BULLETIN DE L'ACADÉMIE
8. POLONAISE DES SCIENCES
Série des sciences techniques
Volume XXIII, No. 5 — 1975

QUANTUM ELECTRONICS

Plasma Parameters in the Positive Column He-Cd$^+$ Lasers*)

by

J. K. MIZERACZYK**)

Presented by R. SZEWALSKI on January 31, 1975

Summary. Electric field, electron temperature and density have been measured over the whole range of the typical He—Cd$^+$ laser discharge conditions with the modified double-probe method. The results can be used for explanation of the saturation effects in He—Cd$^+$ lasers.

In the recent years several papers have been published, for instance, [1—6] which report the results of plasma parameter measurements in a positive-column He—Cd laser discharge. A certain knowledge about such plasma parameters as the electric field, electron temperature and density in addition to transition probabilities and cross section data is necessary for investigation of excitation and saturation mechanisms of a PC He—Cd$^+$ laser power output. But using the values of plasma parameters obtained in [1—6] to estimate the excitation and destruction processes in the He—Cd laser discharge meets with difficulties. Values proposed by different investigators differ not only quantitatively but even qualitatively as in the case of the determination of electron density.

Reviewing the discrepancy between the results of the previous works and following the increasing interest in determination of the plasma parameters in He—Cd laser discharge the demand arises to measure the electric field, electron temperature and density. This paper reports the measurements of the electric field, electron temperature and density in the He—Cd laser discharge in the whole region of interest and it also comprises the comparison of the obtained results with the previous ones.

The cataphoresis type discharge tube used in these measurements was 3 mm in diameter and about 40 cm in active length. Cadmium of natural isotopic abundance was supplied from the sidearm placed at the 2/3 of the active length, closer to the anode. The sidearm temperature was stabilized to better than $\pm 1/2$°C. All parts

*) This work was sponsored by the Institute of Quantum Electronics, Military Academy of Technology (WAT), Warsaw-49, Poland.

**) The author is on leave from the Institute of Fluid Flow Machines, Polish Academy of Sciences, Gdańsk. Now he is with the Department of Electronics, Nagoya University, Nagoya, Japan as visiting scientist sponsored by the Japan Society for the Promotion of Science.

of the tube except the small region of cadmium condensation were put in the oven at a temperature of 350±7.5°C. The experiments were made over the following range of parameters: the discharge current, 15—155 mA, helium pressure, 1.5—6

