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Third harmonics emission with nanosecond and femtosecond lasers in air. Gamma radiation effects on optical fibers

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ABSTRACT

Harmonics generation in plasma by high-power pulsed lasers is an important task for plasma diagnosis. This is because of the strong relationship between the plasma characteristics and the properties of the harmonics radiation. Here we focus on third harmonic generation (THG) process in air breakdown plasma, analyzing the spatial and temporal properties of third harmonic (TH) radiation generated by focusing ns and fs laser pulses in air at intensities of the order of tens of TW/cm^2. We find theoretically and experimentally that the intensity of TH radiation increases linearly with third power of the pump peak intensity, both for ns and fs laser pulses. The theoretical results on the dependence of the TH signal to the driving peak intensity are supported by experimental data.

We further analyze the influence of the gamma radiation on the several commercially optical fibers that are usually employed in the laser-target interaction area. We investigated the change of optical transmission induced by gamma-ray radiation.

The results are important from both fundamental and practical points of view, providing an efficient tool for prediction of the non-linear optical phenomena in laser produced plasmas and for non-contact diagnosis of the harmonics-generating plasmas.

1. THG experiment: ns laser pulses at 1064 nm wavelength were focused in air by a 3 cm focal-length lens, giving beam radius in focus 3.4m and a peak intensity I_o in the range of 5 to 50 TW/cm^2. These intensities are above air breakdown threshold of 5 TW/cm^2. The radiation emerging from the breakdown plasma was spectrally analyzed in the axial direction with a fiber-coupled spectrometer (collecting fiber-tip being set 8 cm away from the lens focus). Typical spectral signal in the 300-400 nm wavelength range is presented in Fig. 1.

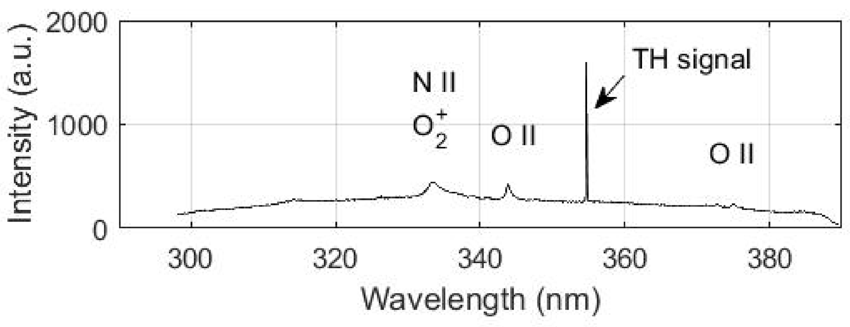

Fig. 1. Spectrum of the radiation emerging in axial direction from the focal volume (TH line is indicated)

2. THG simulations: ns laser pulses with Gaussian intensity profile focused into air which is considered a NL medium generating TH due to the nitrogen molecular ions in the breakdown plasma. We used Newton method implemented in COMSOL software to solve numerically the coupled NL wave equations in the "frequency domain". The rear boundary of the domain is set to "scattering boundary", i.e. non-reflecting boundary. The lateral boundaries are set to "perfect magnetic conductor".

