RAPORT ŞTIINŢIFIC INTERMEDIAR ETAPA DE EXECUTIE NR. 3 CU TITLUL

Experimental study on properties of harmonics and their influence on characteristics of comercial optical fibres used near the target

Year: 2022

Months: 01.01.2022 – 31.12.2022

Project Title: Plasma harmonics for diagnosing plasma and driving laser

Project Work Plan

Stage: III. Experimental study on properties of harmonics and their influence on characteristics of comercial optical fibres used near the target

Activities:

III. 1. Experimental study on properties of harmonics in relation to properties of driving laser in focus for laser diagnosis

III. 2. Determination of main characteristics of optical fibres used near the target when exposed to UV, X and gamma radiation

III.3. Project management and disemination of results

1. Cover Page

- Group list (physicists, staff, postdocs, students);

Director of project: Assoc. Prof. (Conf.) Dr. Mihai Stafe

Team members: Prof. Dr. Niculae N. Pușcaș, Lect (Ș.l.) Dr. Georgiana Vasile, Lect. (Ș.l.) Dr. Constantin Neguțu

PhD students: Alexandru Enciu, Alexandru-Ferencz Filip, Răzvan Mihalcea

Staff: Ec. Ana-Maria Nicoleta Dragomir

- Specific scientific focus of group (state physics of subfield of focus and group's role)

The scientific focus of the group was related to: 1. experimental study on properties of third harmonic radiation (i.e. intensity, beam divergence, polarization) in relation to properties of driving laser in focus (i.e. intensity, polarization). Run numerical simulations using the theoretical models and programs developed in previous phases of the project in order to predict the experimental results. Main work from M. Stafe, N.N. Puscas, G. Vasile, and C. Negutu. 2. experimental determination of main characteristics of optical fibers used near the target when exposed to gamma radiation at different doses. Main work from G. Vasile, R. Mihalcea, N.N. Puscas, C. Negutu, and M. Stafe.

- Summary of accomplishments during the reporting period.

In Phase 3 we realized the following objectives:
- realized the experimental setup for nanosecond and femtosecond laser irradiation of gas and solid target for production on plasma and third harmonic radiation.
- analyzed experimentally the influence of the driving laser intensity and polarization on the properties of the third harmonic radiation generated by focusing ns laser pulses in air. The optical transmission and radiation-induced attenuation (RIA) of optical fibers was measured before and after gamma-rays irradiation.
- published one Q3 paper (P1) on optimum conditions for third harmonic generation in an ISI journal: Mihai STAFE, Constantin NEGUȚU, Georgiana C. VASILE, and Niculae N. PUȘCAȘ, "Theoretical and experimental study on geometry related phase-matching condition for third harmonic generation", U.P.B. Sci. Bull., Series A, Vol. 84, Iss. 2, 163-174 (2022).
- published one Q1 paper (P2) on the effect of laser pressure on acceleration of solid targets: A. Marcu, M. Stafe, M. Barbuta, R. Ungureanu, M. Serbanescu, B. Calin, and N. Puscas, "Photon energy transfer on titanium targets for laser thrusters", High Power Laser Science and Engineering, Vol. 10, e27 (2022)
- presented one poster (OMN200-69) at international conference ATOM-N 2022 (C1). Poster and proceedings paper title: "Third harmonics emission with nanosecond and femtosecond lasers in air. Gamma radiation effects on optical fibers", by Mihai Stafe, Georgiana C. Vasile, Răzvan Mihalcea, Constantin Daniel Neguț, Constantin Neguțu, Niculae N. Pușcaș. The paper was accepted for publication in Proceedings of SPIE, quoted ISI.
- presented one poster (P-18) at international conference ECLIM 2022 (C2): "Picosecond laser plasma impulse transfer", by M. Barbuta, A.Marcu, M.Stafe, R.Ungureanu, M. Serbanescu and N. Puscas.