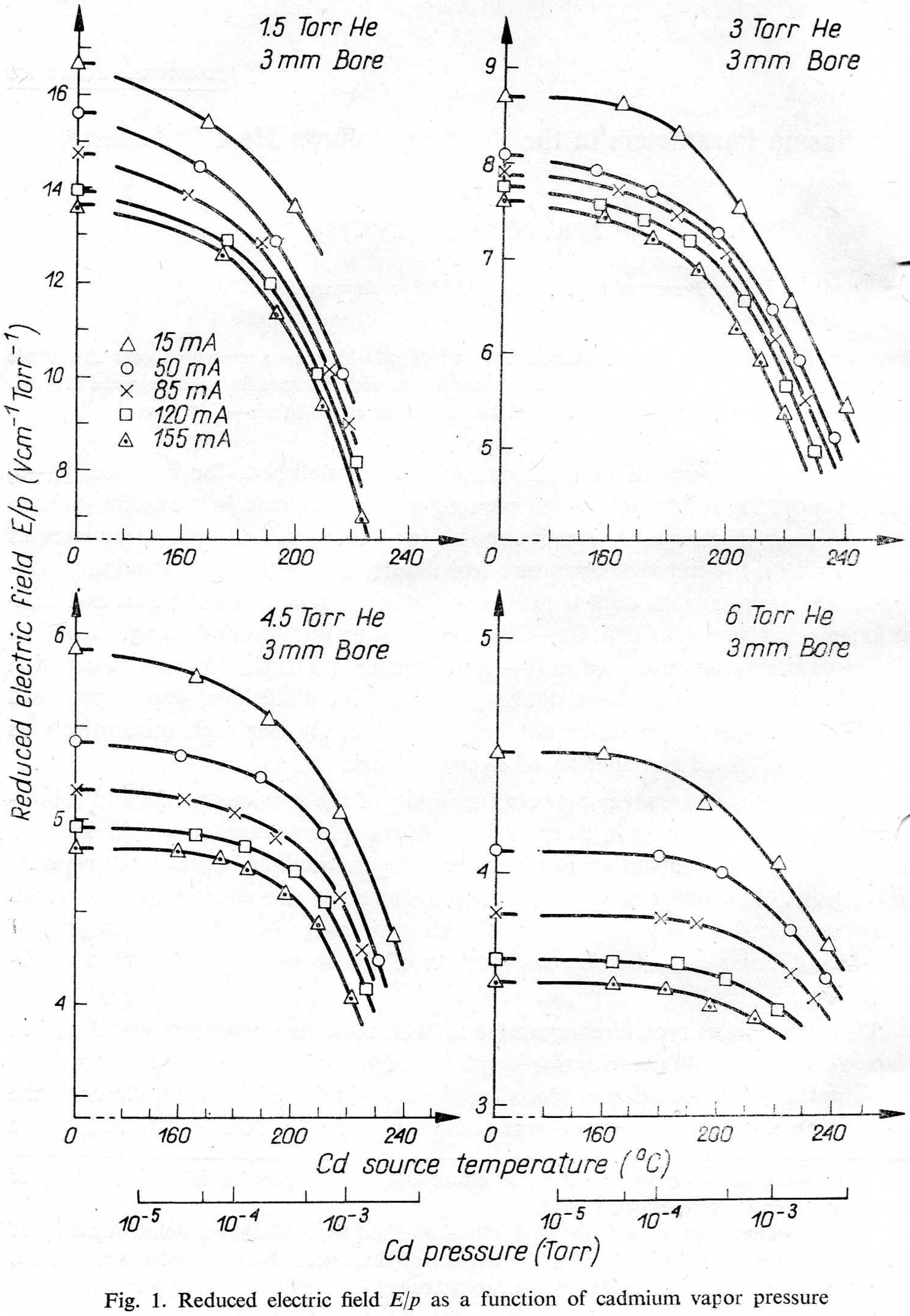

Fig. 1. Reduced electric field E/p as a function of cadmium vapor pressure

Torr, cadmium vapor pressure, 10^{-5}—$2 \cdot 10^{-3}$ Torr. The cadmium pressure in the discharge was estimated from the temperature of the sidearm. The plasma parameters: electric field, electron temperature and density were obtained using the double-probe technique modified [7] to avoid the difficulty in getting the electron density in the He—Cd discharge from the conventional double-probe method [1, 6].

