Spatial and Temporal Control over Filamentation of Mid-IR Pulses in Ambient Air

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Recent advances in ultrafast laser technology made it possible to apply few-cycle intense mid-IR pulses in strong-field experiments. This spectral range is of particular interest because of the predominant role of tunnel ionization and favorable kinetic energy scaling of released electrons [1], which leads to the generation of keV-photon-energy coherent soft x-rays [2], boosts the efficiency of laser-driven incoherent hard x-ray generation [3] and opens new perspectives in relativistic acceleration of electrons under laser-plasma interaction [4]. Particular attention has been devoted to femtosecond filamentation of mid-IR pulses [5], because a quadratic increase of the critical power of self-focusing with wavelength potentially allows for a correspondingly higher energy confinement within a single filament. In addition, because the window of atmospheric transparency around 3.5 µm lies within the vibrational molecular fingerprint region (3—6 µm), femtosecond mid-IR filaments with their strongly broadened spectra might help disclosing the role of plasma in the phenomenon of femtosecond filamentation in gases.

In this contribution, we examine experimentally filamentation of few-cycle 3.9-µm pulses in atmospheric air at different focusing conditions and investigate the influence of frequency chirp of the driving pulse on the filament properties. We trace spectro-temporal evolution and spatial beam profile transformations during filamentation and inspect the ionic plasma density and content. Experiments were performed with sub-100 fs, 30-mJ pulses, spectrally extending from 3.6 µm to 4.2 µm [7]. By adjusting focusing conditions we observe a shift from a spark-like air breakdown in the case of hard focusing (at focal lengths of a focusing element less than 25 cm) to a filamentation with a negligible plasma content (at focal lengths of the focusing element more than 250 cm). In the latter case, the filamentation manifests itself by a beam symmetrization and spatial self-trapping. Filamentation of mid-IR pulses centered at 3.9 µm is extremely sensitive to the chirp which allows control over spatial and temporal foci by tuning temporal/spectral phase of the pulses. In addition, proximity to the CO₂ vibrational resonance at 4.2 µm introduces a nonlinear loss dynamics caused by linear absorption of red-shifted spectral components that are continually produced via stimulated rotational Raman scattering. We show, that the course of spectral and temporal dynamics and the amount and the origin of the losses during filamentation can be controlled by focusing conditions, which determines amount of plasma in the filament, as well as by chirping of mid-IR pulses.

Fig.1. (a) dependence of filamentation losses on focusing conditions; regions I, II and III correspond to hard, moderate and loose focusing respectively, in the sections I and II photographs of plasma luminescence are presented; in the section III absorption spectrum of CO₂ in the vicinity of 4.2 µm is given; (b) dependence of the pulse duration after filamentation on input pulse duration; typical frequency resolved optical gating traces of temporally split, and self-compressed pulses are shown; (c) dependence of beam ellipticity on input pulse duration together with the typical beam profiles.

References