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Dynamic characteristics of the plasma of a helium-cadmium laser

A S Kiselev and E A Smirnov

Department of electronic instruments and devices, Saint Petersburg Electrotechnical University "LETI", 197376, Saint Petersburg, Russia

E-mail: alex.kiselev.epu@gmail.com

Abstract. In this work the dynamic characteristics of a helium-cadmium laser are investigated in the process of entering the working regime. The study of the spectra of oscillations of the coherent radiation power in combination with the study of the spectrum of discharge current oscillations is carried out. The spectra of lateral spontaneous emission were also studied using a small-size diffraction spectrometer in the process of entering the laser into operating mode.

The most typical representative of metal vapor lasers is a helium-cadmium (He-Cd) laser. It is able to generate continuous coherent radiation in the blue (441 nm) and ultraviolet (325 nm) regions of the spectrum. He-Cd lasers are used in printing, holographic, spectroscopy and so on. But a serious drawback of He-Cd lasers is the high level of instability of the coherent radiation power. The level of radiation oscillation depends on the discharge current, the helium pressure, the geometry of the discharge gap, the concentration of cadmium vapor [1].

The construction of helium cadmium He-Cd lasers is far more complex than that of other helium based lasers. The laser tube contains a reservoir for cadmium and a heater to vaporize the metal. As a result, a heated filament cathode is often used in place of the cylindrical tube that comprises a He-Ne laser. Additionally, the laser itself needs to sustain a higher level of internal pressurization allowing the vaporized cadmium to remain in the tube. The lifetime of a specific helium cadmium laser is dictated by the amount of cadmium in the reservoir [2].

The active medium of He-Cd lasers contains an inert gas He under pressure 500...700 Pa and Cd vapor (0.1 Pa). Excited cadmium ions are radiating particles. Because of the low concentration of Cd atoms their excitation due to direct collisions with electrons plays an insignificant role. The main process of pumping the active medium of a He-Cd laser is ionization of Penning – process of formation of an excited ion of an easily ionized particle (Cd atom) upon collision with an excited metastable atom of a He buffer gas having a large excitation cross section:

$$He^{*} + Cd = He + (Cd^{*})^{+} + e.$$

The aim of the study was to search for and analyze the dynamic parameters of the plasma of a helium-cadmium laser, leading to a short-term and long-term instability of its radiation power. The method of investigation is reduced to the study of the spectra and dependences of the coherent fluctuating power for various physical parameters of the laser and to reveal the causes of the appearance of noise of He-Cd lasers, which makes it possible to make assumptions about the occurrence of noise in the laser radiation.

In this work studied the spectra of the oscillations of the coherent radiation power in combination with the study of the spectrum of discharge current oscillations, as well as the spectra of the side spontaneous emission in the process of entering the laser into operating mode. The spectra of spontaneous emission were studied with the help of a small-sized spectrometer [3]; the radiation was fed through the optical fiber. At the initial stage working of laser the discharge proceeds in pure helium (figure 1). This can be seen from the comparison of the spectrum of the lateral spontaneous study combined with the helium emission lines (figure 2). It was found that the intensity of the emission lines of cadmium and helium over time varies, a transient process is observed. In the first minutes of working the laser the intensity of the helium lines is approximately constant. Approximately at the fifth minute of working the laser the emission lines of cadmium begin to appear in the spectrum. Then there is a decline corresponding to the time of the onset of evaporation of cadmium. It can be noted that the oscillations in the intensities of the emission of helium and cadmium are made in antiphase (figure 3).

