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Direct measuring of single-cycle mid-IR light bullets path length in LiF by the laser coloration method

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Abstract. A colour-centre structure formed in a LiF crystal under filamentation of a femtosecond mid-IR laser pulse with a power slightly exceeding the critical power for self-focusing has been experimentally and theoretically investigated. A single-cycle light bullet was recorded for the first time by observation of strictly periodic oscillations for the density of the color centers induced in an isotropic LiF crystal under filamentation of a laser beam with a wavelength tuned in the range from 2600 to 3900 nm, which is due to the periodic change in the light field amplitude in the light bullet formed under filamentation under propagation in dispersive medium. The light bullet path length was not more than one millimeter.

In contrast to the well-studied phenomena of the light beam squeezing due to self-focusing and wideband ultrashort pulse compression the formation of light bullets (LBs) with a high spatiotemporal light field localization is the result of simultaneous and matched laser radiation selfcompression both in space and time in nonlinear dispersive media. The numerical simulations suggest that such compression method may potentially deliver single optical cycle pulses in the 2–4 μm spectral range. In spite of existing methods for a single-cycle pulse duration measurements such LBs have not been recorded so far. The main reason is that LB diameter is about a few wavelengths and when we measure the whole beam not only the duration of the LB but also essentially longer duration of a background surrounding the LB is measured. The sensitivity of our recording technique is not sufficient to take a proper measurement with a lesser aperture. We proposed a novel method for such measuring based on a well known (from the end of the last century) phenomenon, specific only to near-single-cycle pulses, which is very important in attosecond physics - a cyclic transformation of the light field amplitude caused by the phase shift between the carrier wave and the wave packet envelope under propagation in a dispersive medium [1]. This transformation may be recorded by the laser coloration method (LCM), based on microscopic observation of laser-induced long-lived luminescent color centers (CC), which gives a unique possibility to register the filament spatial structure with an accuracy better than one micron after exposure

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and allows to restore the light field structure taking into account multiphoton character of the CC formation [2]. LiF is a unique material for such investigations because it has significantly brighter CC luminescence intensity in comparison with other alkali halide crystals that allowed us to observe a photoinduced transformation inscribed by a single LB produced by only one mid-IR exciting pulse. The CCs are created on a picosecond timescale, so they do not influence the femtosecond pulse dynamics. Opposite to on-line experiments, which demand many pulses exposure and where, in addition, the registration of supercontinuum radiation and plasma emission is inevitable, in LCM the structure of extremely compressed wave packet is recorded via appearance of the CCs in LiF after just single pulse passed through the material, and may be investigated much later by measuring the luminescence of CCs in the weak pump field. At last in LCM only the near-axial region of the beam in the filament without surrounding background is recorded, which has the smallest duration (that is just LB). These features distinguish LCM from the most advanced methods of LB dynamics study, such as 3D imaging technique, and allow us to answer the debated question about light bullet path length. It should be noted that on the base of experiments developed in the accumulation mode by averaging over a large series of LBs, many authors interpreted the extended light channels formed by mid-IR femtosecond pulses in transparent dielectrics as long-living LBs, the scale of which does not change along several centimeters distance. These results are contradictory to our numerical and experimental investigations [3] according to which the LB path length is much shorter.

In our LCM experiments the regular variation of the mid-IR LB parameters in LiF was revealed through the periodic CCs structure formed in a LiF crystal under filamentation of a single femtosecond mid-IR laser pulse with a power slightly exceeding the critical power for self-focusing [4]. Strictly periodic oscillations have been detected for the first time for the density of the CCs induced in an isotropic LiF crystal under filamentation of a laser beam with a wavelength tuned in the range from 2600 to 3900 nm. At the wavelengths shorter than 2500 nm such oscillations have not been observed. This experiment confirmed formation of near-single cycle LB in the presence of strong anomalous group velocity dispersion which ‘breathing’ in filament is a cyclic transformation of the light field amplitude and diameter caused by the phase shift between the carrier wave and the wave packet envelope in dispersive medium in agreement with our numerical modeling [5]. Such an experiment allowed us to unambiguously answer the debated question about light bullet path length which appeared to be of not more than one millimeter.

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