THE EFFECT OF SUBSTITUTING METAL VAPOUR WITH METAL HALIDE VAPOUR IN A HOLLOW CATHODE LASER DISCHARGE

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1. Introduction

For the operation of hollow cathode discharge metal vapour — noble gas lasers high temperature is generally required [1, 2, 3]. New metal vapour lasers e. g. Cu, Pb, that are promising from the point of view of laser operation in the UV spectral region, can not be realized in practice using the conventional technique of heating the metal because of the high temperatures required (above 1000 °C). However, heating some volatile molecule of the metal instead of the pure metal is promising. In this case the molecule is expected to dissociate in the discharge and the optimum metal vapour partial pressure can be achieved at a significantly lower temperature [4, 5].

Systematic comparison of the noble gas-metal vapour and noble gas-metal halide vapour systems was performed. He, He—Zn and He—$ZnCl_2$ were examined in a hollow cathode discharge tube measuring the optical (spontaneous line intensities) and electric parameters of the discharge. The effect of adding pure metal or metal halide vapour to the noble gas in the discharge was investigated, and in this way the difference of the processes occurring in the two systems could be clarified.

2. Experimental results

The experimental setup has been described in Ref. [6]. Measurements were carried out using the hollow cathode discharge tube shown in Fig. 1 with He, He—Zn and He—$ZnCl_2$ fillings.

Curves 1, 2, 3 in Fig. 2 show the discharge voltage in pure He as a function of He pressure at three different temperatures. One can see that with the increase of temperature the maximum of the curves shifts towards high pressures. This same figure shows the He-pressure dependence of the discharge voltage in He—Zn (curves 4, 5) and He—$ZnCl_2$ (curves 6, 7) mixtures. It is interesting to note that for $ZnCl_2$ the voltage is higher than for Zn, already at low temperatures. To observe the variation of Zn concentration the intensity

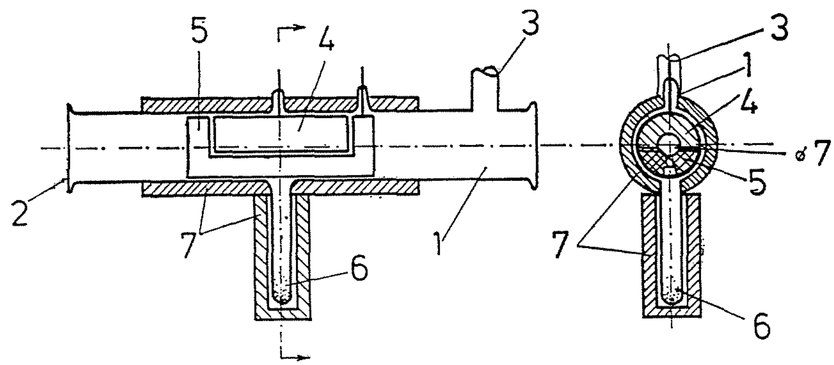

Fig. 1. **The hollow cathode discharge tube 1. pyrex tube, 2. end window, 3. connection to the vacuum system, 4. cathode, 5. anode, 6. Zn or $ZnCl_2$, 7. ovens**

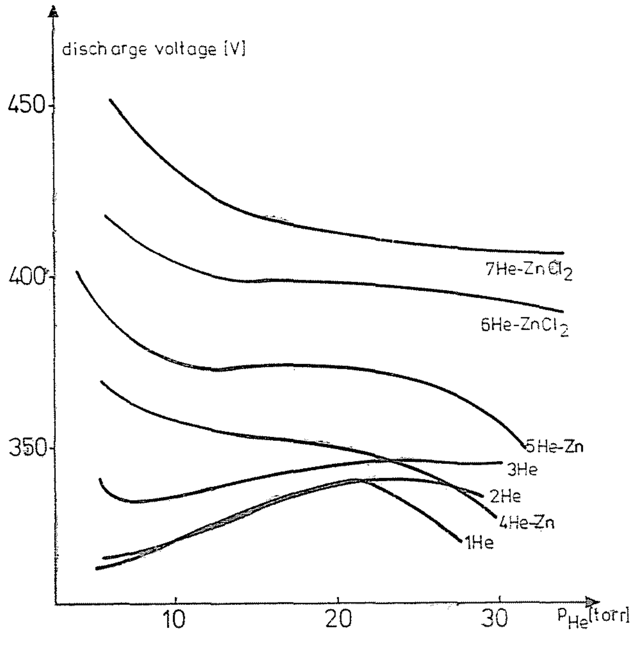

Fig. 2. The variation of discharge voltage with He pressure at constant current (I = 378 mA) for He 1. T = 20 °C, 2. T = 80 °C, 3. T = 440 °C; for He—Zn, 4. T = 440 °C, 5. T = 500 °C and for He—$ZnCl_2$, 6. T = 380 °C, 7. T = 415 °C

of the 481 nm line of Zn I was measured (Fig. 3). It increases approximately linearly with the temperature for pure Zn, while for $ZnCl_2$ the Zn concentration grows faster than linear.

