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LASER SPECTROSCOPY OF LOW-TEMPERATURE PLASMA WITH ULTRA-HIGH SPECTRAL RESOLUTION AND SENSITIVITY USING FABRY - PÉROT INTERFEROMETER AND OPTICAL PARAMETRIC AMPLIFIER

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Abstract

Laser scattering spectroscopy has been commonly used for low-temperature plasma diagnostics. This method has been developed for many years in the laboratory of plasma diagnostics of Jagiellonian University in Kraków. We present a new method for measuring laser light scattering spectra in plasma, which is simultaneously characterized by ultra-high spectral resolving power and sensitivity. The spectral resolution obtained by this method is so high that it allows the measurement of the shape of the central, the so-called ion, part of the Thomson scattering spectrum. At the same time, achieved sensitivity allows us to reduce the energy of the probe laser beam so as not to disturb the studied plasma.

1 Plasma diagnostics using laser scattering

Laser light scattering of Raman, Rayleigh, Thomson, or Mie type is a routine method to study the laser – matter interaction and the properties of the scattering medium – its composition as well as internal and external degrees of freedom of its constituents. This information is contained in both intensity and frequency change, i.e. in the spectrum of scattered light. However, usually the cross-sections for the respective light scattering processes are very small resulting in low values of the signal to noise ratio (S/N). Low S/N are also found where a high spectral resolving power is required for a reliable analysis of the recorded light scattering spectra. In such cases, sufficiently large S/N is achieved by using high-intensity laser beams, which unfortunately can result in significant perturbation

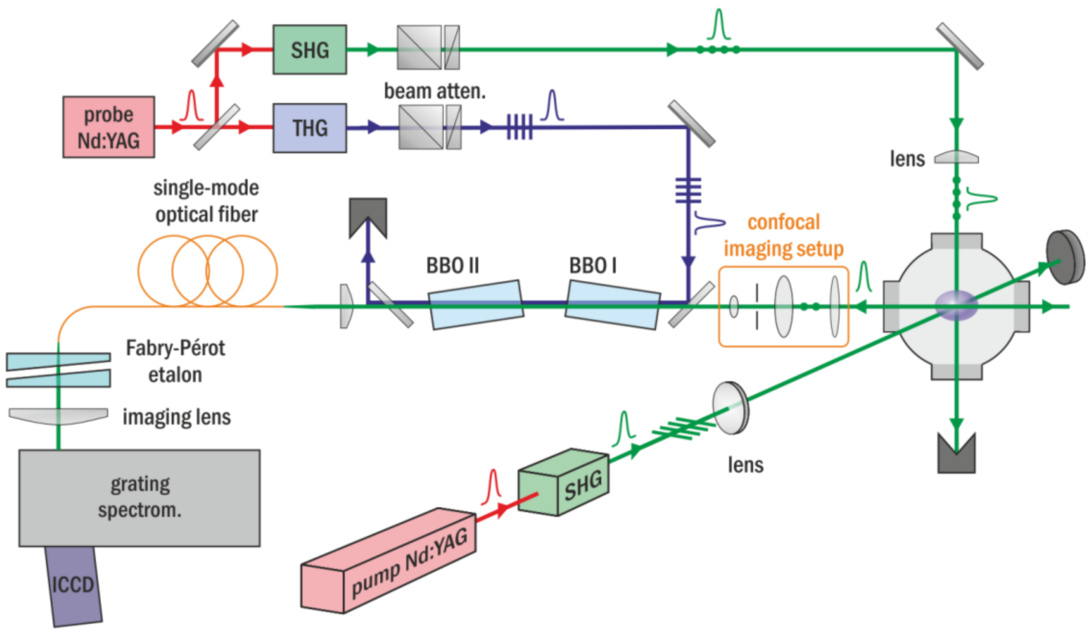

Figure 1 *The experimental setup for ultra-high resolving power and sensitivity measurements of the Thomson and Rayleigh scattering spectrum. The pump Nd:YAG laser with the second harmonic generator is used to produce a plasma plume in a chamber filled with a gas. The second harmonic of the probe laser is scattered on the plasma and the third harmonic of the probe laser is used as a pump beam for a optical parametric amplifier based on two BBO crystals. The amplified signal is coupled to a single-mode optical fiber and analyzed using a Fabry-Pérot etalon coupled with a grating spectrometer which is used as a narrow-band filter. Interferograms are registered using an ICCD camera.*