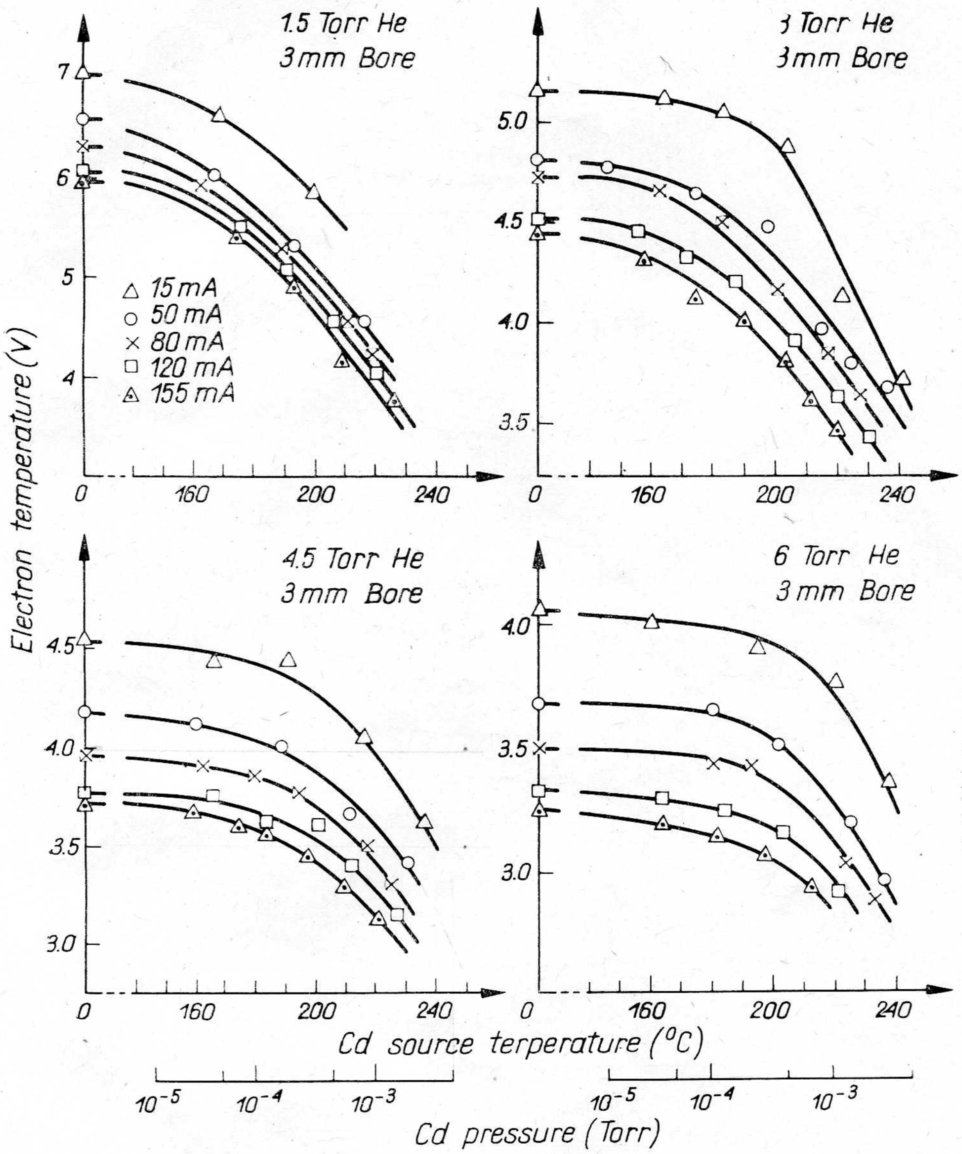

Fig. 2. Electron temperature as a function of cadmium vapor pressure

The results are shown in Figs. 1—3. Fig. 1 presents the reduced electric field E/p in the He—Cd plasma as a function of cadmium vapor pressure (E — electric field, p — helium pressure). It is seen that the reduced electric field decreases rapidly with increasing cadmium pressure. The influence of cadmium vapor on the reduced electric field is smaller at higher helium pressures. The reduced electric field scarcely changes with discharge current but remarkably decreases when the

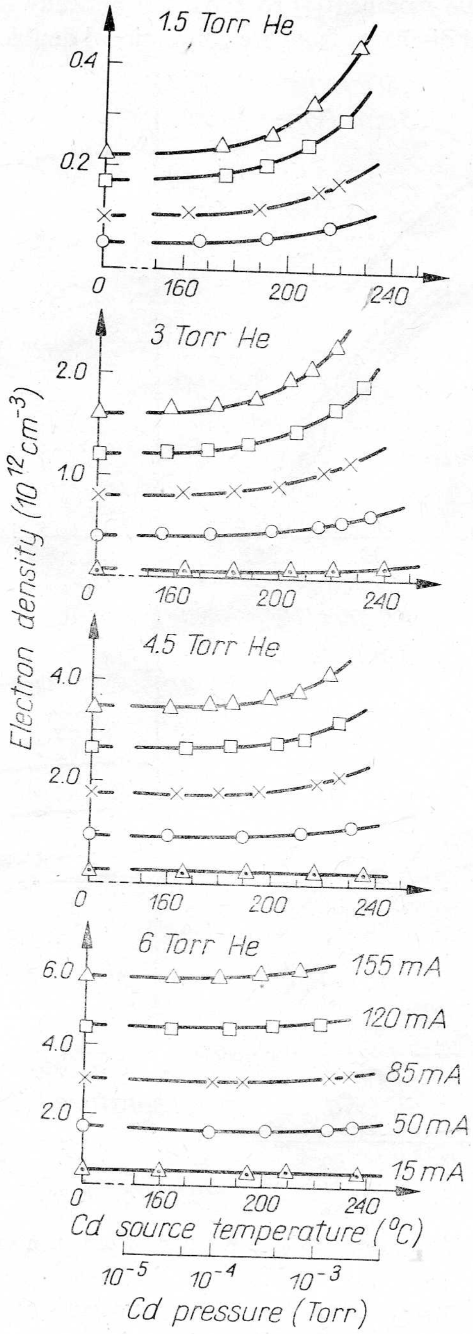

Fig. 3. Electron density as a function of cadmium vapor pressure

helium pressures is increased. The values of the E/p obtained herein are in a good agreement with those not numerous presented in [5].

The dependence of electron temperature in He—Cd laser discharge on cadmium vapor pressure is presented in Fig. 2. The behavior of electron temperature in He-Cd plasma is similar to the behavior of the reduced electric field, i.e. the electron temperature depends strongly on cadmium pressure and remarkably on helium pressure. The influence of cadmium vapor on the electron temperature becomes smaller when helium pressure increases. The dependence of electron temperature on discharge current cannot be neglected. Comparisons show that the values of electron temperature obtained in these experiments for the He—Cd discharge in 3 mm bore tube are fairly close to those [1] in the 5.6 mm bore tube at equal values of the product of pD, where p and D are the helium pressure and diameter of the tube, respectively. Therefore, as proposed in [8], the electron temperature in the helium-metal vapor discharges in the different bore tubes can be estimated roughly from the pD dependence. The values of the electron temperature presented in [3] are higher than those obtained herein or in [1].