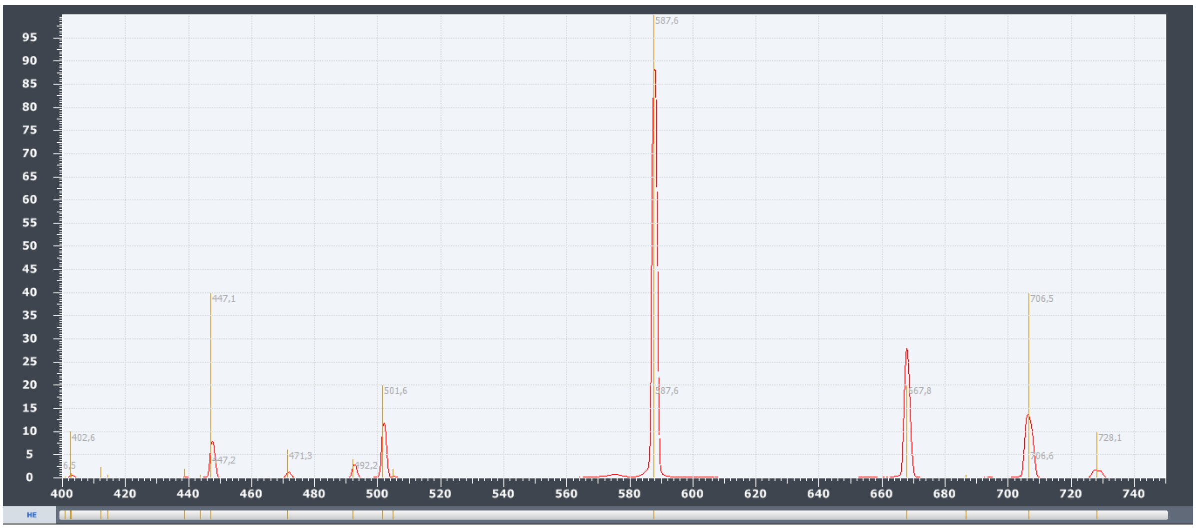

Figure 1. The spectrum of the lateral spontaneous emission of a He-Cd laser at the moment of switching.

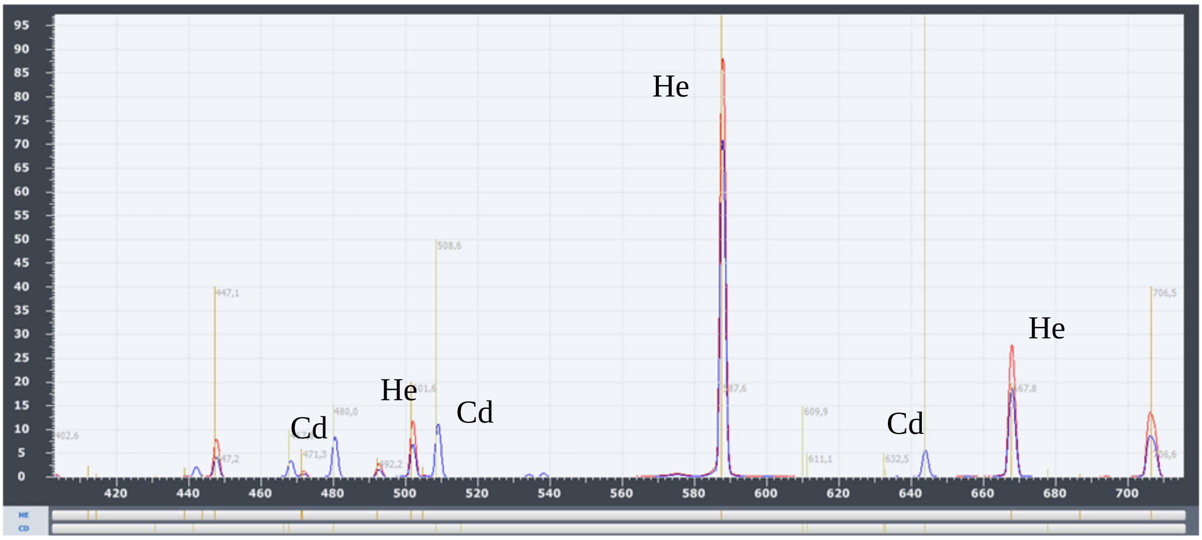

Figure 2. Comparison of the spectrum of the lateral spontaneous study of the He-Cd laser at the moment of switching on and after 25 min.