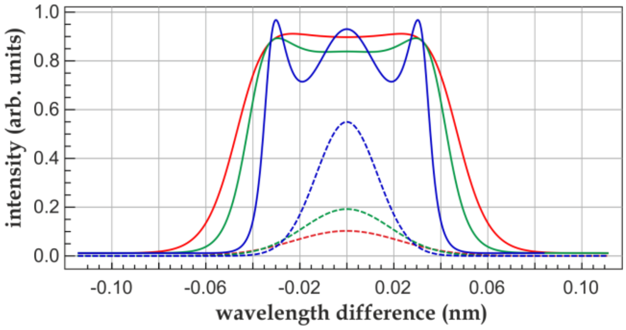

Figure 2 *Simulated spectra of the Thomson and Rayleigh scattering of 532 nm laser beam on the hydrogen plasma under the pressure 1000 mbar. Simulations were made for parameters:* $N_e = 0.3\times10^{23}$ m^{-3}, T_e = *13000* K , *and for the ratio* T_e/T_i *equal to 4/3 (red line), 2 (green line) and 4 (blue line). The Rayleigh scattering spectrum is marked with a dashed line. The sum of Rayleigh and Thomson scattering spectra is marked with a solid line.*

of the investigated sample or even in its damage.

To overcome these problems, a hybrid system for ultrahigh-resolution and sensitivity spectroscopy was developed. It consists of the optical parametric amplifier (OPA) pumped with the third harmonic of the Nd:YAG pulse laser and the Fabry – Pérot (F-P) etalon. This system was then used to measure the spectrum of light scattered on the low-temperature plasma generated by laser breakdown in a gas (hydrogen, helium, neon). Analysis of this spectrum could provide information on some thermodynamic parameters of the induced plasma.

2 Experimental setup

The scheme of our experimental setup is shown in figure 1. It contains two main components. The first one to amplify the scattering signal and the second to resolve its spectrum.

2.1 Optical parametric amplifier

The light of the probe beam (Nd:YAG pulse laser with the second harmonic generator, 532 nm) scattered on the plasma is collected using a confocal imaging setup with spatial resolving power of about 150 µm. Collected light originates only from a small part of the plasma plume (about 3×10^{-3} mm^3 in volume). Consequently, the measured scattering signal is extremely weak and we are forced to extend experiments to several hours to measure it with a satisfying S/N ratio. To improve signal intensity it is amplified using an OPA amplifier based on two BBO crystals pumped by the third harmonic of Nd:YAG laser (355 nm, pulse energy about 15 mJ). Amplification reduces the measurement time to a few minutes.

2.2 Combined setup for high-resolution spectroscopy

The amplified signal beam is either formed into a Gaussian beam using a single mode optical fibre. It is then directed to the Fabry – Pérot etalon (effective finesse ~110). Interference fringes are imagined onto the slit of the grating Czerny-Turner spectrometer by the use of the low-distortion imaging lens. The spectrometer acts as a narrowband filter to reduce the signal bandwidth below a free spectral range of the F-P etalon. Then, the signal is registered using the ICCD camera.

3 Experimental results

During my presentation I will show both simulated and measured spectra of the light scattered on laser-induced plasma. The procedure for deconvolving spectra from Fabry – Pérot interferograms will also be presented. Finally, we will show how some thermodynamic parameters of the plasma, like ionic temperature T_i, concentration of atoms in ground state N_{gr}, and concentration of atoms in excited states N^* could be inferred from these spectra. An example of the simulated spectrum of the central, so-called ionic part of the laser scattering signal for low-temperature plasma is shown in figure 2.

The method described above could become a useful tool for comprehensive plasma diagnostics with high sensitivity to its parameters. The complete set of plasma parameters measured in this way could be used to verify the hypothesis regarding laser-induced plasma thermodynamic equilibrium, which is of paramount importance for considering LIBS (laser-induced breakdown spectroscopy) as a reliable analytical method [1]. We hope that results obtained with this new method will have a significant impact on the discussion taking place in the LIBS community about thermodynamic equilibrium in this type of plasma, which is still an open question [2, 3, 4].

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4 References

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