generation of pulses with a chaotic internal structure. These are noise-like pulses [2–5], composed of very many sub-pulses with random amplitude and duration. The degree of coherence of the noise-like pulse radiation is assumed to be low [6–9]. Nevertheless, only the coherence of radiation between pulses was explicitly measured [10] and was found to be absent, whereas the coherence of radiation within a single noise-like pulse was not actually measured.

The goal of this work is the study of coherence properties of intra-pulse radiation of noise-like pulses.

2. Experiment

For measurement of intra-pulse coherence of noise-like pulses, we used the experimental set-up shown in figure 1. It included a source of noise-like pulses and a Michelson interferometer, into which these pulses were guided. The output from the interferometer containing interference patterns (the optical

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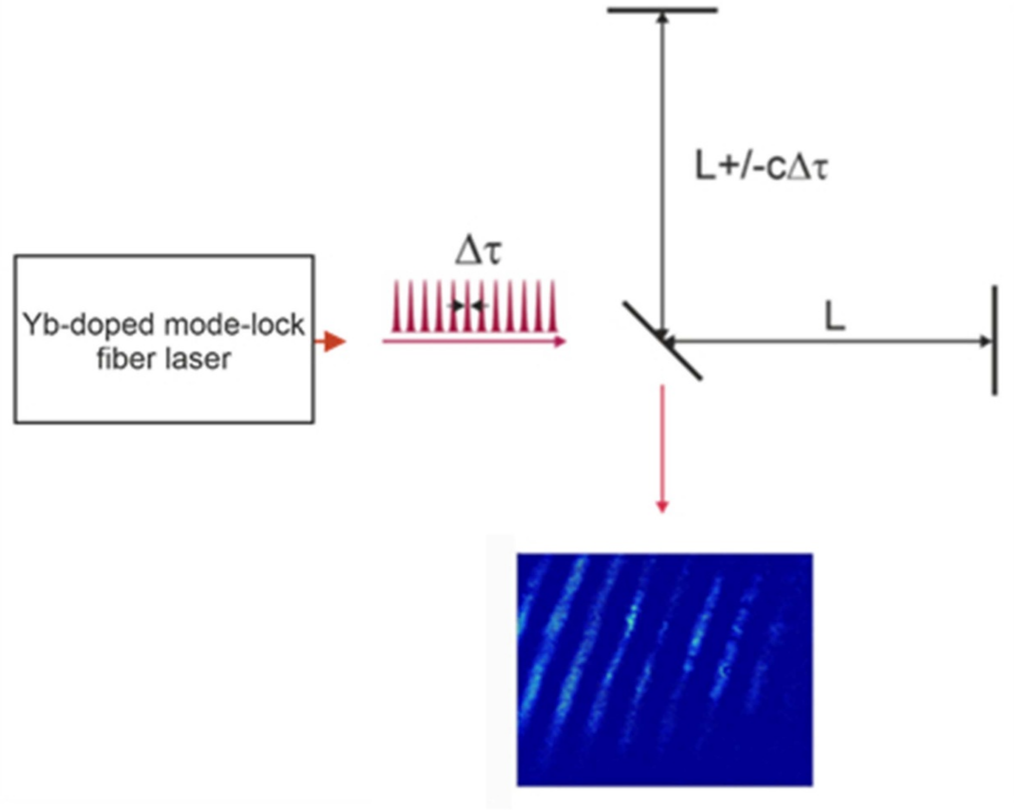

Figure 1. Scheme of the experimental setup.

path difference of the interferometer was adjusted from 0 to ∼±20 mm) was registered with a CCD detector. The degree of coherence was determined from the visibility of the interference fringes. In order to tune and calibrate the system, the laser was operated in CW mode and we made sure that the interference pattern contrast remained constant across the entire range of path difference adjustment. Then, the laser was switched to noise-like pulse generation (a typical auto-correlation function (ACF) of the output pulses is given in figure 2) and measurements were taken for noise-like pulses.

The layout of the fibre laser used as the source of both CW and noise-like pulsed radiation is presented in figure 3. All the elements of the laser cavity were made of polarisation-maintaining fibre. Mode-locked operation was achieved via an artificial saturable absorber [11], a non-linear optical loop mirror (NOLM). The laser was pumped with two laser diodes emitting at 975 nm, and adjustment of the ratio between their output powers allowed the laser to enter different generation regimes. The pump radiation was fed into the laser cavity through the isolation elements and WDM combiners at 975/1064 nm. Active fibre LIEKKI® Yb1200-6/125DC-PM was used as the gain medium. Cavity parameters: full length—14.4 m, right-side NOLM loop—2 m, and left-side loop—12.2 m. Cavity fibre—Corning® PM Specialty Fibres, PM980. Asymmetric 20/80 coupler (between the cavity loops), instead of 50/50, creates an intensity difference of radiation propagating in opposite directions along the NOLM. This difference results in a phase difference between the waves running in opposite directions, which, in turn ensures non-linear transmission of the NOLM.