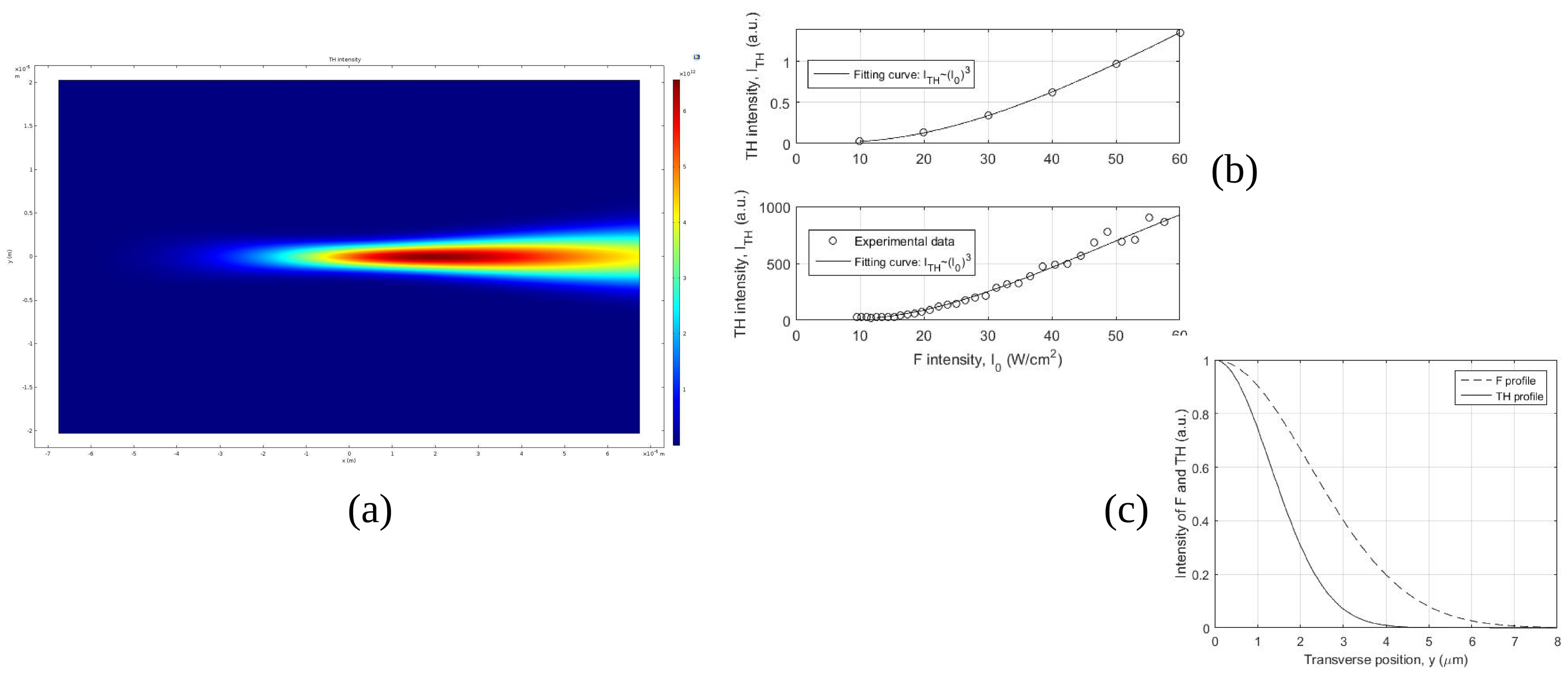

Fig. 2 (a) TH intensity- simulation. **(b)** Numerical (top) and experimental (bottom) results on TH intensity vs pump intensity. **(c)** transverse intensity profiles for TH and pump beams

The time dependent NL wave equation was solved numerically for fs laser pulse, by employing the "time domain" in COMSOL. Typical result 10 fs laser pulse is presented in Fig. 3.

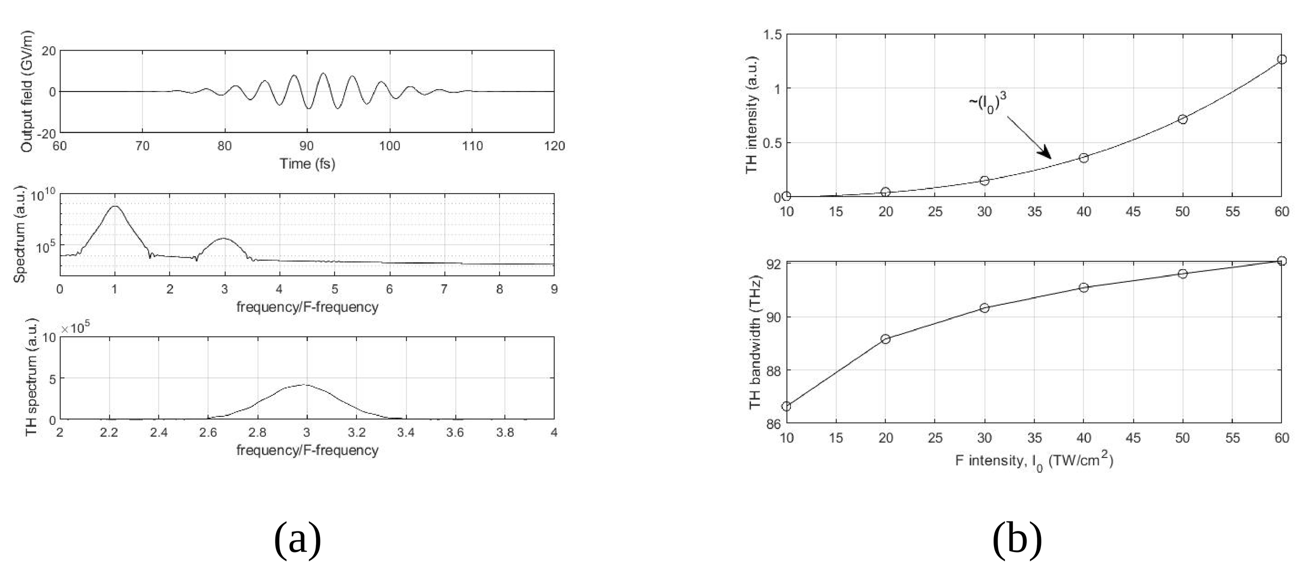

Fig. 3 (a) Numerical results on time dependence of the laser electric field at the output boundary (top), the corresponding spectrum calculated Fourier transform (middle) and spectrum of TH enabling calculation of TH intensity and width (bottom). **(b)** TH intensity (top) and spectral width (bottom) vs pump intensity.

3. Gamma experiments on fibers: we studied the gamma radiation-induced effects on transmission spectrum through ultra-high vacuum and high temperature multimode optical fibers. Two optical fibers with same characteristics were irradiated (at a dose of 8kGy and 16kGy) at 31^{o}C temperature, with a ^{60}Co gamma source. Figs. 4 present the gamma radiation-induced effects on optical fiber transmission spectrum in the 250-700 nm spectral range. The transmitted spectra of the optical fiber have the same shape in the three cases presented here, but the spectrum intensity decreases in case of the irradiated fibers as compared to the non-irradiated fiber.