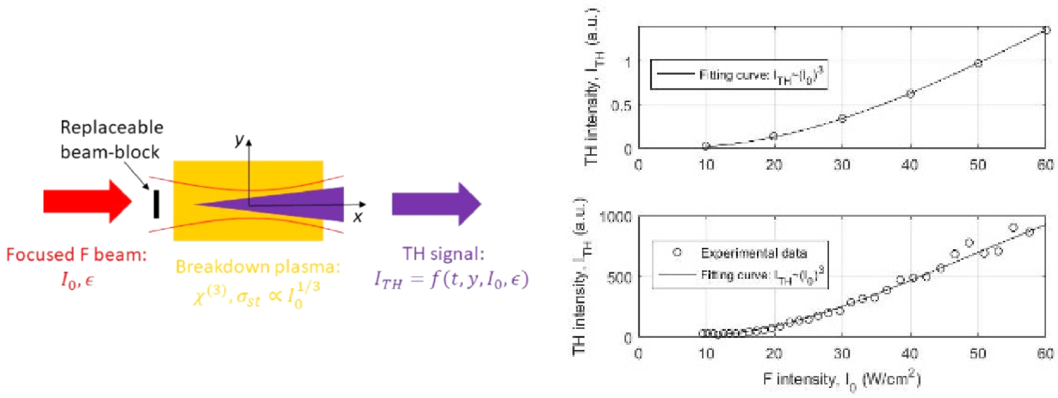
2. Scientific accomplishments – Results obtained during the reporting period.

Activity III. 1. Experimental study on properties of harmonics in relation to properties of driving laser in focus for laser diagnosis.

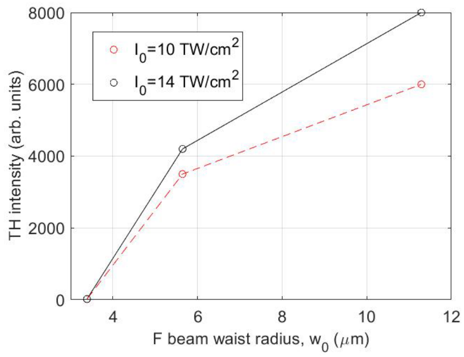
Experiments on generation and characterization of TH radiation were carried out by using: 1) a "Quantel/ Brilliant" Q-switched Nd-YAG laser delivering linearly polarized infrared radiation at 1064 nm wavelength, 4.5 ns pulse duration at 10 Hz repetition rate, 300 mJ maximum energy, and 6 mm beam diameter of the Gaussian intensity profile; 2) a "Light Conversion/ Pharos" Yb based CPA mode-locked femtosecond laser with 200 fs laser pulses at 5 kHz repetition rate, 1030 nm wavelength, 1 mJ maximum energy, and 2 mm beam diameter of the Gaussian intensity profile. Laser pulses were focused on open air with a 3, 5 and 10 cm focal lens, giving beam waists of ~3.5, 5.5 and 11 μm in focus and peak intensities I_0 in the range of 100 TW/cm^2. These intensities are above air breakdown threshold, in accordance to previously reported threshold power $P_{bt} = 1$ MW.

The harmonics radiation emerging from the breakdown plasma was analyzed in the axial direction with a fiber-coupled spectrometer (Ocean Optics HR2000+, 0.1 nm spectral resolution) triggered by the Q-switch signal of the laser system. The collecting fiber-tip was set in axial position ~ 8 cm away from the lens focus. Fig. 1(a) presents the scheme of the experimental setup for generation and characterization of the third harmonic in air with ns and fs laser pulses. The dependence of TH radiation on F intensity for the ns laser is given in Fig. 1(b). The top plot in Fig 1(b) presents our numerical simulations conducted within the model and program developed in the previous phases of this project (results were presented at C1); one note the good agreement between the experiment and simulations.

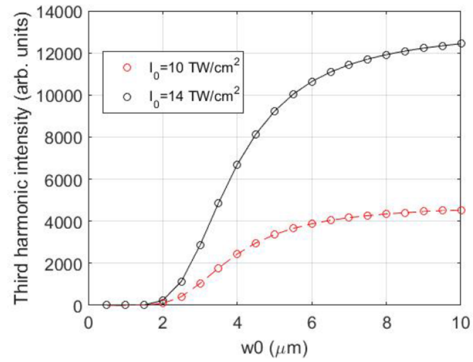
The experimental results on the influence of beam waist radius in focus on the third harmonic intensity is presented in Fig. 1(c). The data were obtained for two different peak intensities. The experiments and the theoretical data presented in Fig. 1(d) demonstrate that at larger beam waists the efficiency of third harmonic generation saturates (results were presented in P1).