In the following the comparison of the two laser media were carried out at temperatures coresponding to equal Zn I line intensities assuming that the Zn concentrations are approximately equal at these two temperatures. A lower

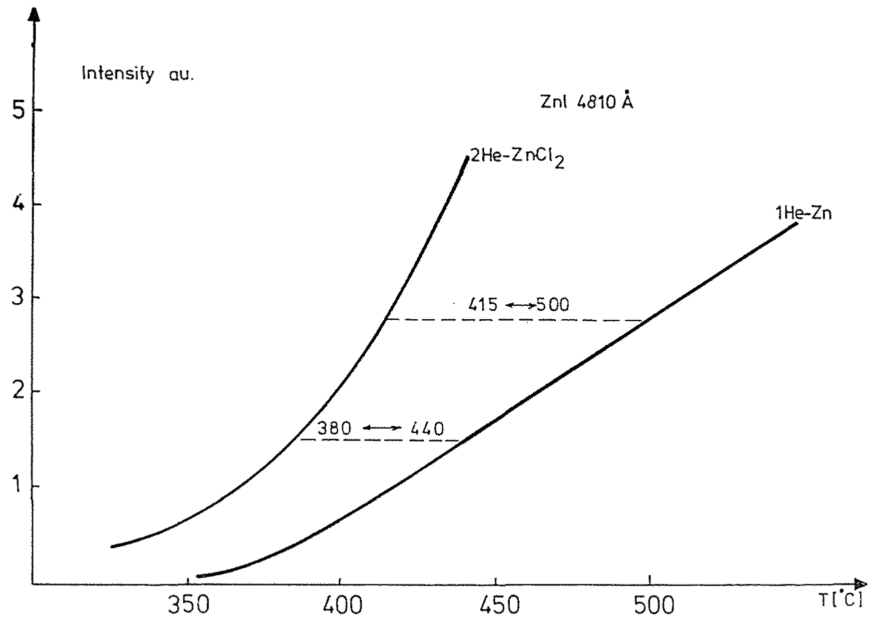

Fig. 3. The intensity of the 4810 Å Zn I line as a function of oven temperatures, i.e. Zn concentration at constant current (I = 378 mA) in arbitrary units for 1. He—Zn and 2. He—$ZnCl_2$, p_{He} = 10 torr

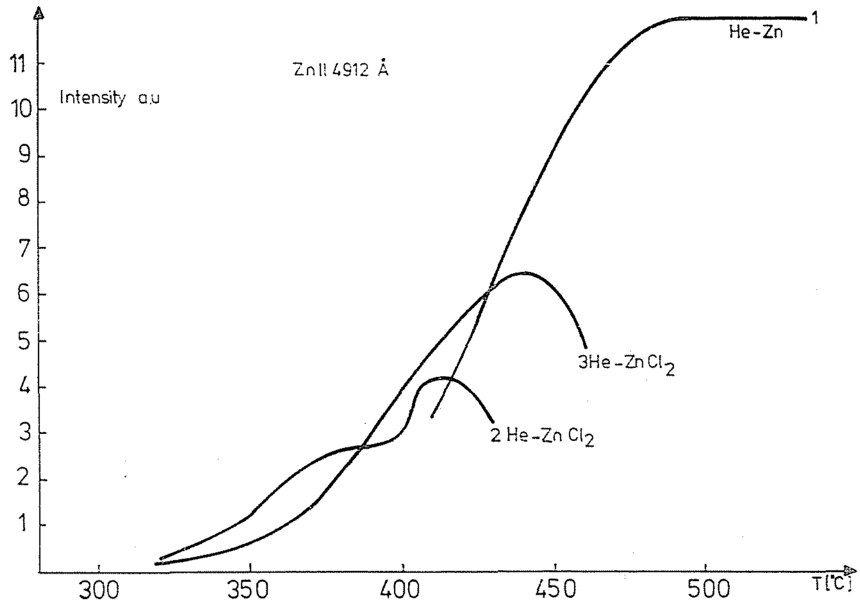

Fig. 4. The intensity of the 4912 Å Zn II line as a function of oven temperatures (Zn concentration) at constant current (I = 378 mA) in arbitrary units for 1. He—Zn, p_{He} = 10 torr, 2. He—$ZnCl_2$, p_{He} = 10 torr, 3. He—$ZnCl_2$, p_{He} = 20 torr