Fig. 3 shows the electron density as a function of cadmium vapor pressure. The electron density increases almost linearly with the increasing discharge current and a little faster than linearly when helium pressure is increased. This behavior of electron density in He—Cd discharge was observed in [1] and [3], too. However, when the cadmium vapor pressure increases the electron density increases on the contrary to the results of [1] and [6], where the electron density decreases over the range of cadmium pressure between 10^{-5}—10^{-3} Torr. This discrepancy is due to the using of the conventional double-probe method in [1] and [6] to measure the electron density in the gas mixture discharge. The modifying of conventional double-probe method [7] allows to obtain the present results which are in a good agreement with not numerous results of [3] and [4] measured by a microwave cavity technique.

The region in which the optimum output power of the 4416—A° He—Cd^+ laser action in 3 mm bore tube is observed corresponds to a cadmium vapor pressure approximately 10^{-3} Torr [5, 7, 9, 11]. It is seen from Figs. 1—3 that in this region the reduced electric field and the electron temperature rapidly decreases, whereas the electron density begins to increase rapidly with increasing cadmium pressure. Such behavior of the He—Cd plasma parameters affects the saturation of the He—Cd^+ laser power output. It was proved [11] using the results presented herein.

The author is grateful to Doc. Dr. Z. Zakrzewski and Dr. T. Kopiczyński for helpful discussions and their cooperations in preliminary experiments, and to Dr. J. Konieczka for his useful suggestions about the construction of discharge tube. The author would like to express his thanks to Professor Shuzo Hattori and Dr. T. Goto of Nagoya University for many helpful discussions at final stage of this work. Finally, the author would also like to thank Mr. J. Ziemann for the technical assistance and Mr. H. Stawski for performance of the tube.

INSTITUTE OF FLUID FLOW MACHINES, POLISH ACADEMY OF SCIENCES, GEN. FISZERA 14, 80-231 GDAŃSK
(INSTYTUT MASZYN PRZEPŁYWOWYCH, PAN, GDAŃSK)

REFERENCES

[1] T. Goto, A. Kawahara, G. J. Collins, S. Hattori, *Electron temperature and density in positive column He-Cd$^+$ lasers*, J. Appl. Phys., **42** (1971), 3816—3818.

[2] I. G. Ivanov, J. L. Latush, W. F. Papakin, M. F. Sem, *Plasma parameters and pumping mechanism in He-Cd laser*, Izv. V.U.Z., Fizika, **87** (1972), No. 8.

[3] I. G. Ivanov, M. F. Sem, *Determination of charged-particle density in the plasma of a cadmium-helium cataphoresis laser*, Zh.T.F., **42** (1972), 1542.

[4] M. H. Dunn, *Electron densities and drift velocities in a positive column He-Cd laser discharge*, J. Phys. B, Atom Molec. Phys., **5** (1972), 665—672.

[5] P. G. Browne, M. H. Dunn, *Metastable density and excitation processes in the He-Cd laser discharge*, ibid., **6** (1973), 1103—1117.

[6] T. Kopiczyński, J. Mizeraczyk, Z. Zakrzewski, *Measurements of plasma parameters in He-Cd$^+$ laser using double electric probe*, *Proc. of Quantum Electronics and Nonlinear Optics*, [in Polish], *Poznań*, 1974, *pp.* 149—155.

[7] J. K. Mizeraczyk, *A simple method of determination of electron density in positive-column He-metal laser discharges,* J. Appl. Phys., **46** (1975), 1847–1848.

[8] T. Goto, [private information].

[9] W. T. Silfvast, *Penning ionization in a He-Cd discharge*, Phys. Rev. Lett., **27** (1971), 1489—1492.

[10] T. Goto, A. Kawahara, S. Hattori, *Excitation mechanism in a positive-column He-Cd$^+$ laser*, *Plasma Symposium at Inst. Electrical Eng. Japan*, *EP*-71—7, 1971.

[11] J. K. Mizeraczyk, *On saturation mechanisms in PC He-Cd$^+$ lasers*, IEEE J. Quantum Electron., **QE-11**, (1975), 218–220.

Е. К. Мизерачик, **Параметры плазмы в He-Cd$^+$ лазере с положительном столбом**

Содержание. При помощи модифицированного метода двойного зонда поизводились измерения электрического поля, температуры и плотности электронов во всей области параметров разряда, типичных для He—Cd$^+$ лазеров. Полученные результаты могут быть применены для выясьнения эффектов насыщения в He—Cd$^+$ лазерах.