(a) (b)



(c)



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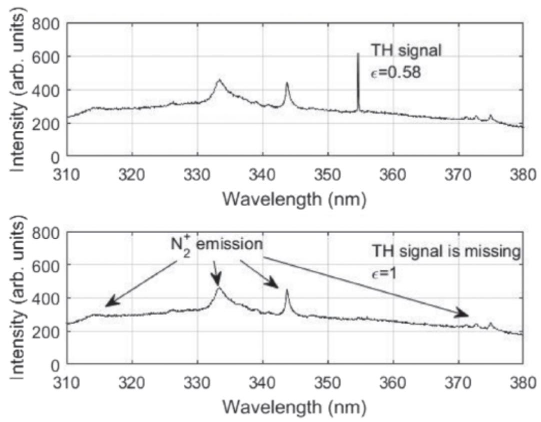
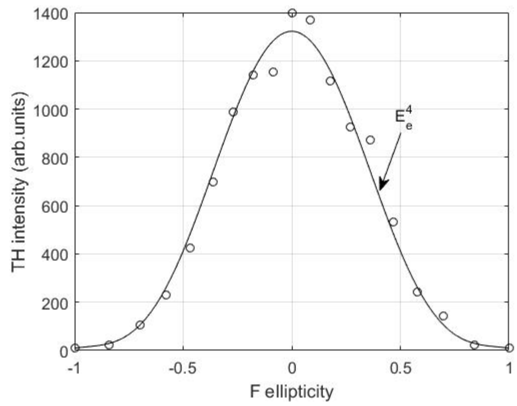
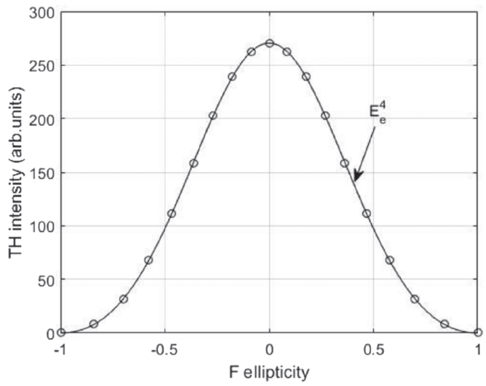


(e)



(f)



(g)

Fig. 1. (a) Experimental setup for third harmonic (TH) generation in air. (b) TH signal vs. F intensity. (c) TH signal vs beam waist- experimental data. (d) TH signal vs beam waist- numerical data. (e) typical spectrum obtained for two ellipticities of the fundamental driving laser. (f) TH signal vs. F ellipticity- experimental data. (g) TH signal vs. F ellipticity- numerical data.

The influence of F polarization on the efficiency of THG was investigated by rotating a quarter waveplate in the range -45 to 45 degrees, with 5 degrees increment, to change the polarization state from circular to linear and back to circular. During plate rotation, the ellipticity ϵ was varied between -1 and 1, where $\epsilon = \pm 1$ correspond to circular polarization and $\epsilon = 0$ to linear polarization. Fig. 1(e) presents the recorded radiation spectrum for two different ellipticities, noting the lack of third harmonic signal for circular polarization.

Experimental data regarding the dependence of TH intensity on the ellipticity of the fundamental driving laser is presented in Fig 1(f), noting that the circular radiation inhibited the TH emission. The experimental data are in good agreement with the numerical results presented in Fig. 1(g).

Activity III. 2. Determination of main characteristics of optical fibres used near the target when exposed to UV, X and gamma radiation.

We analyzed the influence of the gamma radiation on the several commercially optical fibers that are usually employed in the laser-target interaction area. The radiation effects such as photo-darkening induced in optical fibers can severely decrease the performance of optical transmission. We investigated the change of optical transmission induced by gamma-ray radiation and the gamma radiation-induced attenuation (RIA). Multimode optical fibers, with a core diameter of 200µm (usable in UV, ultra-high-vacuum and high temperatures conditions), were investigated in order to evaluate their possible use for diagnosis of plasmas produced by high power lasers. All optical fibers studied were identical, with same characteristics. In this experiment, optical spectra, measured at the optical fiber output, were recorded over a wavelength range of 250-700 nm. Integration time of the spectral data was 143 µs.

