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Amplification of spontaneous emission on sodium D-lines using nonresonance broadband optical pumping

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ABSTRACT

This work describes an experimental study of obtaining the amplified spontaneous emission (ASE) on sodium D-lines using nonresonance broadband optical pumping. ASE is observed at transitions D_2 and D_1 line: 589 nm ($3^2P_{3/2} - 3^2S_{1/2}$) and 589.6 nm ($3^2P_{1/2} - 3^2S_{1/2}$). The active medium was pumped by the dye laser with FWHM of 5 nm, maximum radiation in the range 584.5-586.5 nm, and pulse energy above 2 mJ. The working temperature of the active medium was 260 ºC, initial pressure of buffer gas-helium was 300 torr (operating pressure - 500 torr). A change in the absorption spectra at D lines at different temperatures of the active medium and buffer gas pressures was observed.

Keywords: alkaline laser, optical pumping, active media, amplified spontaneous emission (ASE), brightness amplifier.

1. INTRODUCTION

Alkali vapor lasers are becoming popular nowadays, and a lot of works on this topic are focused on delivering high power and its amplification [1-3]. We consider it promising to use active media on alkali vapors in active optical systems (AOS) as image brightness amplifiers [4,5]. According to the data of [3,6-7], they can provide a continuous wave (CW), the coefficient of single-run amplification reaches 2.5 cm^{-1}, the width of the emission line is 20-50 pm. The amplification of radiation on sodium D-lines is registered under resonance and nonresonance optical pumping in the presence of a buffer gas [1-3, 6-9].

When using resonance optical pumping of the level D_2 by a narrow line (width of about 10 pm) at buffer gas pressure (helium, ethane, methane, etc.) more than 200 torr, the radiation is observed on the D_1 line ($3^2P_{1/2} - 3^2S_{1/2}$) [7,10-11]. The main source of pumping of such lasers is laser diodes, and they are called diode pumped alkali lasers (DPAL). Small shifts in the wavelength of the pump radiation causes the decrease in the amplification of the radiation on the D_1 line. When the pump is shifted to the red region, the decrease in the amplification on the line D_1 is faster than in the blue region. According to [7,10], the region of "small" pump detuning from the D_2 line in sodium to the blue region is 70 pm and 50 pm in the red region. It means that the resonance optical pumping of sodium has the maximum efficiency with a pump line width of not more than 140 pm.

Nonresonance optical pumping of sodium with a large detuning from the D_2 level to the blue region is described in [4,5]. Pumping with a large detuning is possible at high buffer gas pressure (more than 500 torr) and it causes the amplification of the radiation simultaneously on the lines D_2 and D_1 with a sufficiently high efficiency in comparison with resonance pumping. Two mechanisms of nonresonance pumping are described in the literature. The first mechanism is based on the transfer of energy to the upper working levels due to frequent collisions with buffer gas atoms [8-9]. The second one is based on the existence of quasimolecules in excited states consisting of atoms of alkali vapor with atoms (molecules) of the buffer gas, in the decay of which the upper working states of the metal atoms are populated [12-14]. They are referred to as excimer-pumped alkali lasers (XPAL).

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The investigated region of "large" detuning starts from the edge of the region of "small" detuning (588.9 nm) [8,10] up to the two-photon transition at 578 nm ($4^2D_{5/2,3/2} - 3^2S_{1/2}$) [9]. The width of the range of detuning depends on the pressure of the buffer gas and reaches 578 nm at pressures of more than 1 atm.

We assume that it is possible to efficiently pump D-lines of sodium with broadband radiation in the range from 588.9 to 578 nm (Fig. 1). Then the luminescence is observed on the lines D_2 and D_1. Amplified spontaneous emission (ASE) is observed when the pump threshold is exceeded [8]. Because of transitions competition the generation may be implemented in one of two possible ones - D_2-line (589 nm) and D_1-line (589.6 nm).

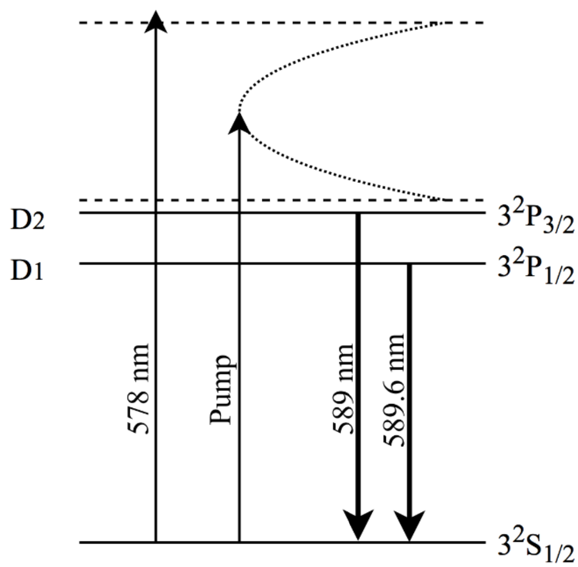


Fig. 1 Energy scheme of Na-atom

Broadband optical pumping will allow a more stable gain on the D_1 line from pulse to pulse, because when using narrow-band pumping the amplification is strongly dependent on the detuning it from the line D_2. Also, the use of broadband pumping will simplify the technique of the experiment and increase the pump power and its efficiency.