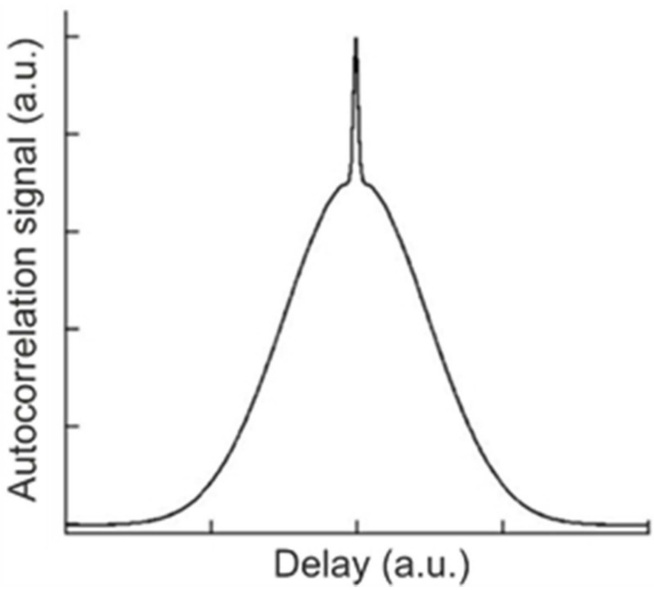

Figure 2. Common pattern of autocorrelation function of noise-like pulses.

Selection of the desired generation regime is done through a map of the laser's generation regimes. This map was compiled by consecutive scanning of the ratio between the two

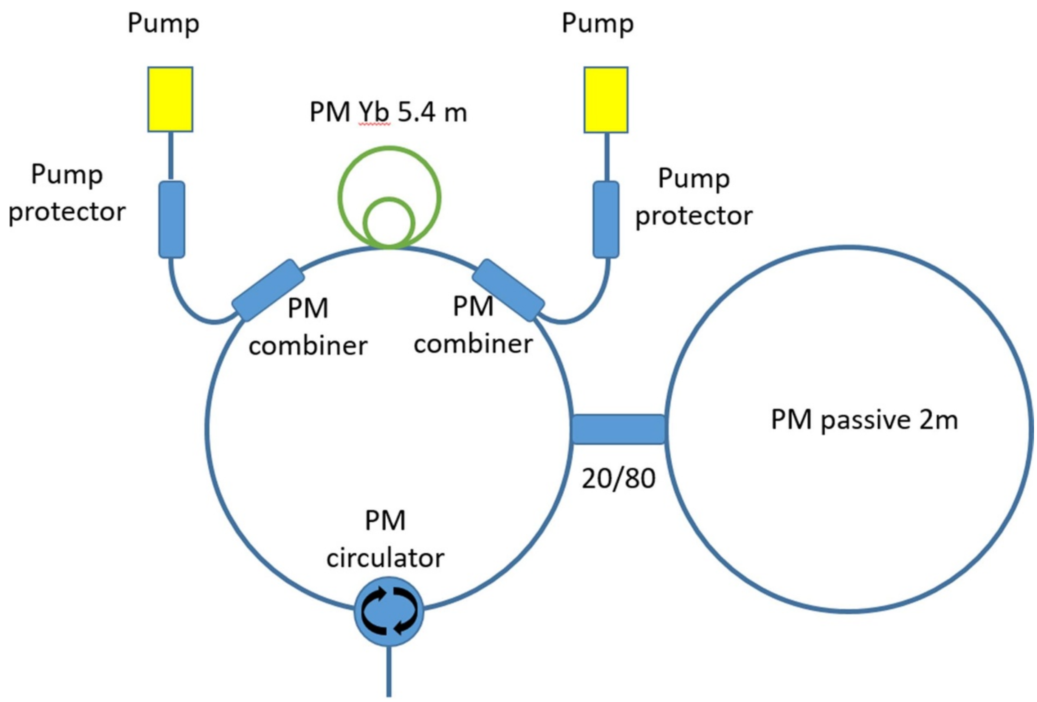

Figure 3. Scheme of the Yb-doped mode-lock fibre laser, which is a source of noise-like pulses.

