Non-Stationary Optical Transmission Spectra of Inhomogeneous Plasma of Nanosecond Electrical Discharges near Narrow Spectral Absorption Lines

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Non-stationary optical plasma transmission spectra of high-speed ionization waves in cylindrical plasma waveguides filled with neon gas in the pressure range of 1-60 Torr have been experimentally investigated. The analysis of the results obtained in the experimental study of transmission spectra of nanosecond discharge plasma shows that in the propagation of laser irradiation at an angle to the axis of the plasma waveguide, the classical ratio for absorption by Beer-Lambert law is shifting.

Keywords: ionization waves, nanosecond discharge, nonlinear phenomena

1 INTRODUCTION

The effect of optical transmission spectrum contour formation of the dispersion type near the narrow absorption spectral line in the plasma of neon in the pressure range of 1-60 Torr at 650.2 nm wavelength was demonstrated.

The interaction of broadband polychromatic laser pulses with optically dense resonant extended medium without population inversion is accompanied by a series of linear and nonlinear effects. In particular, while investigating the processes of intracavity interaction of polychromatic laser irradiation with dense absorbing medium, we discovered a number of very interesting collective effects primarily caused by a high concentration ($\sim 10^{12}$ cm^{-3}) of metastable atoms in the plasma [1, 2]. The theoretical model describing these effects is based on the solution of the semiclassical Maxwell-Bloch equations for the conditions under which the pump field does not destroy the dipole interaction of atoms through the photons of the probe field.

The aim of the present work is the experimental study of the transient optical transmission spectra of nanosecond electrical discharge plasma, developing in plasma waveguides during the formation and propagation of high-speed ionization waves.

2 EXPERIMENTAL

The plasma waveguide was a glass discharge tube 50 cm long and about 1 cm in internal diameter equipped with internal electrodes. The electrodes were made of aluminum in the form of hollow cylinders, through which laser irradiation was propagating and optical irradiation was recorded along the tube. The discharge tube was placed in a metal screen 2 cm in diameter and formed the waveguide together with the plasma discharge tube.

To form HSIWs, a special high-voltage pulse generator was designed. It was assembled as a transformer circuit of coaxial design with the primary winding of four turns, while the secondary winding consisted of two windings 12 coils each. Such voltage pulse generator (VPG) produced pulses with the amplitude of up to 40 kV, with the repetition rate of up to 100 Hz and with the duration of voltage pulses at half-maximum of about 70 ns. Detailed description of the experimental setup is given in [3]. The schematic view of the discharge chamber with hollow cylindrical electrodes is shown in Fig 1. As a source of the probe laser irradiation, a dye laser pumped by an eximer laser on XeCl molecules with laser generation wavelength of 308 nm and laser pulse with duration of about 5 ns was used.

To measure plasma transmission spectra, Monochromator / Spectrograph of MS 7504i

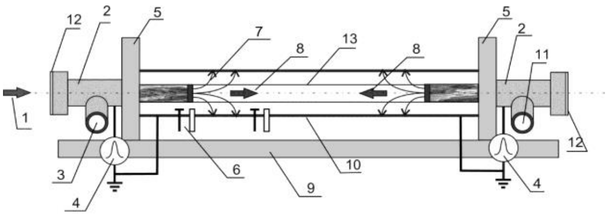

Fig.1: Flowchart of the discharge tube and the formation of HSIW. 1 – laser beam; 2 – hollow cathode; 3 – input pump; 4 – nanosecond pulse generator; 5 – discharge limiters (isolator); 6 – capacitive and optical sensors; 7 – electric field lines; 8 – direction of HSIW propagation; 9 – stand (isolator); 10 – metallic screen; 11 – output pump; 12 – quartz windows; 13 – quartz tube

type was used as a spectral instrument. The wavelength range of the spectrograph is 180 nm – 1200 nm, inverse linear dispersion - 0.9 nm/mm, spectral resolution – 0.015 nm. For the registration of the spectral distribution of the irradiation intensity, a digital CCD HS 102H camera with a type of photosensitive charge-transfer device (CCD) of S9840 model by Hamamatsu company, was used with the monochromator. The number of photo-sensitive elements is 2048 × 14, the size of the photosensitive element (length × height) – 14 × 14 microns, the photosensitive field size (length × height) – 28.672 × 0.196 mm. The dark current of the chamber makes 40 pA/cm.

Two series of experiments were performed. In the first series of experiments, optical plasma transmission spectra of nanosecond electric discharge in neon behind the HSIW front at laser irradiation propagation parallel to the axis of the plasma waveguide were investigated. In the second series of experiments, laser irradiation was propagating at a small angle to the axis of the plasma waveguide. When plasma was probed by laser irradiation, membranes 1 mm in diameter were laid on the input and output ends of the discharge tube. In doing so, the parallelism of the passing light beam of the dye laser and the optical axis of the discharge tube was achieved.