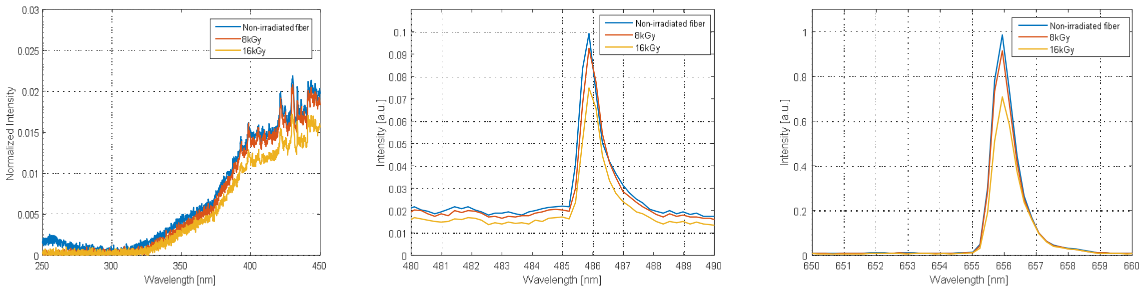


Fig. 2. The gamma radiation-induced effects on optical transmission spectrum in the 250-450 nm, 480-490 nm and 650-660 nm spectral band for a non-irradiated multimode optical fiber, an optical fiber irradiated by gamma-ray at 8 kGy and for an optical fiber exposed to gamma-ray irradiation at 16 kGy.

Two optical fibers with same characteristics were irradiated at 31^{o}C temperature, with a ^{60}Co gamma source. One fiber was irradiated with a dose of 8 kGy and the second optical fiber was exposed at a dose of 16 kGy. Fig. 2 present the gamma radiation-induced effects on optical fiber transmission spectrum. For better visibility we divided the spectral range into several spectral bands: 200-450 nm, 480-490 nm, 650-660 nm. As can be seen in Fig. 2, the intensity decreases with the increase of the dose radiation. From the results presented in Fig. 2 one can see that, if gamma radiation is present, the degradation of the optical fibers occurs. In our case, the degradation manifests as photo-darkening, i.e. the decrease of the transmitted spectral intensity due to gamma irradiation. 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. Thus, the spectral intensity at 485.9 nm wavelength decreases by approximately 5% for the optical fiber irradiated at a dose of 8kGy, and by approximately 25% for the optical fiber exposed at a dose of 16kGy.

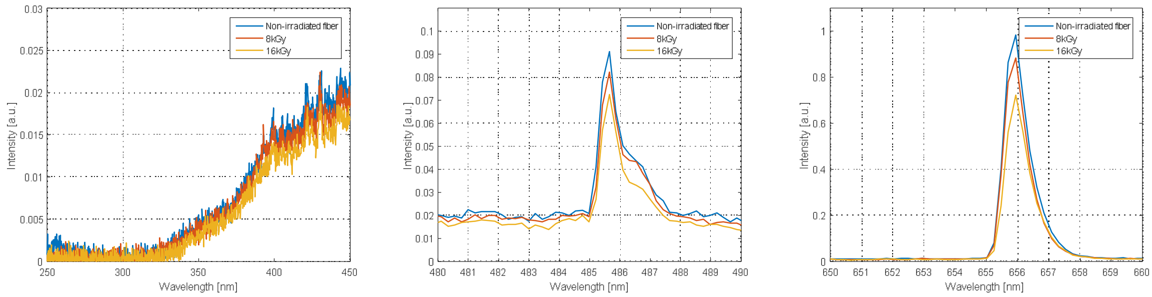


Fig. 3. The gamma radiation-induced effects on optical transmission spectrum.

The optical fiber transmission spectrum was measured three months after irradiation. From Figs. 3 we can observed that after irradiation the optical fiber characteristics isn't recovery.

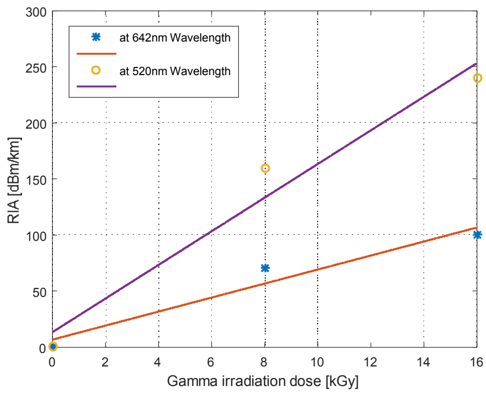


Fig. 4. The gamma radiation-induced effects on output power.

The change in optical transmission of the optical fiber at 520nm and 642nm wavelength with report to the gamma radiation dose was measured. The gamma radiation-induced attenuation (RIA) was calculated by equation: $RIA\left(\frac{dBm}{km}\right)=\frac{P_1(dBm)-P_2(dBm)}{L(km)}$, where P_1 is the optical transmission power before the gamma irradiation, P_2 is the optical transmission power after the gamma irradiation, and L represente the exposed optical fiber length. The RIA at 520nm and 642nm wavelength is presented in Fig. 4. The radiation-induced power loss increases with the doses of gamma radiation compared to the non-irradiated fiber.