In this paper, we consider the mechanism of amplification of radiation of sodium D-lines by using nonresonance broadband optical pumping by a dye laser. The changes in the absorption spectra on D-lines are shown as the functions of the concentration of sodium atoms and the pressure of the buffer gas in the active medium.

2. EXPERIMENTAL SETUP

The experimental setup is shown in Fig.2. We used a cell with sodium vapors with the following parameters: the diameter of 1.6 cm and the length of a heated zone of 10.5 cm. The temperature of the outer wall of the cell varied in the range 25-300 °C, the pressure of the buffer gas - helium at the operating temperature reached 500 torr (with the initial pressure being 300 torr).

The medium was pumped by a Pyrometer 597 dye laser. The resonator of the dye laser consisted of a plane-plane mirror (M) and the output window of the dye cell (C). The dye was excited with the second harmonic of Nd3+:YAG laser (LQ-529B, Solar LS) 532 nm, with the pulse duration being 5 ns and pulse repetition frequency 1 Hz. The full width at half maximum (FWHM) was 5 nm in the range from 584.5 nm to 586.5 nm. The radiation of the dye laser passed through the diaphragm (D) of 5 mm diameter and directed along the axis of the cell with sodium vapor.

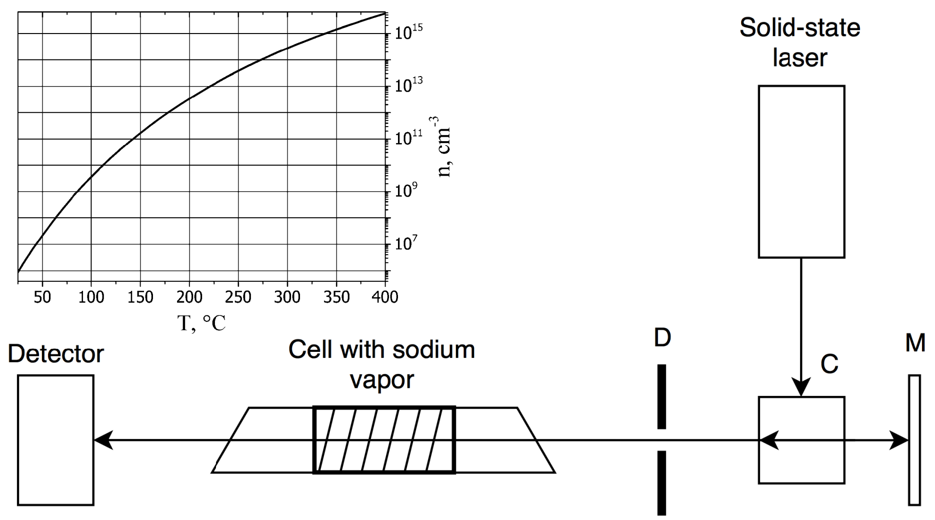


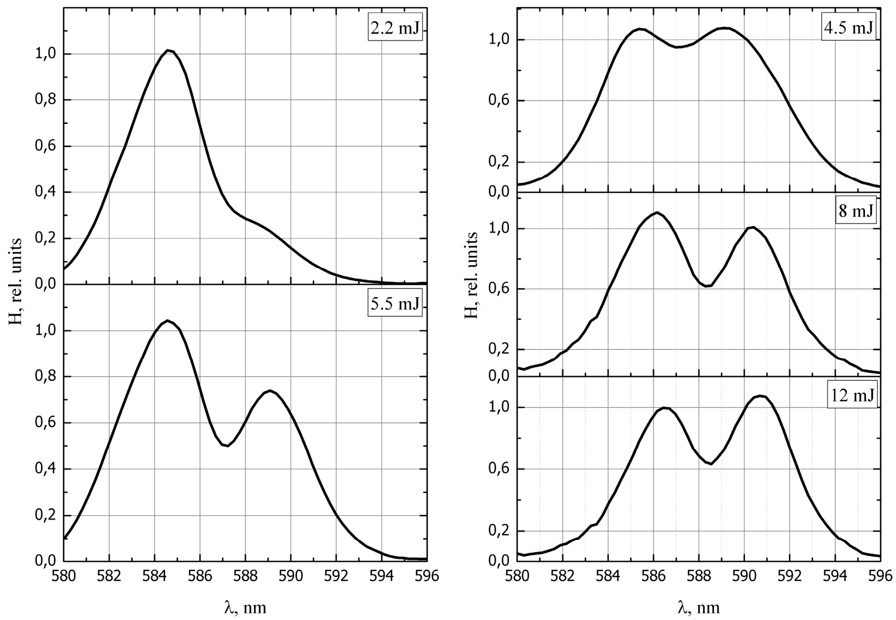
Fig. 2 Experimental setup
D – diaphragm, C – dye cell, M –mirror
The inset shows the dependence of the concentration of sodium atoms on the temperature

