Study of Ne:He Plasma of a Periodically Pulsed Discharge for Optically Pumped Rare Gas Laser

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Abstract. Optically pumped rare gas lasers (OPRGL) suggested recently as a chemically inert analog of diode-pumped alkali lasers are under extensive study at present. OPRGLs employ metastable atoms of heavier rare gases (Rg*) in He bath produced in discharge plasma. Ar* OPRGL is the most popular system at present, due to presence of a narrow band diode pump and abundance of Ar. However, Ne* OPRGL is interesting due to its visible lasing wavelength at 703.2 nm and presence of channels of energy transfer in Ne-He plasma that facilitate Ne* production. We present the first results of experiments with Ne* OPRGL that include Ne* number density in its active medium, and lasing experiments to determine pumping threshold for s5 → p9 transition in a transverse pumping configuration using a narrow band pulsed dye laser as a pump.

1. Introduction

Hybrid gas-phase / solid-state lasers are promising for the development of highly efficient high-power laser systems with good beam quality. The mainstream solution at present is the diode-pumped alkali metal vapor laser (DPAL), but its further development is limited by a number of problems: chemically aggressive nature of alkali metals; the need for heating of the laser cell; arrangements for circulation of highly reactive gaseous medium; the use of methane or ethane as a buffer gas which are fire hazardous and chemically active in the conditions of DPAL. In this regard, the development of a chemically inert analogue of DPAL is an urgent scientific and technical problem. If we restrict ourselves to the search for alternative systems pumped from the ground state, the choice turns out to be limited. However, over the past few years, the concept of optical pumping of atoms from metastable electronic states has been developed. The production of metastable atoms can be achieved using a low-power electric discharge.

Optically pumped rare gas lasers (OPRGL) are under extensive study at present. OPRGLs employ metastable atoms of heavier rare gases (Rg*) in He bath produced in discharge plasma. It is well known that Rg excited to metastable states are similar to alkali metal atoms [1]. Amplification and lasing were observed during optical pumping of metastable atoms of heavy inert gases Rg* = Ne*, Ar*, Kr* and Xe* [2–4]. OPRGLs are, in essence, three-level systems. The typical energy level diagram of OPRGL with lasing and pump wavelengths is presented in figure 1. Optical pumping is achieved by excitation of the s5 → p9 transition (here and after the Paschen notation is used). A population inversion between p10 and the s5 level is generated by rapid collisional relaxation from p9 to p10. The collisional partner for this step is He. The system then lases on the p9 → s4 transition [5]. Hence, the entire lasing medium is chemically inert. Analogous to DPAL, this lasing medium can
provide hundreds of watts of laser output out of cubic centimeter. Diode-pumped rare gas laser systems may ultimately outperform the classic DPAL system. Recent progress includes CW laser demonstrations of Ar* and Xe* lasers operating at 7.3 and 1.3 W, respectively [6,7]. However, Ne* OPRGL is interesting due to its visible lasing wavelength (703.2 nm) and presence of channels of energy transfer in Ne-He plasma that facilitate Ne* production.

The aim of this work was to obtain lasing in a Ne*/He mixture in a pulsed regime with transverse pumping, to study the effect of the active medium parameters on lasing and to measure the pumping threshold. The studies performed are necessary to verify the numerical model of the OPRGL.

2. Experiment
Schematic view of the experimental setup for the experiments with lasing is shown in figure 2. Metastable neon atoms Ne* were produced in the plasma of a repetitively pulsed glow discharge (RPD). The discharge was ignited between a pair of tungsten (cathode) and platinum-coated titanium electrodes with geometric dimensions of 1.5 × 0.4 cm and 3 mm interelectrode distance. A photograph of electrodes with the burning discharge is shown in figure 3. The electrodes were located inside a 0.5 L stainless steel chamber (figure 4) with mutually perpendicular channels for optical pumping and laser output.
The RPD could exist in a wide range of pressures - from several Torr to more than atmospheric pressure. A laboratory made high-voltage pulse generator operated at 200 kHz with pulse duration 80 ns to sustain the discharge. Obtaining the required number densities of metastable atoms requires a high purity of the discharge chamber and gases, therefore, the experimental setup was equipped with oil-free pumping, chemically inert tubing and Swagelok vacuum fittings. A stable gas mixture flowrate (2.3 standard liters per minute) through the discharge chamber was organized with the help of gas flow controllers Bronkhorst F-201CV.

Transverse optical pumping at 640.2 nm, corresponding to the Ne $s_3 \rightarrow p_9$ transition, was provided by a dye laser Sirah PrecisionScan, pumped by the second harmonic of a Quanta-Ray Pro Nd:YAG laser. Pump laser radiation was formed into a narrow oval beam to provide a high power density of optical pumping with the help of a x3 beam expander and a system of cylindrical lenses.
Figure 5. Ne($s_5$) number densities dependencies on discharge power (4% Ne in He) for three total pressures.

