Studies on UV Filaments in Air

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Abstract: UV filaments in air have been examined on the basis of the diameter and length of the filament, the generation of new spectral components, and the ionization by multiphoton processes.

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There have been numerous observations of filaments at 800 nm [1, 2, 3]. The general perception is that, above a critical power, the beam focuses because nonlinear self-lensing overcomes diffraction. The self-focusing proceeds until an opposing higher order nonlinearity forms a stable balance.

Fig. 1. (right) Diameter of filaments burnt in photographic films, as a function of a distance from the final optics of the beam reducer. (left) Image of the plasma produced by the filament, as recorded by a CCD camera.

To explore UV filaments, we use a Ti:Sapphire/excimer system capable of 50 mJ in 1.1 ps at 248 nm. For a 5 mm diameter collimated beam, hot spots appear in the beam after propagating a short distance. These can make small craters in film as reported previously [5]. The crater diameter (Fig. 1 (right)) remains around 120±20 μm over a distance of 12 m. By comparison, the Rayleigh range for a waist w₀ = 200 μm would be z₀ = πw₀²/λ = 50 cm. To better estimate the filament size, the beam is made to impinge on a steel plate to create a plasma plume. The recorded image of this plasma has a diameter of 105±5 μm FWHM (Fig. 1 (left)). Isolated in a single filament via a 500 μm hole, the filament energy measures 200 μJ.

One manifestation of near-IR filaments is the visible conical emission [2]. For deep-UV filaments, such emission is not obvious. With the beam aperture to a single filament, a UV spectrometer scan (Fig. 2), indicates that, for the measured 4 orders of dynamic range, there is no significant generation of new wavelengths from 190 nm to 300 nm.

The filament electron density can be estimated considering the volume ionized due to its pulse energy. We make the assumption of a trapped 200 μJ pulse decaying in 10 meter. If the 248 nm (5 eV) filamentation process is out of balance when the intensity has dropped by 10%. We find that the energy consumed by a 3-photon ionization of O₂ yields 9.8 × 10¹³ e⁻. For a filament volume of 5 × 10⁻² cm³, this is an electron density of 1.6 × 10¹⁴ e⁻/cm³, which agrees with the Ne = 5×10¹⁴ e⁻/cm³ needed to balance with self-focusing at a filament intensity of 2 × 10¹² W/cm² and also with independent measurements of the ionization cross-section 6.6 × 10⁻³² cm²e²/J². These measurements combined with the absence of conical emission support the interpretation of a timely trapped light pulse with ionization as a balancing mechanism. The ionization of 5 × 10¹⁴ e⁻/cm³ by the UV filament is used as a reference to determine the ionization by the IR filament,
Fig. 2. Comparison of the spectrum of the unfilamented beam (dots) with the spectrum of the filament (squares).

Fig. 3. Setup to measure the conductivity induced by the filaments (right). Typical measurement with a UV filament (left).

using the conductivity setup sketched in Fig. 3. An IR filament of 200 fs and 2 mJ can only generate a signal of less than 10 mV, while a single UV filament of 1.1 ps and 0.2 mJ generates a signal of 200 mV. Comparing the ionization of 800 nm with 248 nm filaments yields $8 \times 10^{12}$ e$^-$/$\text{cm}^3$ for the IR case, a number in agreement with measured values [4]. Since an electron density of $10^{16}$ e$^-$/cm$^3$ [2] is needed to balance plasma defocusing with self-focusing, this lower density in the 800 nm filaments eliminates ionization as their only stabilization mechanism.

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References
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