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On Probe Measurements of Plasma Parameters in Ion Metal Vapor Lasers

by

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Summary. The specific features resulting from the presence of the electron-neutral and ion-neutral collisions in ion metal-vapor lasers are discussed in detail. The resulting criteria for the probe dimensions are presented. A method of interpretation of results is described which allows to calculate the electron density without the laborious iteration procedure.

List of regular symbols

D — discharge tube diameter,
e — electron charge,
I_i — ion current,
I_{i0} — random thermal current,
k — Boltzmann constant,
l_p — probe length,
m_i, m_e — ion and electron mass,
n — electron number density,
p — neutral gas pressure,
r_p — probe radius,
$r_p x_0$ — sheath radius,
$s = r_p (x_0 - 1)$ — sheath thickness,
V_p — probe potential,
$V_e = \frac{kT_e}{e}$ — electron temperature,
x_0 — normalized sheath radius
λ_D — Debye length,
λ_i — ion mean free path,
μ_i — ion mobility.

Subscripts

1, 2 — numerical designation for double-probe electrodes,
e — electron,
i — ion,
p — probe.

1. Introduction. In recent years considerable amount of work has been done [1—6] in application of the cylindrical probe technique to measurements of plasma parameters in ion metal-vapor lasers (e.g. the $He\text{-}Cd^+$, $He\text{-}Se^+$, $He\text{-}J_2$ lasers). Nevertheless there is a lack of a general analysis of the factors involved. This concerns both the theoretical principles and the experimental technique of such measurements.

The conditions existing in ion metal-vapor lasers cause some difficulties in probe measurements. On the other hand, application of the probe technique is impelled by its indisputable advantages, first of all simplicity of the equipment and procedure.

In ion metal-vapor lasers the optimal conditions for laser operation are defined as

$$(1) \qquad (pD)_{opt} = \text{const}.$$

The constant (1) depends on the kind of gas and of metal vapor used. Typical values of the total pressure p and the plasma diameter D are few torr and few millimetres, respectively. It means that the mean free parts of electrons and ions are comparable to the radius of cylindrical probe. Also the transversal dimensions of a plasma column are comparable to the probe length. These are the reasons that the electron-neutral and ion-neutral collisions and also the spatial nonuniformity of plasma have to be taken into account.

It is the purpose of the present work to discuss the specific features of probe measurements resulting from the factors mentioned above. The conclusions important for preparation of an experiment and for interpretation of its results are pointed out.

There exist additional difficulties in the probe measurements performed on plasma of ion metal-vapor lasers. They are connected mainly with the presence of metal vapors in the laser tube. These will not be discussed in this note.

2. Effect of ion collisions on probe measurements. The following measured data are required to determine an electron temperature and density from the probe measurements. For a single probe: the slope of the lin-log characteristic in the electron retarding region and the saturation ion current. For a floating double probe: the slope of lin-lin characteristic in the point of zero probe current and the value of saturation ion currents.

As shown by Talbot *et al.* [8, 9] the electron current to a probe is strongly affected by the presence of even scarce collisions in plasma. Therefore, the measurements with a single probe no longer yield the correct value of the electron temperature in our case. On the other hand, the value of the electron temperature determined from the double probe characteristic remains to all intentions and purposes unaffected by the presence of collisions.

The saturation ion current depends strongly on collisions. There exists a recognized theory of Talbot *et al.* [8] of the ion collection by probe in the presence of collisions. It covers the entire range of λ_i/λ_D and r_p/λ_D and predicts a monotonic decrease of probe current with growing r_p/λ_D or r_p/λ_i. However, the recent measurement by the authors [7] indicates an occurrence of a well pronounced resonance effect in ion collection by a probe when the thickness of the space charge sheath surrounding the probe is comparable with the mean free path of ions ($\lambda_i \sim s$). The dependence of dimensionless ion current on λ_D/λ_i and r_p/λ_D postulated in [7] is shown in Fig. 1.