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Amplification and absorption in a positive column He-Se laser tube

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Perturbation spectroscopy was used to evidence the amplification and absorption regions in a positive column of a He-Se laser tube. An all Pyrex, self-heating laser tube, 60 cm active length, 2 mm ID was used. The total laser power was about 28 mW. The presence of a magnetic field in the metal reservoir shows a significant increase of the laser power. Three different regions along the laser tube have been investigated. In the reservoir's region a strong absorption has been detected. A possible explanation of this phenomenon is presented.

1. Introduction

The first cw laser action in He-Se mixture was observed and reported by Silfast and Klein [1], [2] on many wavelengths in visible and near infrared region.

The Se_8 molecules are normally present in the gas mixture. When the temperature is about 1500 K, the Se_2 molecules become the dominant particles. For the low temperature of 260 °C the vapour pressure of selenium is about 5×10^{-3} torr [3]. Such vapours, present in an electric gas discharge, will be broken into selenium atoms by the electron collisions. The same mechanism will develop a high density of positive selenium ions that, by cataphoresis, penetrate the active region of the discharge moving to cathode.

The energy level diagram of Se^+ [4] shows many levels for electronic configuration $4s^24p^25p$, whose energies are very close to that of the He^+ ground state. These levels are highly populated. It is known that a charge transfer process between the ground state Se atoms and He^+ ions takes place according to the reaction

$$He^+ + Se \rightarrow He + (Se^+)^* + \Delta E. \tag{1}$$

The decay of selenium excited levels is predominantly radiative to levels corresponding to electronic configuration $4s^24p^25s$. Over 60 laser radiations were generated when a 2 meter active length laser tube had operated. The most powerful emitted radiations are in blue-green region of the spectrum.

2. Experimental laser tube and set-up

We have developed an original geometry for He-Se laser tube, entirely from Pyrex glass [5]. The metal is heated by the discharge itself, so that there is a connection between the current value and the vapour pressure.

The inner diameter of the capillary is 2 mm. The capillary is firmly welded at one end and has the possibility to dilate to the other. Also, it consists of two pieces: one is long and the other is short, and it is placed in the metal reservoir. To decrease the helium losses by diffusion through the capillary at the high operating temperature, a glass mantle surrounds it, so that is remains relatively cold in the operating time.

By heating the spectroscopic pure selenium, the metal vapours are generated. The discharge current heats the capillary and, by radiation, the metal is also heated. In our experiment, the optimum laser operation was obtained when the metal was almost completely melted.

To avoid the melting of the glass capillary, the discharge current is limited to a small value, about 130 mA. As a consequence, the helium pressure must be higher than that reported in literature by other authors [2]. So, for an optimum discharge current value, an adequate helium pressure was 20 torr.

The laser tube has the cut ends at Brewster angle for 500 nm wavelength. Loctite UV 358 has been used to seal the windows on the laser tube. The resonator consists of a pair of the total reflecting dielectric mirrors having radius of curvature of 2 m, 100 nm bandwidth centered on 500 nm. Seven Se^+ lines oscillated simultaneously.