3. Deliverables in the last year related to the project:

- List of papers (journal or conference proceeding):

3.1. Mihai Stafe, Constantin Negutu, Georgiana Vasile, Niculae N. Puscas, ”Theoretical and Experimental Study on the Geometry Related Phase-Matching Condition for Third Harmonic Generation”, Scientific Bulletin, Series A: Applied Mathematics and Physics, ISSN 1223-7027, Vol. 84, Iss. 2 , 163-174 (2022) (Q3 paper).

3.2. A. Marcu, M. Stafe, M. Barbuta, R. Ungureanu, M. Serbanescu, B. Calin, and N. Puscas, “Photon energy transfer on titanium targets for laser thrusters”, High Power Laser Science and Engineering, Vol. 10, e27 (2022) (Q1 paper)

3.3. Mihai Stafe, Georgiana C. Vasile, Răzvan Mihalcea, Constantin Daniel Neguț, Constantin Neguțu, Niculae N. Pușcaș, “Third harmonics emission with nanosecond and femtosecond lasers in air. Gamma radiation effects on optical fibers”, accepted for publication in Proceedings of SPIE of International Conference ATOM-N2022 (25 – 28 august 2022, Constanta, Romania) (ISI paper).

- List of conference presentations:

3.4. poster presentation (OMN200-69) at international conference ATOM-N 2022, “Third harmonics emission with nanosecond and femtosecond lasers in air. Gamma radiation effects on optical fibers”, by Mihai Stafe, Georgiana C. Vasile, Răzvan Mihalcea, Constantin Daniel Neguț, Constantin Neguțu, Niculae N. Pușcaș.

3.5. poster presentation (P-18) at international conference ECLIM 2022, "Picosecond laser plasma impulse transfer", by M. Barbuta, A. Marcu, M.Stafe, R.Ungureanu, M. Serbanescu and N.N. Puscas.

- Other deliverables (patents, books etc.):

resume of the project for “Noaptea cercetatorilor” fair, middle report and presentation, phase report.

4. Further group activities:

- Collaborations, education, outreach.

M. Stafe, N. N. Pușcaș,and C. Negutu collaborate with INFLPR for studying theoretically and experimentally the target and particle acceleration by ultrashort high intensity laser pulses. They published the results in 2022 in “High Power Laser Science and Engineering”, Vol. 10, e27.

Mihai Stafe, Niculae N. Pușcaș, Georgiana Vasile and Constantin Negutu collaborated in 2020-2022 with INOE for the research project FOMAN. University POLITEHNICA of Bucharest was a partner in the project.

The knowledge acquired during this project is used for teaching two courses in the IALA master program at University "Politehnica" of Bucharest: "Laser and Optics" given by Prof. Dr. Niculae N. Puscas, and "High Power Lasers Engineering and applications" given by Conf. Dr. Mihai Stafe.

5. Research plan and goals for the next year

Stage IV. Spectroscopic analysis of the laser produced plasma in relation to the generated harmonics properties for plasma diagnosis.

Activity IV.1. Spectroscopic study on the properties of the generating plasmas as a function of laser properties.

Optical spectroscopy measurements of the gas and solid plasmas will be carried in order to determine the plasma properties (density and temperature) as a function of driving laser parameters (intensity, polarization, duration). The spectroscopic data will be analyzed in connection to the harmonic emission (intensity, polarization, duration, divergence) in order to determine the relation between the harmonic radiation properties and plasma properties. Phase-matching condition in laser produced plasma will be analyzed in order to determine the magnitude of different factors (e.g. type of atoms, ionization degree, propagation distance, focusing type: tight or loose focusing, front or back focusing) influencing the phase of different wavelengths propagating in the plasma.

Activity IV.2. Experimental study on properties of harmonics in relation to properties of generating plasma for plasma diagnosis.

Experiments will be carried in order to evaluate space distribution of the plasma properties: femtosecond laser pulses will be focused in different positions in the laser produced plasmas to generate the harmonics. The properties of the harmonic radiation will get information on the laser plasma at different positions within the plasma plume.

Activity IV.3. Project management and disemination of results.

We propose to present the results in 2 reports and 1-2 ISI papers, and apply for a national patent for the real-time method of diagnosing the plasma through the generated harmonics.