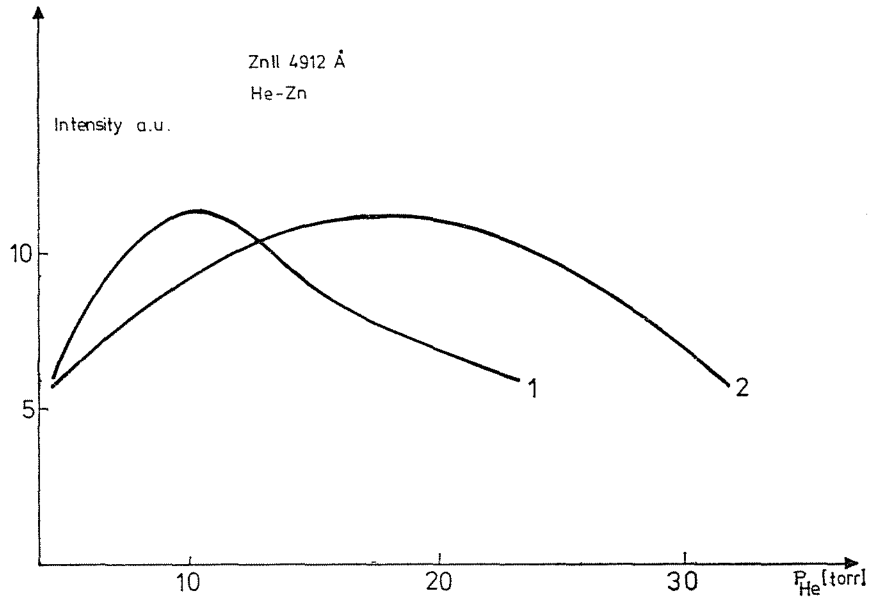

Fig. 5. The intensity of 4912 Å Zn II line as a function of He pressure at constant current (I = 387 mA) in He—Zn at different oven temperatures i. e. Zn concentrations in arbitrary units 1. T = 440°C, 2. T = 500°C

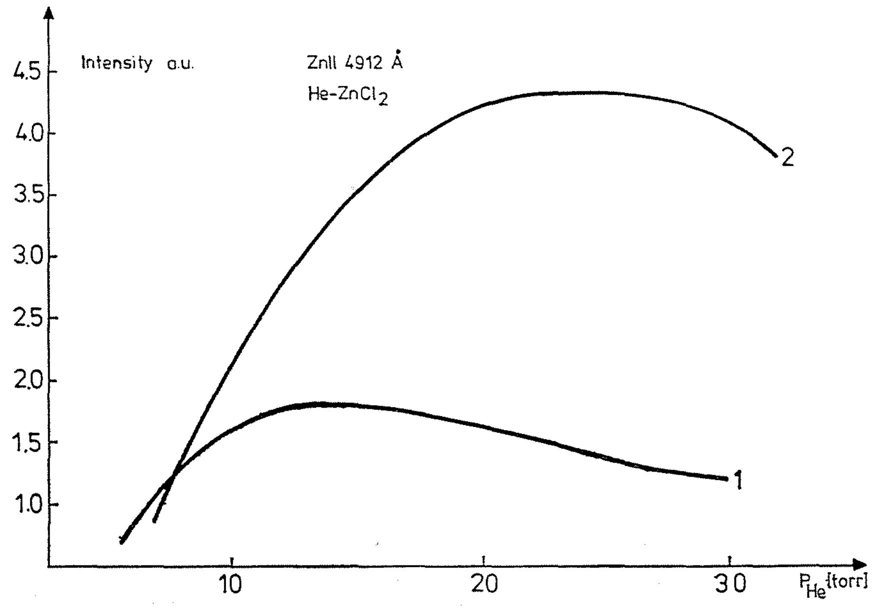

Fig. 6. The intensity of 4912 Å Zn II line as a function of He pressure at constant current (I = 378 mA) in He—ZnCl at different oven temperatures i.e. Zn concentrations in arbitrary units 1. T = 380 °C, 2. T = 415 °C

and a higher pair of temperatures were selected (380 °C—440 °C, 415 °C—
—550 °C Fig. 3). The lower values are just slightly above the melting points of the materials.

From the Zn II laser lines the one with $\lambda = 491.2$ nm was selected. Its spontaneous line intensity was measured as a function of temperature (Fig. 4) and He-pressure (Figs 5. and 6). The temperature dependence shows saturation for the pure metal, while an optimum can be observed for $ZnCl_2$. Cl I lines could not be observed in the discharge, Cl II lines were very weak including the laser lines, as well [7].

