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# ELECTRON TEMPERATURE IN THE ELECTRIC DISCHARGE USED FOR THE ARGON ION LASER

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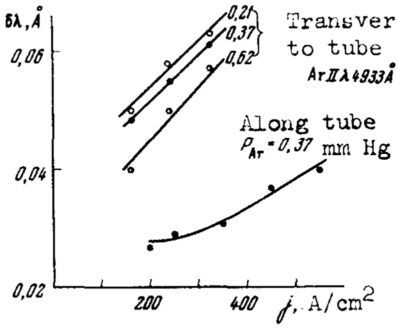
In an earlier investigation [1] we obtained information on the charged-particles concentration and the gas temperature in argon under conditions typical of the operation of a continuously operating ionic argon laser ($p_{Ar} \simeq 0.4$ Torr, $j = 200 - 550$ A/cm$^2$, capillary radius $r = 0.8$ mm).

The gas temperature turned out to be 1600 - 3600°K, and the electron concentration $\sim(3 - 4) \times 10^{13}$ cm$^{-3}$.

It follows from these results that the degree of ionization of the gas in such a discharge is ~1% and the ion mean free path $\lambda_i$ is larger than the capillary radius r, if a value $5 \times 10^{-15}$ cm$^2$ is assumed for the charge-exchange cross section [2] and account is taken of the crowding out of the argon from the capillary by the high temperature of the gas. Thus, we can assume that under the indicated conditions the decisive influence on the ion motion in the discharge column is exerted by the drift of the ions to the wall and their recombination.

The present investigation was devoted to a determination of the electron temperature in a discharge of this type.

To this end, measurements were made of the half-width of the Ar II lines radiated transverse to the discharge. The investigations were made in a tube of 2.8 mm diameter and ~40 cm length, with a bypass channel. The gas pressure ranged from 0.21 to 0.62 Torr and the current density from 150 to 350 A/cm$^2$.



The figure shows the measured half-width of the λ 4933-Å line of Ar II, transverse to and along the discharge, as a function of the current density. The thickness of the Fabry-Perot etalon was 1 cm.

As seen from the figure, the width of the Ar II line increases with increasing current density. The width $\delta\lambda_{i\perp}$ of the line radiated transverse to the channel exceeds the width $\delta\lambda_{i\parallel}$ of the line radiated along the discharge by a factor ~1.5-2.

From the widths $\delta\lambda_{il}$ of the ion lines we determined the "effective temperature" of the ions transverse to the discharge, $T^*_\perp(\delta\lambda_{il}) = 2\sqrt{\ln 2}\,(\lambda_i/c)\,\sqrt{2RT^*_\perp/\mu}$.

Recognizing that $\lambda_i > r$, we can determine the electron temperature $T_e$ by using the theory of Yu. M. Kagan and V. I. Perel' [3], which gives the connection between $T^*_\perp$ and $T_e$ in the form

$$T^*_\perp = 0.56T + 0.13T_e,$$

where T is the gas temperature.

The term $0.13T_e$ reflects the existence of a transverse potential $U_\perp$, which accelerates the ions toward the tube walls, and which is connected with $T_e$, under the condition $\lambda_i > r$, by the relation $eU_\perp = 1.1\ kT_e$.

| j, A/cm$^2$ | $T_e \times 10^{-4}$ °K | | | $N_e \times 10^{-13}$ cm$^{-3}$ | | | $N_e \times 10^{-13}$, exper. |
|---|---|---|---|---|---|---|---|
| | P, Torr | | | P, Torr | | | P, Torr |
| | 0.21 | 0.37 | 0.62 | 0.21 | 0.37 | 0.62 | 0.4 |
| 150 | 5.5 | 5 | 3.3 | 1.0 | 1.8 | 2.4 | |
| 200 | 6.6 | 5.9 | 4.3 | 1.4 | 2.3 | 3.3 | 3.4 |
| 250 | 7.6 | 6.9 | 5.3 | 1.6 | 2.8 | 4.1 | |
| 300 | 8.7 | 7.9 | 6.3 | 1.8 | 3.1 | 4.6 | |
| 350 | 9.9 | 9.1 | 7.6 | 1.9 | 3.2 | 4.8 | |

