Multiphoton air ionization under filamentation of subpicosecond UV laser pulses

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A self-focusing of powerful ultrashort pulses (USP) of laser radiation produces weakly ionized channels with a typical length of hundreds meters, which are of interest for guiding of high-voltage extended discharges and active lightning protection [1], as well as for a directed microwave radiation transfer in plasma waveguides [2] and atmospheric laser pumping for lidar applications [3]. Refraction of laser radiation in plasma filaments balances Kerr self-focusing of the laser beam [4], thus allowing it’s a “diffraction-free” long-distance propagation.

The present paper continues our previous investigation of the filamentation effect at the Ti:Sapphire/KrF laser system GARPUN-MTW [1]. At the UV radiation wavelength 248 nm (quanta energy ~5 eV) and long pulse duration of *τ*~ 20 ns, electron density in air plasma quadratically depended of on laser intensity , which is typical for resonance-enhanced multiphoton ionization 2 + 1 (REMPI) of oxygen molecules (ionization potential *Ui*= 12.06 eV), which goes through a resonant 2-photon excitation of an intermediate metastable Rydberg molecular state. For a 100-fs UV USP a cubic dependence was observed, being typical for a direct 3-photon ionization. At the same time the REMPI theory in a coherent limit predicts a similar dependence but on a cumulative energy density of the USP [1]. In the present studies it is shown that for the USP of fs duration a direct 3-photon ionization of the oxygen takes place. When the USP with a peak power up to *P*~ 1 GW, which exceeds a critical power for filamentation (*Pcr* ~ 0.1 GW), was focused in the intensity range *I*  = 5·1011 ÷ 2·1013 W/сm2, a transition to the nonlinear propagation regime was observed and a single filament was formed. The highest electron density in filaments was measured to be   
**cm–3, and it corresponded to a cross section of the direct 3-photon ionization  cm6·s–1·W–3. Other authors have reported earlier cross section values varying by three orders of magnitude. The USPs with a peak power up to *P*~ 0.2 ТW (*P* ≈ 2000·*Pcr*) and duration of *τ ~*1 ps in a free propagation along an extended distance (~100 m) formed a few hundreds filaments with the intensity of *I* ≈ 2·1011 W/сm2 in the each filament. An electron density in filaments of  cm–3 was managed by the 2 + 1 REMPI of oxygen. For long UV pulses with *τ*~ 20 ns a spectral dependence of REMPI was measured in the tuning range of a narrow-band KrF laser of ~ 1 nm for the first time.

This work was supported by the RFBR grants Nos. 15-02-09410 and 14-22-02021.

References

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