The output radiation was recorded with a spectrum analyzer AvaSpec-2048 (with a resolution of about 1 nm). The time dependence of radiation is obtained by a semiconductor detector Thorlabs DET10A. The energy of the pump radiation was measured by the instrument OPHIR NOVA II receiver PE50-V2.

The emission of the LED was directed along the axis of the cell with sodium vapor to record the absorption on lines, LED FWHM was 20 nm and the maximum was observed at 589 nm. The temperature of the cell with sodium vapor varied from 25 °C to 285 °C. The concentration varied from 10^6 to 10^{14} cm^{-3} (Fig. 2) according to the data [15]. The pressure of the buffer gas-helium was set at 10 torr, 100 torr, and 500 torr in the initial state. Absorption was recorded by a Solar SHR measuring instrument with a spectrometer function and a resolution of the order of 18 pm at a wavelength of 589 nm, with an accuracy of ±3 pm.

3. EXPERIMENTAL RESULTS

When dye laser radiation passes through a cell with sodium vapor at a temperature of 250-265 ºC, at the same time, the reduced pump radiation and radiation on lines D_2 and D_1 are observed. The radiation intensity on the D-lines increases faster at pump energies greater than 2-3 mJ (Fig. 3a), which corresponds to a power density of 1.5 - 2.0 MW/cm^2. This means stimulated emission (ASE) appears when exceeding the threshold pump energy.



a) b)

Fig. 3 Spectra of output radiation at different pump energies

The best ratio 1:1 was obtained between the intensity of the transmitted pump radiation and the emission of sodium lines at different energies (Fig. 3b). This suggests that the most part of the pump energy of the dye laser is transformed into the radiation on sodium lines. The radiation is recorded on two lines of sodium (D_2 and D_1), this can be seen from the shift of the maximum of the right peak in Fig. 3b. Unfortunately, the spectrometer used in this experiment (AvaSpec-2048) has a low resolution, and these lines were not separated.

The time dependence also shows the transformation of the dye laser radiation into ASE on sodium lines (Fig. 4). At low sodium concentrations, less than 10^{12} cm^{-3}, at the temperature of 190 °C [15] (inset in Fig. 2), pump radiation with a duration of 5 ns prevails at the cell exit.

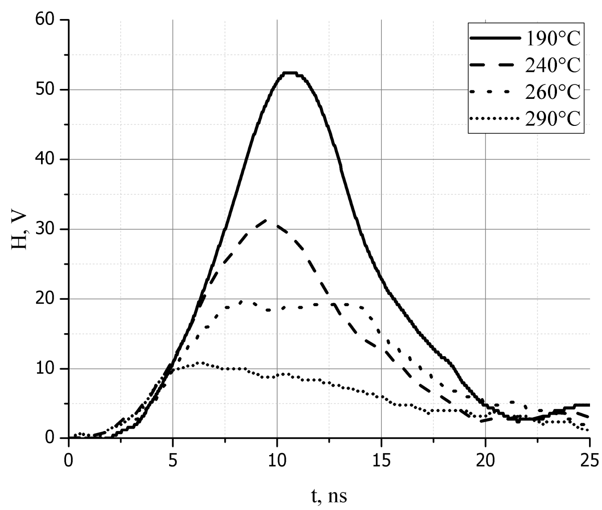
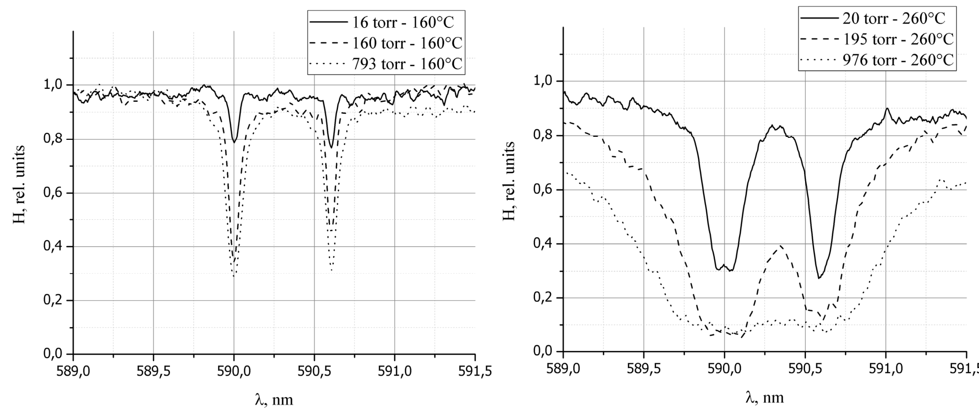


