Generation of stationary on-axis optical filaments by means of Dammann lenses

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Abstract: Dynamical spatial shaping of a 30 fs laser beam by encoding Dammann lenses in a spatial light modulator allows us the formation up to six on-axis stable and stationary filaments in a fused silica sample.

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1. Introduction

The generation of filaments with ultrashort laser pulses is based on the sustained balance between self-focusing (Kerr effect) and ionization. When the peak power of the laser pulse is close to a critical self-focusing power value (P_{cr}) a single filament develops. If the beam power exceeds about more than 10 times P_{cr}, modulation instability can cause several co-propagating filaments formed from a single laser beam spontaneously, thus entering into the multiple filaments (MFs) regime. To avoid the random space–time localization of MFs, the initial beam is modified by methods that include, among others, changes in its ellipticity or wavefront shaping. However, although the generation of controlled off-axis MFs has been extensively studied, less attention has been paid to the generation of sequential on-axis MFs. This is the key point of this work.

Dammann diffraction gratings are binary phase distributions of alternative 0, π zones for well-defined transient points [1]. These gratings generate far-field diffraction patterns characterized by a number N of diffraction orders all having the same intensity. This concept can be easily extended to lenses, thus obtaining N on-axis focal spots of the same intensity when we used a CW source as illumination.

For ultrafast optics, diffractive optic elements (DOEs) play a significant role in tailoring non-linear processes, since they allow us to modify the spatiotemporal structure of the pulse. In particular, DOEs encoded into spatial light modulators (SLMs) can be changed dynamically with a refresh rate of 60 Hz or above. In this context, Dammann lenses encoded into a SLM, working together with a refractive lens, allow us to generate equal peak intensity foci separated by a controllable distance [2]. We take advance of multifocal irradiance due to Dammann lenses to induce, in a controllable manner, on-axis MFs within a fused silica sample [3].

2. Results and discussion

First of all we analyze the influence of broadband light spectra on the irradiance given by Dammann lenses under ultrashort pulsed illumination. As an example, we show here the on-axis irradiance obtained with a Dammann lens of 4 equal foci separated by 1.92 mm. As it can be seen in the top part of Fig. 1, the simulation was carried out for two different Fourier transform limited Gaussian laser pulses, and an ideal CW source.

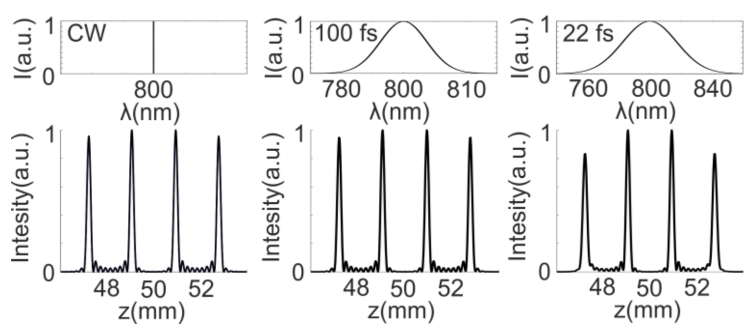

Fig. 1 Simulated irrandiance pattern obtained with a Dammann lens which is illuminated with (a) monochromatic beam, (b) 100 fs laser pulse, and (c) 22 fs laser pulse.

The theoretical irradiance uniformity in the case of the CW source is approximately 10^{-5}. However, small discrepancies in the height of the peaks are caused mainly due to deviations of the 0-π transition locations from their ideal values when encoding Dammann lenses into a SLM due to the pixilated nature of SLMs. For an ultrashort laser pulse of 100 fs falls of 0.2% and 1.4% (for n=±1 and n=±3 orders, respectively) were registered. The equivalent values for 22 fs pulses were 5% and 16%. Therefore, chromatic aberrations will increase the spatial width and decrease the peak irradiance of the foci, reducing the uniformity of the generated irradiance patterns.

In Fig. 2 our experimental results are shown. A fused silica sample (20x10x5 mm^3, all faces polished) was placed along the multifocal axial distribution. The number and separation of the focal spots can be controlled through the parameters of the Dammann lenses. The plasma emission of the filaments was registered in a CCD from one of the sides of the sample. In Fig. 2a six foci having a distance of 0.85 mm among them, are generated. Fig. 2b and 2c correspond to four equal foci with spatial period of 0.4 mm and 2.1 mm, respectively. At the bottom of Fig. 1 both the binary phase masks and the central irradiance profile of the filaments are included as insets. As it can be seen in Fig. 2, the shape and peak intensity of the filaments slowly change with the sample depth. This might be expected from the spherical aberration induced by the refraction at the air-glass interface.

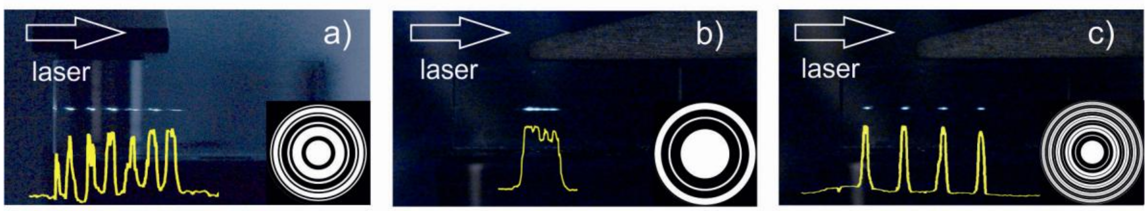

Fig. 2 Experimental on-axis plasma filaments generated in a fused silica glass by means of programmable Dammann lenses. The laser beam propagates from right to left.

3. Conclusions

In summary, by using a phase-only SLM programmable, on-axis multiple MFs have been generated in a fused silica glass with femtosecond laser pulses. By changing the Dammann lenses parameters we demonstrated a complete control over the position, width and peak intensity of the MFs. Several applications are expected to benefit from these results, such as in-depth parallel processing of transparent dielectrics or the creation of long filaments by the concatenation of shorter ones.

4. References

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