# EXPERIMENTAL PECULIARITIES IN LEAD VAPOR PUMPING WITH RESONANCE FLASH LAMPS

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*We discuss here some peculiarities in lead vapor pumping with resonance flash lamps and describe the experimental equipment used. The problem of spurious displacement current that may appear when switching the resonance lamp on is considered. Glow spectrum of lead vapor is found to markedly differ from the radiation spectrum of the pumping resonance lamp. Some spectral lines, intense in a pulsed discharge, are absent in the vapor glow. Other lines, on the contrary, are more intense in the glow spectrum. Appearance of the lead ion lines in the glow is indicative of photoresonance plasma formation in the chamber under the irradiation.*

## INTRODUCTION

Optical pumping is a classic method for creating of inverse population in a medium. The mixture of mercury vapor and nitrogen is an example of gaseous medium in which the optical pumping was successfully used.[1] In this mixture, inversion is created at the transition $7S-6P$ with $\lambda = 546$ nm due to a stepwise excitation of mercury atoms by emission from a mercury lamp and collisional de-excitation of mercury states in atom-molecule collisions with nitrogen. Low efficiency of such a laser is caused by a stepwise excitation. Taking into account the above-said, it is worth considering the possibility of obtaining steady state lasing when optical pumping a medium through the transitions from resonance levels of some metals to the metastable ones. Such a pumping can easily be performed at a pulse excitation in a gas-discharge plasma.

However, there are several problems in this way. The first one concerns the material that would suit making walls of a laser chamber and pumping lamps. Such a material must be transparent for resonance radiation at working temperatures of the medium. The second problem is to reach the selective and fast collisional de-excitation of metastable levels. There exists a wide literature on the studies on quenching the metastable states of atoms by atomic and molecular gases,[2] showing that the cross-sections of these processes range from $10^{-16}$ to $10^{-17}$ cm$^2$. To reach the relaxation rate about $10^7$ s$^{-1}$ at such a low cross-sections, the pressure of quenching gases should be much higher than the atmospheric pressure. This imposes strict restrictions on the mechanical strength of a laser chamber.

In this connection, let us note the lack of literature data on quenching cross-sections for the resonance levels, that is indirectly indicative of small values of these cross-sections too. Under conditions conventional for a gas discharge (1–100 Torr), relaxation processes are insignificant in the kinetics of resonance levels.

To make a forecast of the prospects of the photoresonance method of pumping, we have studied the lead vapor radiation spectra and the emission kinetics when excited with resonance[3] flash lamps.

Toward this end in view, we have constructed the chambers for photoresonance pumping of metal vapor and studied different methods of energy deposition into the working volume, as well as the radiation spectra of lead vapor column during the resonance pumping.

The reasons for which we have chosen the lead vapor are as follows. First, lead is a typical element, for which pulsed lasing is achievable; second, chambers and lamps can be made from quartz.

The pulsed mode of pumping enables one to deposit significant amount of energy into the discharge.

## EXPERIMENTAL EQUIPMENT

To excite optically the lead vapor we used quartz chambers with the internal flash lamps. Figure 1 shows one of the constructions used. The quartz lamp *2* with electrodes *1* is sealed into the chamber *4* (quartz tube). The lamp *2* has special branches for loading lead portions in tantalum capsules. The same capsules were loaded into the chamber, as well. The chamber was placed into a furnace the temperature within which is monitored with a chromel-alumel thermocouple. The lamp position inside the volume irradiated provides for high density of resonance radiation near the resonance quartz lamp wall, minimum losses of the pump radiation energy, and make the work with such a chamber explosion-proof.

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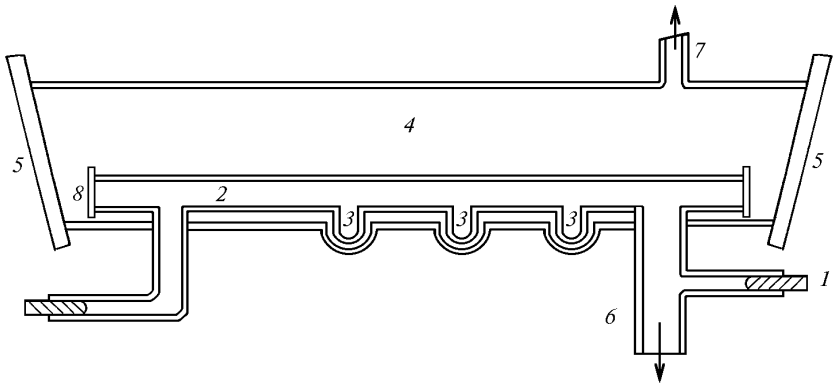


*FIG. 1. Quartz chamber for optical resonance pumping and formation of photoresonance plasma in lead vapor: lamp electrodes (1), gas discharge resonance flash lamp (2), branches for metal (3), chamber volume irradiated by the lamp (4), chamber windows (5), lamp exhaust channel (6), chamber exhaust channel (7), and lamp windows (8).*

However, the lamp position inside the chamber has, at the same time, certain drawbacks. Thus, in particular, the temperature inside the resonance lamp with the lead load cannot be changed independently of the temperature in the outer chamber. One more drawback is that the displacement current that occurs during the flash lamp operation may ionize the medium inside the chamber.