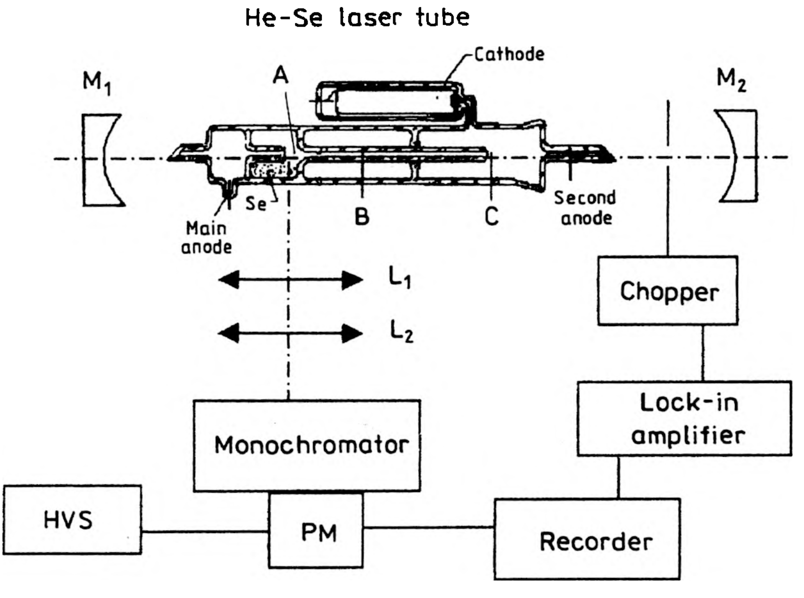

Fig. 1. Experimental set-up for lock-in signal analysis. M_1, M_2 – laser mirrors, L_1, L_2 – optical lenses, HVS – high voltage supply, PM – photomultiplier.

Figure 1 shows the experimental set-up. On the axis of the resonator there is a chopper.

The spontaneous emission at 90 degree was monitored. An optical system consisting of a pair of identical lenses focalizes the light on the monochromator slit An EMI 9558 B photomultiplier as well as a synchronous detection block and a recorder were used.

3. Results and discussion

Inside the laser tube, three specific regions A, B and C have been chosen. The amplification region B is just the active medium (a mixture of helium and selenium atoms and ions); the plasma parameters are about the same as reported elsewhere [6]. The C region is at the end of the long capillary. The A region is placed in the metal reservoir, at the end of the short capillary. In both regions A and C, the current density is much lower than in the B region. A blue cloud appears in the A region, between the end of the short capillary and the beginning of the long capillary. This cloud consists of selenium and helium atoms and ions.

Both mirrors are full reflecting. The laser beam is chopped and the lock-in signal is recorded using the experimental set-up described in Fig. 1.

The spectral lines corresponding to the laser oscillation are presented in Tab. 1.

Table 1. Spectral lines corresponding to the laser oscillations.

λ [nm]	Upper level	Lower level
497.57	$5p^2D_{5/2}$	$4s4p^{4\,2}P_{3/2}$
499.20	$5p^4P_{3/2}$	$5s^4P_{3/2}$
506.86	$5p^4P_{5/2}$	$5s^4P_{5/2}$
517.60	$5p^4D_{5/2}$	$5s^4P_{3/2}$
522.75	$5p^4D_{7/2}$	$5s^4P_{5/2}$
525.36	$5p^4D_{1/2}$	$5s^4P_{1/2}$
530.53	$5p^2D_{3/2}$	$5s^2P_{1/2}$

The sign of the recorded signal must be opposite for the amplification and absorption, respectively. We denoted the signal recorded from B region by the positive sign. The discharge current was 130 mA in all cases.

Table 2 presents modifications of the intensities of the lock-in signals with regard to the spectral lines presented in Tab. 1.

Table 2. Variations of the intensities of the spectral lines from the three regions A, B and C without magnetic field (a), with magnetic field (b).

ΔI [a.u.] \ λ [nm]	497.57	499.20	506.86	517.60	522.75	525.36	530.53	
	10	38	18	32	75	10	13	a
ΔI_B [a.u.]	23	62	28	50	95	17	20	b
	−15	−26	−11	−25	−60	0	−5	a
ΔI_A [a.u.]	−48	−65	−31	−47	−100	0	−16	b
	7	28	43	35	77	6	13	a
ΔI_C [a.u.]	15	46	20	46	98	10	20	b

The spectral scanning records show the presence of signals with opposite phase for A region regarding those recorded from B and C regions. From Tab. 2 we can conclude that in the A region the laser radiation is absorbed for all wavelengths, except the 525.36 nm radiation for which this region is perfectly transparent, in opposition to B and C regions.

The measurements from these regions were made without the presence of a magnetic field (**a**) and in the presence of a magnetic field (**b**), respectively. The magnetic field had an influence only if it was placed in the A region.