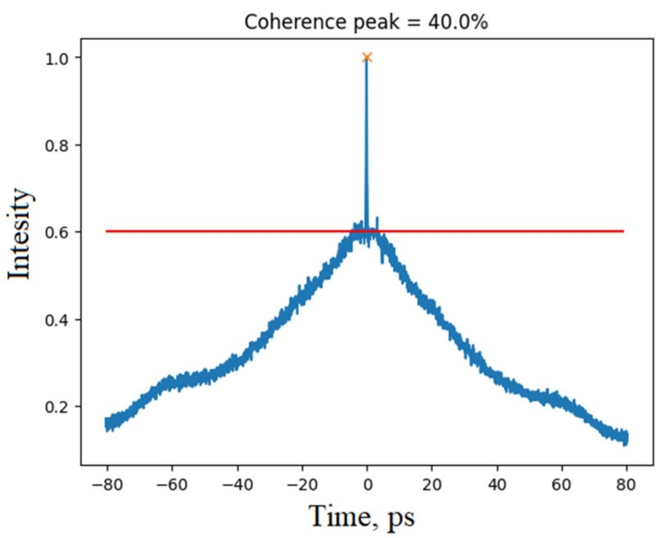

Figure 4. Auto-correlation function of noise-like pulses in identified regime.

pump source powers with simultaneous measurement of the ACF of the output pulses, their spectrum, and average power. We defined the optimal generation regime as such that combines a significant output power with a high amplitude of the central peak of the ACF and with minimal fluctuations of the output power. The ACF of the identified regime is shown in figure 4.

The algorithm of scanning the ratio between the pump source powers was implemented with a special control code [12]. The typical time required for compilation of the map was around 6 h. The generated maps are given in figure 5. We identified the optimal generation space as the vicinity of the parameters $I1 = 0.9$ A, $I2 = 1.75$A, where I1 and I2 are the pump source injection currents. In this space, the average output power of the laser was 45 mW, relative height of the ACF peak (measured from the pedestal) was 40% (see figure 4), peak-to-peak fluctuation of the output power was 8.5%.

Pk-pk fluctuations of 8.5% correspond to a root-mean-square value not exceeding 3% (this depends on the character of the fluctuations). This is a satisfactory level of stability for the output power of the laser source.

As may be seen from figure 5, identification of the desired generation regime by the optimal criteria combination (high ACF peak amplitude, low pk-pk fluctuations, and sufficient output power) is practically unambiguous. The dependence of the coherence degree of NLP radiation upon other pulse parameters, such as envelope duration and radiation spectrum width was not studied in this work.

Analysing the generation regime maps, it is possible to note that the optimal pulse parameters (a combination of acceptable output power with the largest amplitude of the central peak of the ACF and the lowest output power fluctuations) are practically achieved only in one area marked with red circles in figure 5. The desirable area is not located at the highest output power of the laser (that corresponds to the highest injection currents of both pump lasers), but at a relatively low output power that is achieved at a close to the maximal current of one pump laser and medium current of the other pump laser. When selecting the optimal area, we assigned a higher priority to the achievement of the highest possible central peak of the