3 RESULTS AND DISCUSSION

Experimental studies have shown that under the propagation of laser irradiation along the optical axis of the plasma waveguide, classical absorption with Voigt profile of the spectral absorption line contour against the broadband spectrum of the dye laser irradiation is observed.

Measuring the absorption of laser irradiation within a selected spectral line of neon has shown that at laser beam passing along the walls of the tube (2 mm from the walls) the power of absorption is greater than in the case of its passing along the center of the tube. When irradiation passes along the wall of the discharge tube, almost complete absorption of the dye laser irradiation near the neon wavelength of 650.6 nm is observed, which is due to light absorption by metastable neon atoms. In these conditions, estimates obtained by laser absorption spectroscopy method have shown that their concentration makes approximately 10^{13} cm^{-3}.

The second series of experiments was carried out in the case where laser irradiation was propagating at a small angle (of approximately 0,01 radian) to the optical axis of the discharge tube. In this case, the contour of the spectral transmission line took the form of the dispersion curve. With the decrease in the value of the said angle, the dispersive circuit transforms into classical absorption with Voigt profile.

The curvature of the absorption line and the formation of the dispersion-type profile were observed when the laser beam entered the tube at one end, and egressed at the opposite end.

Fig. 2 shows the characteristic shape of the spectrum contour of the dye laser near the absorption line in neon after passing through the plasma waveguide. As seen, the curved contour of the spectral plasma transmission line takes the form of the dispersion curve characteristic of anomalous dispersion. It is with the passage of laser irradiation at an angle to the waveguide when the bending of the absorption line contour is observed. Laser irradiation in this case passes in the plasma waveguide through the area with an inhomogeneous distribution of the refractive index along the propagation direction. The specific form of the refractive index heterogeneity depends on the

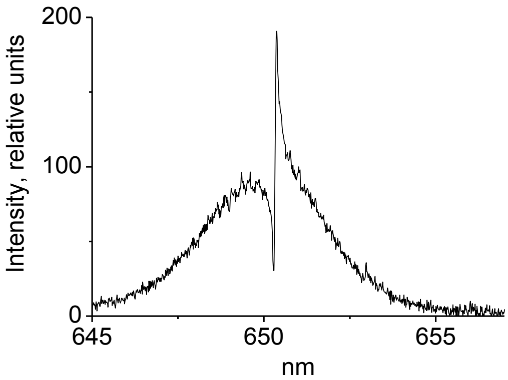

Fig. 2: A typical optical transmission spectrum of plasma column close to a spectral absorption line in neon with the wavelength of 650.6 nm when laser irradiation propagates at an angle to the axis of the discharge tube

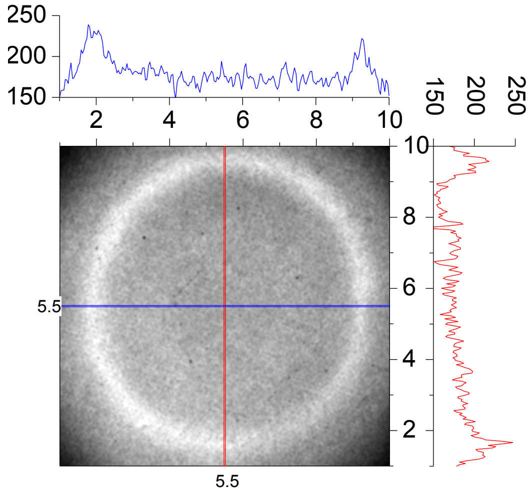

Fig.3: The photo of the discharge in the cross-section of the tube and the distribution of optical irradiation intensity along the centre of the tube in arbitrary units.

distribution density of metastable atoms of plasma in the cross section of the discharge tube. Under the conditions analyzed in this work, this dependence has its maximum near the walls of the tube, while the minimum occurs along the center (Fig.3).

4 CONCLUSION

The analysis of the results obtained in the experimental study of transmission spectra of nanosecond discharge plasma shows that in the propagation of laser irradiation at an angle to the axis of the plasma waveguide, the classical ratio for absorption by Beer-Lambert law is shifting. Different mechanisms for deviations from Beer-Lambert law are known to be based on coherent cooperative, nonlinear or parametric phenomena [1, 2]. The experimental study of the observed effects dependence on laser irradiation power has shown that the effects of laser beams self-action due to nonlinear lens in the conditions considered are insignificant. Apparently, under these conditions, coherent parametric processes of broadband laser irradiation interaction with dense resonant absorbing medium are observed. Revealing the specific formation mechanism of the transmission spectrum of dispersion type close to spectral absorption lines requires additional research.

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