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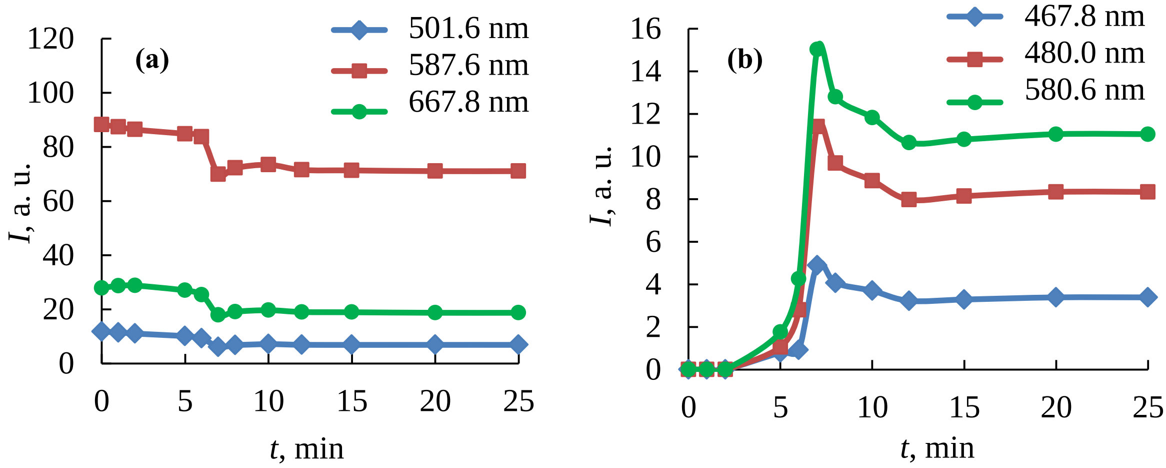

Figure 3. Time dependences of emission intensity of some spectral lines: **(a)** – helium; **(b)** – cadmium.

A significant influence on the output power of a He-Cd laser is exerted by the temperature of the evaporator, which determines the vapor pressure Cd in the positive column of the discharge. Initially the increase in concentration with increasing temperature of the evaporator is accompanied by an increase in the output power due to an increase in the number of emitting particles Cd^{+*}. A further increase in the concentration of readily ionisable Cd leads to a decrease in the electron temperature and the potential gradient in the positive column. The mechanism for reducing the energy of electrons is as follows. As the electron energy increases, so does the number of Cd^{+} ions involved in the process of compensating for the negative space charge of electrons in the plasma [4].

The own oscillations of the discharge current are determined by the variety of processes of interaction of particles in the plasma, and also by the interaction of the external electric circuit and the discharge as a whole. Such oscillations include reactive (relaxation) oscillations, stratification of discharge, double layer oscillations and cathode oscillations. Reactive oscillations (tens–hundreds kHz) are manifested at small discharge currents corresponding to the cessation of its existence. The steepness of the dropping current-voltage characteristic of the discharge has large values. Reactive oscillations increase with increasing parasitic capacitance "cathode–anode" [5]. The stratification of discharge, or layered oscillations, is due to the discrepancy in the length of the discharge of the ionisation and excitation maxima of the atoms [6]. As a result spatial layers (ionization waves) with an increased concentration of either ions or excited atoms arise. Layers move at high speed along the axis of the discharge, forming running stratification layers, increasing from the cathode to the anode. Stratification layers not only modulate current and radiation in time, but also make the discharge spatially non-uniform [7].

In a He-Cd laser are more often present non-regular stratification layers – oscillations not one frequency, but noise ones, the spectrum of which includes a large number of harmonics. The difference frequencies of the harmonics fall into the low-frequency region (up to 80...100 kHz) and strongly modulate the coherent radiation with amplitudes from one to tens of percent, forming a Poisson noise $1/F$. In the discharge of a He-Cd laser, the conditions ensuring maximum amplification of the active medium are simultaneously favourable for the existence of intense stratification layers. In this work studies were made of the spectrum of the discharge current oscillations during the evaporation of cadmium (figure 4). It was found that with an increase in the concentration of cadmium in the discharge, the spectrum shifted to low frequencies, and at the same time the increases amplitude of current oscillations (by an order of magnitude).