When optically exciting lead vapor with a resonance quartz lamp, the temperature of quartz chamber must not exceed 1000°C. Since at working temperatures lead reacts with the quartz wall, quartz loses its strength with time. The lamp walls are gradually being coated with a dark bloom, and transmittance to resonance radiation decreases.

The pulse discharge circuit of the lamp power supply comprises a high voltage source (0–30 kV), a discharge resistor, and an energy storage capacitor of 1500 pF to 0.1 μF capacitance. The discharge circuit is commuted with two series dischargers RU–62 with the total voltage of self-breakdown of 22 kV. The voltage is regulated discretely by shunting one of the dischargers with the capacitors of different capacitance. The dischargers operate in the self-breakdown mode.

The lamp and the chamber heated up to the working temperature were separately filled in with certain gas mixtures and then a pulse-periodic discharge, at 10 to 20 Hz repetition rate, was initiated in the lamp. Neon, helium, and neon-helium mixtures were used as buffer gases. As a rule, buffer gas pressure in the chamber was much higher than the gas pressure in the resonance lamp with the pulse-periodic discharge. Gas pressure in the chamber (at working temperature) reached 0.9 atm.

The emitting part of the chamber was 30 cm long, and it was 250 cm far from the slit of an MDR–23 monochromator. The observations of the glow were performed from the chamber end.

## RESULTS AND DISCUSSION

The fact that displacement current can initiate a spurious discharge in the chamber during the resonance lamp operation makes a subject for a special discussion. The spurious discharge that develops in the photoresonance plasma formed due to irradiation of the "metal vapor – inert gas" mixture by a resonance radiation from the lamp. This discharge may distort the picture of physical processes in plasma. To elucidate this problem we have conducted special experiments. The lamp *2* was filled with helium, while the chamber *4* with neon. It was found that the discharge occurs in the chamber at low neon pressure. It is well seen by reddish glow of neon. At a higher pressure it disappears. The glow was localized near (outer) wall of the lamp *2*. The presence or absence of the spurious discharge in the chamber, as our experiments showed, can be reliably detected by the place of glow localization, by its appearance, and by differences between the discharge spectra in the tube and the spectrum of optically excited fluorescence of lead vapor in the chamber. In this paper we present some results obtained only under conditions when no spurious glow initiated by the displacement current was observed.

To test the capability of the resonance lamp power supply, we obtained lasing at the lead atom line of 722.9 nm wavelength in the lamp itself. The glow of the lead vapor column observed in the chamber *4* irradiated with the flash lamp *2* was of purely blue color, highly transparent and homogeneous. In contrast to the chamber, the plasma in the discharge lamp *2* is to a great degree opaque.

It is interesting that while under the same conditions no generation at 722.9 nm lead line was observed in the chamber. Even spontaneous radiation was practically absent at this line. Visual differences in the glow within the lamp discharge tube and in the

chamber were confirmed by differences in the corresponding spectra of spontaneous radiation recorded with a PMT and the oscilloscope. In so doing, we first recorded the pulses of total emission from the chamber and the lamp, and then only from the chamber. (To find the intensity of resonance radiation from the lamp, at any particular line and certain moment in time, one should subtract the spectrum of the emission coming from the chamber from the spectrum of the combined emission.)

The spectrum of the emission from the chamber was compared with the spectrum emitted by the resonance lamp. As a result, the following peculiarities of the emission from the chamber were revealed.

First, we did not manage to detect, in the emission spectrum from the chamber, some lines that are sufficiently intense in the spectrum of the discharge lamp, the line 722.9 nm being among them. The length of the emission pulses at the spectral lines in the chamber was somewhat shorter than that in the lamp. The ratio between the intensities of the same lines in the chamber and the lamp may differ. Some lines are more intense in the chamber, while others in the lamp. At the same time, there are lines with practically equal intensity in the chamber and the lamp.

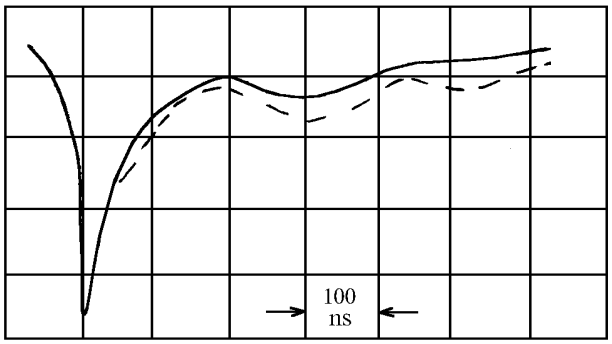


*FIG. 2. Oscillograms of spontaneous emission pulses at* 205.3 nm *line of the atomic lead. One division on time scale equals* 100 ns. *Radiation from the chamber (solid curve), combined radiation from the chamber and the lamp (dashed curve). The device is shown in Fig. 1. Charging voltage is* 22 kV, *capacitance of the storage capacitor is* 1600 pF. *Wall temperature is* 866°C. *At the working temperature the helium pressure in the chamber is* 0.5 atm, *neon pressure in the lamp is* 75 Torr.