The influence of the magnetic field on selenium ion density was described in [7]. Figure 2 presents the absorption of 522.75 laser radiation vs. the distance measured from the end of the small capillary. This radiation was the preferred for representation because it was strongest one, as we can see from Tab. 2. The absorption region was scanned along the tube axis using a 0.5 mm diaphragm. We can observe that the absorption is significant only for one millimeter length in the absence of a magnetic field (**a**), and two millimeters in the presence of a magnetic field (**b**), respectively.

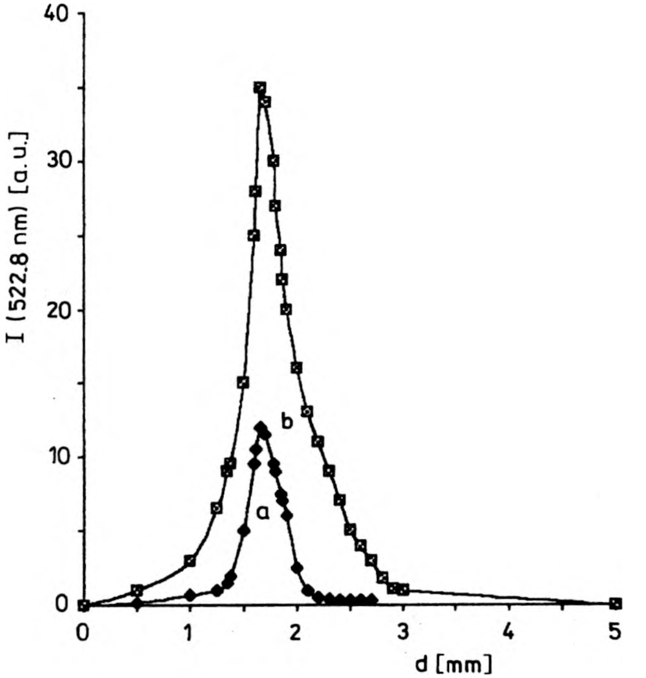

Fig. 2. Absorption of 522.75 nm radiation vs. the distance from the end of the small capillary: **a** — without magnetic field, **b** — with the magnetic field.

The absorption region appears just where the selenium vapour clouds penetrate the discharge region. By electron collisions, the metal molecules are broken into atoms and ions. As a result, the electronic temperature in that region is low, so that the density of helium ions is also low.

As a consequence, relation (1) has a low rate and the population inversion does not appar here. The existence of the strong absorption of laser radiation shows that the lower laser levels are highly populated by electronic collisions or, alternatively, by the reaction

$$\mathrm{Se}+\mathrm{He}(2^1\mathrm{S}_0 \text{ or } 2^3\mathrm{S}_1) \rightarrow (\mathrm{Se}^+)^* + \mathrm{He} + \Delta E \quad (2)$$

where $(\mathrm{Se}^+)^*$ signify the lower laser levels of the selenium ion. Energetically this corresponds to

$$\mathrm{O}+\mathrm{He}[(19.82 \text{ or } 20.61)\mathrm{eV}] \rightarrow \mathrm{Se}[(21.55 \div 23.25)\mathrm{eV}] + \mathrm{O} + \Delta E. \quad (3)$$

In He-Se positive column, on the tube axis, $kT \approx 2.5$ eV [3], so that the superposition of the existence of reaction (2) seems to be valid.

The presence of such a reaction can explain the appearance of the laser radiation absorption in the region A. Evidently, it takes place also in the amplifying region B but at a lower rate, contributing, however, to a reduction of the population inversion.

4. Conclusions

Using the perturbation spectroscopy method in a home-made self-heating He-Se laser tube, a strong absorption region was detected. The reduction of the emitted laser radiation power is not very important because this region is thin enough.

An important contribution of helium metastable levels is to generate the selenium ions by electron collisions, and also to populate the lower laser levels.

In our opinion, the reaction presented by Eq. (2) is responsible for absorption of the laser beam. The reaction takes place also in the amplification region B but at a lower rate, and contributes to a decrease of the population inversion.

The presence of the magnetic field involves the increasing of the laser beam power, and also, it influences the absorption of the laser radiation.

We intend to continue this study in order to find the way for improving the laser operation.

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