The mechanisms described above significantly influence the output power of the He-Cd laser radiation. During the evaporation of cadmium occurs inertia in active medium. Also in the laser there are natural oscillations of the discharge. This leads to modulation of the discharge current. An obligatory condition for the efficient use of lasers based on cadmium vapor is the presence of systems for stabilizing the power of their radiation.

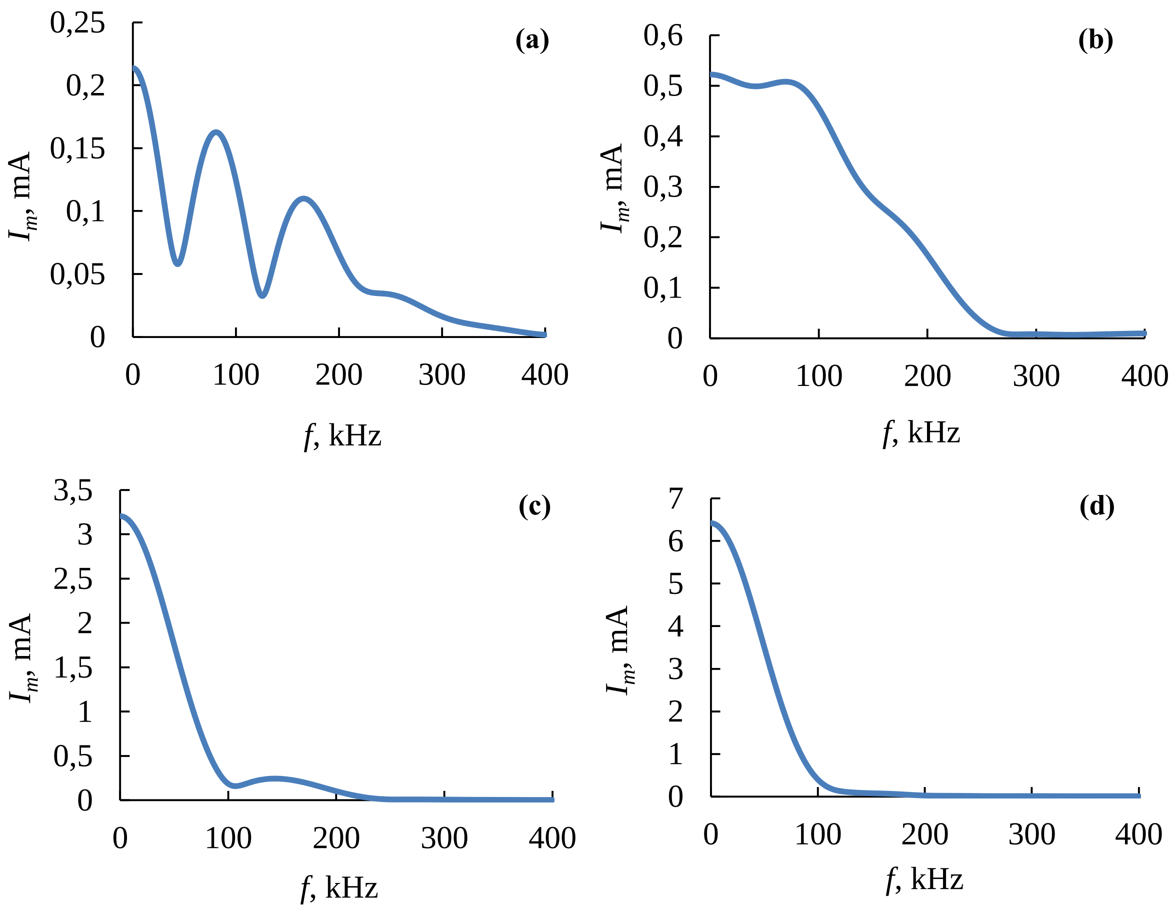

Figure 4. The spectra of discharge current oscillations: **(a)** – in pure helium; **(b)** – 2 min after the evaporator has been switched on; **(c)** – 7 min; **(d)** – 25 min.

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