Figures 2 and 3 show the oscillograms of pulses of lead spontaneous emission from the chamber (solid curve) and pulses of combined emission, from the chamber and the lamp (dashed curve). As is seen from Fig. 2, the radiation at 205.3 nm PbI line is practically totally due to the emission from chamber. The PbI line at 406.2 nm in the leading edge of the pulse is practically of the same intensity both in the chamber and in the lamp discharge tube, while then the radiation from the chamber dominates.

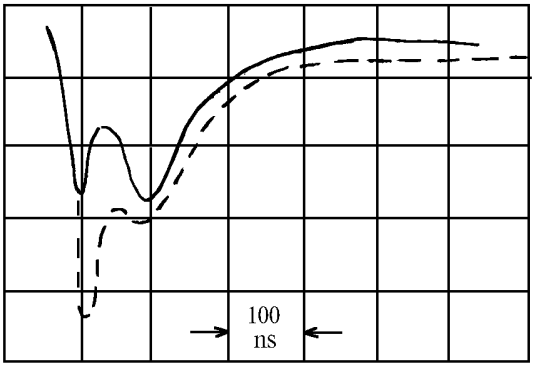


*FIG. 3. The same as in Fig. 2, but for the line of atomic lead at* 406.2 nm.

In the system similar to that shown in Fig. 1, there may work many complex mechanisms of excitation and redistribution of ionization and relaxation energy. Absorption by a layer of nonexcited vapor at the chamber periphery may significantly weaken lines of resonance radiation from the chamber.

The presence of strong ion lines, for example, of PbII line at 537.2 nm (Fig. 4) in the chamber, is indicative of the formation of a photoresonance plasma.[4,5] The process forming the plasma breaks the selectivity of optical excitation. However, from the results presented by the oscillograms of spontaneous emission at the spectral lines (in particular, at 722.9 nm), a conclusion can be drawn that collisional mixing of levels and excitation by electron impact manifest themselves only weakly. As a result, the electron concentration (and temperature) is low. At the temperatures that were set in our experiments the density of lead atoms reaches $10^{15}$ $cm^{-3}$. Short duration of pumping pulses of resonance radiation (300–600 ns full duration) also does not favor obtaining high electron density. Then radiation from the resonance lamp of small diameter (about 0.8 cm) irradiates the chamber volume of 3 cm in diameter. As a consequence, the density of energy deposited into the absorbing medium decreases as compared to that in the lamp.

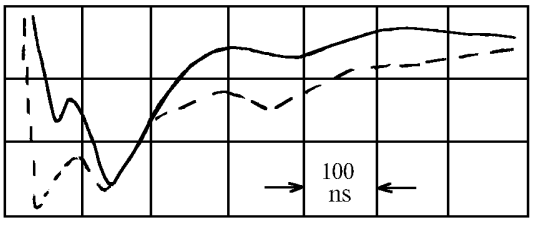


*FIG. 4. The same as in Fig. 2, but for the line of atomic lead at* 537.2 nm.

The shape of spontaneous emission pulse at the spectral lines from chamber is very sensitive (at the same temperature of the gas-discharge device and the same charging voltage, capacity, and gas medium composition in the tube) to pressure and composition of

the gas medium in the chamber. Taking into account high variability of the emission spectrum and the many-factor character of the experiment one may conclude that selection of the proper experimental conditions is quite an ambiguous task.

## CONCLUSIONS

From the comparison of pulses of spontaneous emission at the same spectral lines it is seen that a noticeable portion of the resonance radiation of a pulse-periodic gas discharge in the lamp is deposited into the medium of lead vapor and inert gases in the chamber. The efficiency of pulsed pumping of the medium at a selected spectral line by the resonance radiation may be comparable with the efficiency of pumping in a gas discharge or even higher.

The many-line pulsed resonance optical excitation of the lead vapor and inert gas mixture in the chamber at pressures up to 0.9 atm yields the formation of a photoresonance plasma.

The spectrum of emission from the chamber markedly differs from that in the pumping lamp and changes when changing the buffer gas in the chamber and its pressure. This is indicative of a great difference in the mechanisms of excitation of the atomic and ion levels in the mixture of metal vapor and a buffer gas by the resonance radiation, and by a pulsed discharge in the pumping lamp.

High variability of radiation spectrum in the chamber due to varying experimental conditions enables us to look forward for obtaining a medium with parameters that may be controlled better than in the gas discharge plasma.

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