Then, the oval laser beam was cut using a 15 x 1 mm slit and transferred to the center between the electrodes. The input and output of radiation was carried out through quartz windows 38.1 mm in diameter and 3 mm thick, inclined at the Brewster angle. The pump intensity varied by no more than 20% along the optical axis of the resonator. The laser resonator consisted of two plain mirrors separated by ~40 cm. The output mirror transmission was specified by the manufacturer to be ~5%. The intracavity losses did not exceed 8%. Lasing at 703.2 nm, corresponding to the Ne p$_{10}$ → s$_5$ transition, was recorded with the help of an Avantes fiber spectrometer, the input fiber of which was located on the optical axis of the resonator.

In experiments determining the lasing threshold, the pump intensity was attenuated using Thorlabs’ neutral filters. The data for the filters’ transmission at 640.2 nm was obtained from the Thorlabs website. Pump laser energy was measured by a power meter Ophir PE50 BF-C.

A sync pulse from the power supply triggered a Stanford Research Systems DG645 delay generator, which triggered the pump laser with a predetermined delay of about 1 μs. Such a scheme made it possible to position the pump pulse at any place of the voltage period applied to the electrodes, thereby ensuring a constant number density of metastables for each pump pulse.

Number density measurements of Ne($s_5$) metastable atoms in discharge zone were carried out using the tunable diode-laser absorption spectroscopy method. A tunable diode laser provided continuous probe radiation, which was recorded by a photodiode. The observed absorption profiles of the s$_5$ → p$_9$ transition were fitted to a Voigt function. Further, the Ne($s_5$) number densities were determined in the same manner as in [8]. The RPD produced [Ne($s_5$)] ~ 10$^{13}$ cm$^{-3}$, resulting in opaqueness near the line centre. To avoid incorrect interpretation of the data recorded in the opaque range, the central part of the absorption profile was excluded from the fit.

3. Results and discussion

Figure 5 presents the results of the tunable diode-laser absorption spectroscopy experiments. Ne($s_5$) number densities dependencies on discharge power were determined for three total pressures of Ne-He mixtures in the discharge chamber. The neon content in helium was 4%. The observed results demonstrate two experimental facts. First, number densities of Ne($s_5$) are weakly dependent on gas pressure. Second, the electrode materials chosen in present study (tungsten cathode and platinum-coated titanium anode) and the RPD power supply system provided necessary for efficient lasing [Ne($s_5$)] ~ 10$^{13}$ cm$^{-3}$.

Experiments with transverse optical pumping by a narrow band dye laser showed that lasing in the Ne*:He mixture could be produced easily. Pumping at the maximum of pump intensity distribution 2 MW cm$^{-2}$ was transferred to the central region of the discharge at an equal distance from the...
electrodes. A preliminary experimental check of the effect of the neon content on the lasing efficiency showed that when 4% Ne in He was exceeded, the laser pulse energy ceased to grow. Figure 6 shows the dependence of the lasing energy on the total pressure in the discharge chamber, obtained at an electric discharge power 20 W, 4% Ne in He and pump intensity 2 MW cm⁻². The lasing reaches maximum near 600 Torr and then a slight decrease is observed, which, taking into account accuracy of the measurements, can be regarded as a plateau up to the atmospheric pressure. This data correlate well with our previous results obtained for the Ar*-He system [2] where a similar dependence was observed.

The main goal of this work was to determine the pump intensity threshold of the for s₅ → p₉ transition. The 640.2 nm pump radiation was attenuated using calibrated Thorlabs neutral light filters. In the experiments, it was found that the lasing threshold strongly depended on various geometric factors, such as the width of the pump laser beam, the position of the pumping region between the electrodes and the quality of the resonator alignment, as well as on quality of synchronization of the discharge with the pump laser. Figure 7 shows the typical dependence of the lasing pulse energy on the pump intensity obtained at a pressure in the discharge chamber 650 Torr, 4% neon content in the gas mixture and a discharge power 20 W. The exponential approximation of the dependence section where weak lasing appears allowed determining the minimum value of pumping intensity threshold to be 9.4 ± 1.1 kW cm⁻². For comparison, according to the results of our previous work [2] in the same discharge chamber the measured pumping threshold for pumping of the p₉ state of argon in Ar*-He was 250 ± 150 W cm⁻².

4. Conclusion
In this work, lasing was obtained employing metastable neon atoms in a mixture with helium with transverse optical pumping at the Ne s₅ → p₉ transition using a 200 kHz repetitively pulsed glow discharge as Ne* source and a pair of tungsten (cathode) and platinum-coated titanium electrodes. The pumping threshold for lasing in the Ne*/He medium was measured for the first time and amounted to 9.4 ± 1.1 kW cm⁻². It was shown that with pressure the energy of laser pulses reached maximum at near 600 Torr, with further pressure increase pressure dependence was weak. The number densities of metastable neon atoms Ne(s₅) were weakly dependent on the total pressure of the gas mixture. The obtained results will be used for design and development of Ne OPRGL.

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