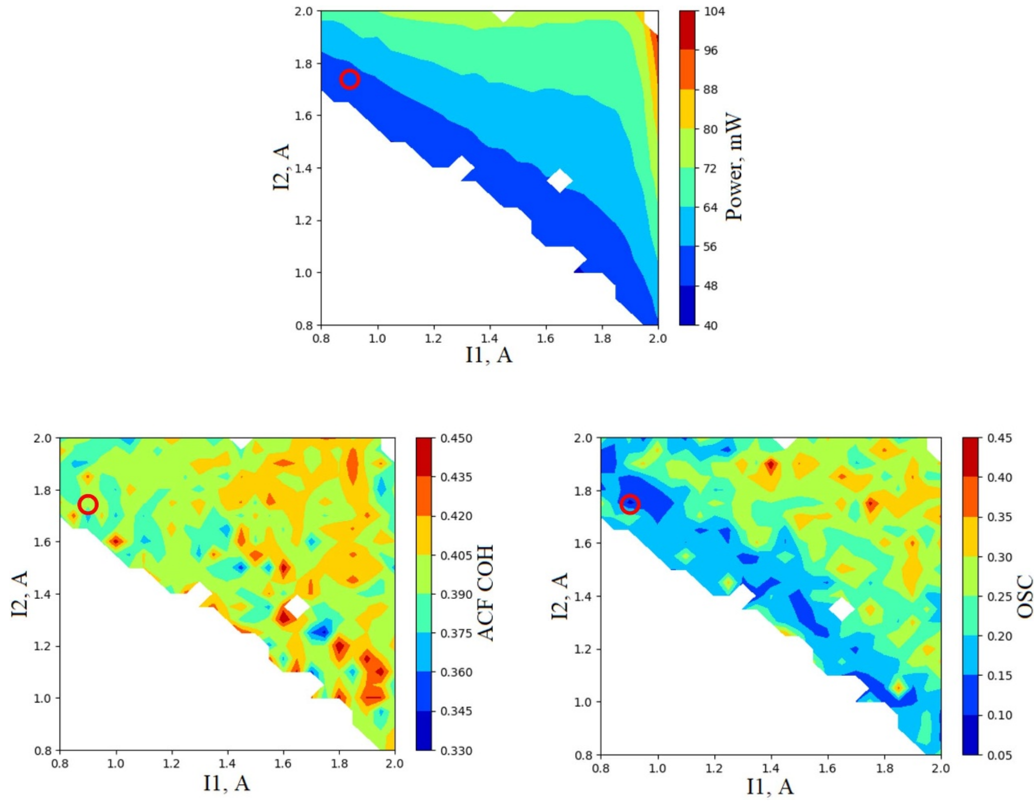

Figure 5. Generation regime maps of the studied Yb-doped mode-locked fibre laser: an empty lower left corner corresponds to generation regimes of conventional unstructured solitons and continuous-wave radiation. The red circle denotes the selected generation area.

ACF and the lowest possible fluctuations of the output power. The average output power amounting to tens of mW was considered as sufficient for a master oscillator.

It is necessary to note that at least one more range exists (I1 ~ 1.8 A, I2 ~ 1 A), which is close by selection criteria to the identified one. However, this range (lower right corner of figure 5) is characterised by fast changing parameters (which is especially true for high ACF peak amplitudes) as a function of the pumping currents. Therefore, choosing this range entails higher requirements for the stability of internal and external parameters. Moreover, in this area, fluctuations of the output are relatively large.

Noise-like pulses with radiation parameters corresponding to the selected area were guided into a Michelson interferometer. The difference in the length of the interferometer arms could be varied from zero to a value exceeding the laser pulse length in physical space (approximately > ± 25 mm).

Initially, we selected a continuous-wave generation regime and ensured stability of the output interferogram over the entire adjustment range of the interferometer arm length difference. This was done to ensure that the interferometer remains aligned as the arm length difference is changed. Then, generation regimes of noise-like pulses and conventional unstructured solitons were selected consecutively. The reduction of the interference fringe visibility at the exit from the Michelson interferometer when illuminated by these pulses is shown in figure 6.

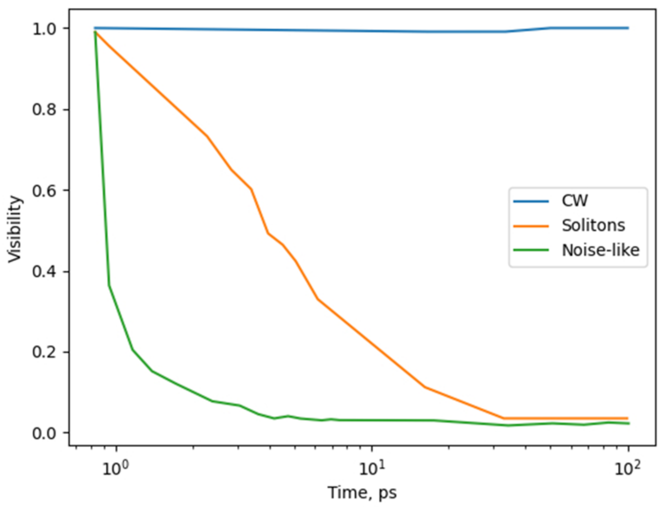

Figure 6. Decrease in the visibility of interference fringes at the output of the Michelson interferometer with an increase in the arms difference with radiation of different pulses.

3. Conclusion

The data collected from experiments confirmed that intra-pulse radiation of noise-like pulses has a low degree of coherence. The obtained results match the data [10] where the inter-pulse coherence degree of noise-like pulses was measured and also found to be low. Low degree of coherence (0.1 and below) of the inter- and intra-pulse radiation of these pulses allows the classification of noise-like pulse sources as laser sources of low-coherence radiation (the degree of coherence is relatively low and depends on the pulse parameters). Preliminary data (both experimental and theoretical) indicate that the coherence degree of the noise-like pulse radiation becomes lower at higher amplitudes of the central peak of the double-scale [3] ACF of these pulses. This will be discussed more thoroughly in a separate work. An additional mechanism lowering the degree of coherence of noise-like pulses is the significant uncompensated chirp of pulses generated in the cavity of a mode-locked fibre laser.

It should be pointed out that a very low degree of coherence is not typical of laser radiation. Therefore, a laser generator of noise-like pulses uniquely combines a low degree of radiation coherence with high directivity and the possibility of focusing its output into a small spot. A source of low-coherence radiation based on fibre laser emitting noise-like pulses may be important in a variety of applications that require the absence of speckle patterns.

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