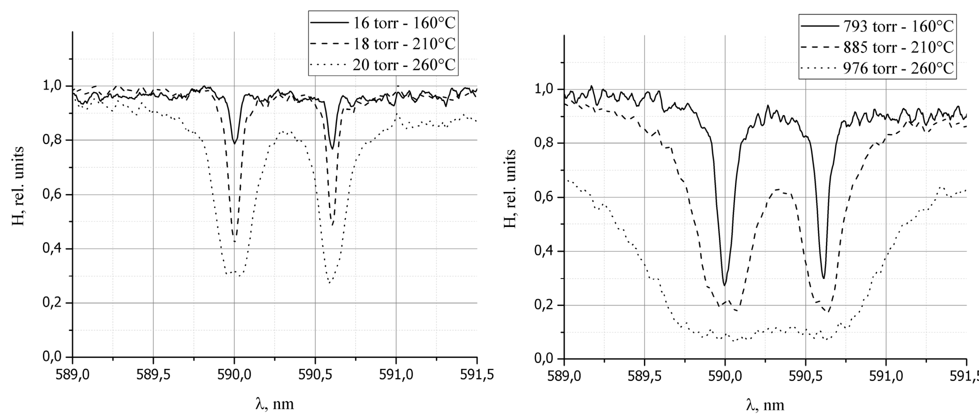
Fig. 4 Time dependence of the single pass of radiation on the temperature of the active medium

At temperatures 190-240 ºC there is a slight elongation of the falling edge of the pump pulse. This is due to the appearance of spontaneous emission on the D-lines of sodium, the lifetime of which is 16 ns [16]. The second peak can be observed after the pump pulse in 5-7 ns at a temperature of 260 ºC. This corresponds to the appearance of amplified spontaneous emission (ASE) on sodium D-lines. This is confirmed by the intensity comparable with the intensity of the pump radiation and shortening of the falling edge of the pulse. At a temperature of 290 ºC the falling edge of the pulse of 15 ns was observed. Temperature increase, as a consequence of the increase in the concentration of sodium atoms above 10^{14} cm^{-3}, leads both to intense absorption of the pump radiation and self-radiation of the environment (the effect of the radiation capture). We believe that only spontaneous radiation from the far zone of the cell is registered because the falling edge of the pulse corresponds to the lifetime of level D_1.

The results of the experiments shown in Fig. 5 show the change in the absorption spectra at the D-lines of sodium with a change in the pressure of the buffer gas and the temperature of the active medium (concentration).



a)



b)

Fig.5 The absorption spectrum at the D lines of sodium, depending on the pressure of the buffer gas (a), the temperature of the active medium (b)

Fig. 5 shows that an increase in the concentration of atoms in a cell with sodium vapor and an increase in the pressure of the buffer gas lead to a considerable broadening of the absorption lines. Increasing the concentration of sodium atoms in the active medium leads to the greatest broadening of the lines D_2 and D_1, up to confluence of lines in one greater than 1 nm. The width of the absorption line D_2 makes it possible to estimate the maximum width of the pump line, which will be efficiently and resonantly absorbed and converted to emission of the D_1 line. Similarly, the absorption lines show the maximum possible widths of the emission lines; in reality the emission lines have the width which is smaller in magnitude [10-12].

4. CONCLUSIONS

The results of the experiments show that the amplification on sodium D-lines is obtained in the case of nonresonance broadband optical pumping, with FWHM being 5 nm, maximum of 584-586 nm and the pressure of the buffer gas-helium 600 torr at an operating temperature of 260 °C in the active medium. This is confirmed the threshold pump energy (density), after which intense radiation is detected on D-lines, shortening of the pulse transmitted radiation front relative to the spontaneous emission life time at the moment of occurrence of stimulated emission.

The obtained data on the absorption and emission show that the width of the ASE line will be smaller than the absorption line, but not less than 20-50 pm [8-12], which is an order greater than in active media on self-limited transitions (2-3 pm) [17].

Consequently, when using an active medium on sodium vapor as an active element in the image brightness amplifier, active filtration of the image of the object under background illumination conditions will be less than with active media on self-limited transitions in metal vapors. At the same time, the possibility appears to create an image brightness amplifier with a continuous wave mode, which will greatly simplify the technique of recording fast processes [18-19].

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