The 491.2 nm laser line increased monotonously with the discharge current [1, 4] therefore all the measurements were carried out at a constant current value (378 mA).

3. Discussion

The anode-cathode distance outside the hollow cathode region was 0.5 mm for the discharge tube used for these experiments. The length of cathode dark space for He is about 1 cm torr [8], i.e. above 20 torr the discharge can occur outside the hollow cathode, as well. This may cause drop in discharge voltage for pure He at room temperature above 22 torr (Fig. 2, curve 1.). This point is shifted towards higher pressures at higher temperatures that can be attributed to the decrease in gas density. At 440 °C the drop can be expected only above 50 torr in pure He. This also shows that one has to be careful interpreting high temperature data when pressure is measured outside the high temperature zone. Adding Zn or $ZnCl_2$ causes a rise in discharge voltage (Fig. 2) because of the appearance of the ions with lower ionization potential but larger mass in the ion current [8]. The discharge voltage is expected to tend towards the values measured in pure He with increasing He pressure. Instead of this the discharge voltage in Zn filling drops at 440 °C to a pressure corresponding to the 20 °C curve. At 500 °C the drop occurs a few torrs higher. This shows that the presence of Zn significantly changes the length of the cathode dark space. At the same time similar effect was not observable for $ZnCl_2$ in the range of our measurements. Addition of $ZnCl_2$ to the He discharge causes a much higher raise in voltage than pure metal vapour does already at low temperature because a part of the charge carriers must take part in the dissociation of the $ZnCl_2$ molecule.

Let us consider the intensity of Zn II line as a function of temperature at constant current (I = 378 mA) in the media Zn and $ZnCl_2$ (Fig. 4). In pure metallic discharge (1. curve: $p_{He} = 10$ torr) the intensity of ion line is greater, however increasing the temperature it becomes saturated, while in the case of $ZnCl_2$ at both pressures (2. curve $p_{He} = 10$ torr, 3. curve $p_{He} = 20$ torr) it shows an optimum. Since the number of the ionizing participants is limited, therefore the number of Zn ions is limited, too. So it is evident, that the intensity of Zn II line does not increase after a certain temperature. (1. curve). In the case of $ZnCl_2$ with increasing temperature, the number of molecules that are able to take part in dissociation process, also increases. Fig. 3 shows that the Zn concentration increases with increasing temperature. This indicates that the molecules take part in the dissociation process indeed. This process decreases the number of molecules participating in ionization of Zn atoms, therefore the intensity of ion line after an optimum of the temperature (concentration) does not increase already, at a constant pressure and current. This optimum temperature depends on the pressure of He, i.e. on the number of participants taking part in the dissociation and ionization processes. This phenomenon gives an explanation for the weakness of Zn ion line and that the optimum temperature increases at higher He-pressure. Figs 5 and 6 show the intensity of 4912 Å Zn II line as a function of He-pressure, at same Zn concentrations in both cases. It is clear that these temperatures are different for the different media. At small concentration in both media the He-pressure dependence is very strong, and at higher temperatures the curves broaden. In the temperature range where the He-pressure dependence is strong, it is probable that the $He^{+}+Zn \rightarrow Zn^{+*}+He$ charge exchange reaction plays an important role. Laser operation occurs in the range of selective excitation. Optimum temperatures 440–460 °C for He–Zn and 380–400 °C for He–$ZnCl_2$ were observed [1, 4] well agreeing with our measurements.

Decreasing of line intensity in the case of $ZnCl_2$ at low temperatures in the range of selective excitation suggests the presence of He in the dissociation of molecule $ZnCl_2$. Threshold currents were higher for He–$ZnCl_2$ by a factor of 5, corresponding to the ratio of line intensities observed by us.

4. Conclusions

Substitution of pure metal with metal-halide in a hollow cathode metal vapour laser causes no difficulties with the discharge. Optimum metal vapour density can be reached at a low temperature. For Zn this is about 60 °C. On the other hand an increase in threshold current can be expected because of the role He plays in the dissociation of the molecule. This was observed in [4] for all laser transitions for different metal halides. This decrease in efficiency seems to be worth if considering the decrease in operating temperature that can otherwise reach about 1000 °C for He–Cu lasers.

Summary

He–Zn and He–$ZnCl_2$ hollow cathode discharges were compared. The metal vapour concentration necessary for laser operation can be achieved at a lower temperature for the molecular substance. On the other hand the efficiency decreases because part of the He ions, necessary for the selective excitation of the upper laser level of the metal ion, is lost in the dissociation process.

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