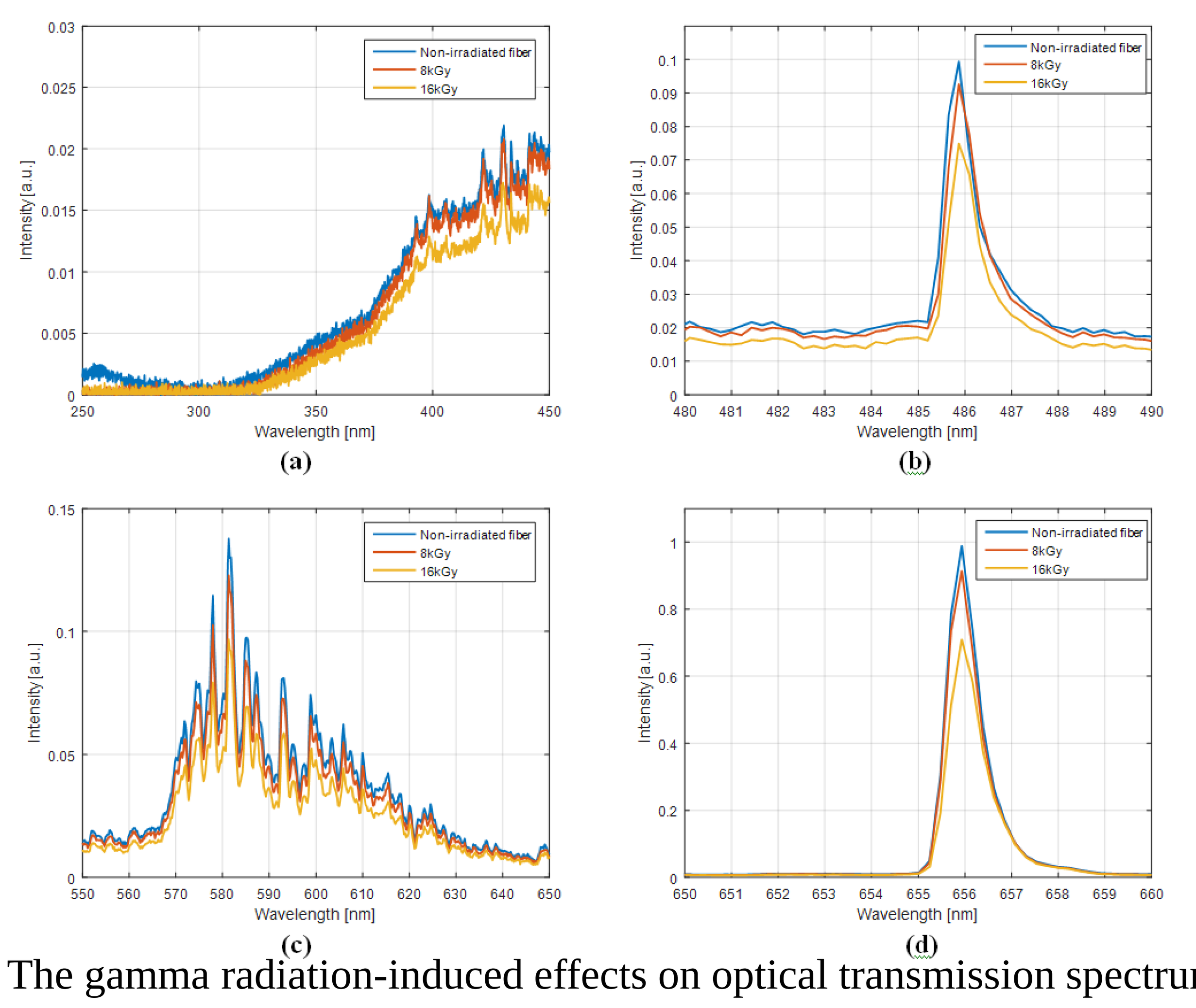

Fig. 4. The gamma radiation-induced effects on optical transmission spectrum in different spectral domains.

CONCLUSIONS

The numerical simulations presented here concern the spatial and temporal properties of TH radiation generated in air breakdown plasma by ns and fs laser pulses at intensities of the order of tens of TW/cm^2. We analyzed the intensity of TH signal at the output boundary of the NL medium, demonstrating that TH intensity increases linearly with third power of the pump peak intensity, both for ns and fs laser pulses. In case of fs pulses, we demonstrated that TH spectral bandwidth increases with pump intensity, indicating the decrease of the TH pulse duration, in correlation to the plasma properties. In case of ns laser pulses, we demonstrate that the TH beam diameter is two times smaller than the fundamental's. The theoretical results are supported by experimental data.

We also analyzed the gamma radiation-induced effects on ultra-high vacuum and high temperature multimode optical fibers. We investigated the transmitted spectra of the fibers at two different gamma doses: 8 kGy and 16 kGy. We found that the increase of gamma-ray dose leads decrease of the optical transmission of the fibers.

Acknowledgments

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