The obtained values of $T_e$ are listed in the table. It is seen from the table that $T_e$ increases from $5 \times 10^4$ to $9 \times 10^4$ (for $p_{Ar} = 0.37$ Torr) when the current density rises from 150 to 350 A/cm$^2$. If the growth of $T_e$ with increasing j remains linear at larger current densities, too, then we can expect $T_e$ to reach a value $13 \times 10^4$ °K at $j = 550$ A/cm$^2$. When the temperature $T_e$ rises from $5 \times 10^4$ to $9 \times 10^4$, $U_\perp$ increases accordingly from 4.6 to ~8.3 V.

It follows from our results that the increase of the intensity of the spontaneous radiation of the Ar II lines and the increase of the power of the coherent radiation of the laser with increasing current density in the capillary are due primarily to the increase in the electron temperature.

If the electron temperature is known, the electron density can be determined by using a formula given by Kolesnikov [4] for the electric conductivity

$$\sigma = \frac{407N_e k_\sigma(0)}{T_e^{1/2}[N_i\langle Q_i\rangle + N_a\langle Q_a\rangle]}$$

and the connection between the electric conductivity and the current density, $j = \sigma E$. The values of j and E are known from experiment; $N_i$ and $N_a$ are the concentrations of the ions and atoms in the discharge; $\langle Q_i \rangle$ and $\langle Q_a \rangle$ are the corresponding cross sections for the electric conductivity. Estimates indicate that in our case the term $N_i \langle Q_i \rangle$ ($\langle Q_i \rangle \sim 10^{-14}$ cm$^2$) can be neglected, with accuracy ~15%, compared with the term $N_a \langle Q_a \rangle\ k_\sigma(0) \sim 1$. The electric-conductivity cross section $\langle Q_a \rangle$ was calculated as a function of the electron temperature by P. L. Rubin 1). It is equal to $8 \times 10^{-16}$ cm$^2$ at $5 \times 10^4$ °K and $6 \times 10^{-16}$ cm$^2$ at $9 \times 10^4$ °K. The calculated values of $N_e$ are listed in the table. They are in satisfactory agreement with the values experimentally determined from the half width of the hydrogen line $H_\beta$. It is also seen from the table that when j is doubled, $N_e$ (the electron concentration) also almost doubles. Summarizing, we can state that the foregoing investigations have yielded the basic characteristics of the discharge used for the argon ionic laser, which are of undisputed interest for the explanation of the mechanism that ensures population inversion. We emphasize that the fact established by us, that $T_e$ increases with current density, is not subject to doubt, but the absolute values of the temperature must be verified by other independent methods.

In conclusion the authors thank A. A. Rukhadze for valuable discussions and advice.

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# THE DE HAAS - VAN ALPHEN EFFECT IN ZINC IN PULSED MAGNETIC FIELDS

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The present investigation was devoted to the de Haas - van Alphen effect in zinc in pulsed magnetic fields up to 75 kOe. The experiments in static magnetic fields up to 30 kOe [1,2] (a review of earlier work is given in the paper by Joseph and Gordon [1]) did not give a sufficiently complete picture of the high-frequency oscillations connected with the large parts of the Fermi surface. This connection, as is well known, is given by the relation $F = cS/2\pi e\hbar$ [3], where F is the oscillation frequency in Oe and S the area of the extremal section of the Fermi surface in a plane perpendicular to the direction of the magnetic field in k-space, in units of $(2\pi/\text{Å})^2$.

The pulsed magnetic field was produced by discharging a 2000 μF capacitor bank charged to 2100 V through an inductance coil. A test coil containing the sample was placed in the center of the solenoid and its axis could be rotated ±30° relative to the direction of the magnetic field. The elements of the apparatus will be described in detail in a separate