

SPECTROSCOPIC STUDIES OF InI-Hg HIGH-PRESSURE ARC  
TUŠ GEGAJ\*, VIŠNJA HENČ-BARTOLIĆ\*\*, GORAN PICHLER, JADRANKA  
RUKAVINA<sup>+</sup> and TIHOMIR ŠETINC<sup>+</sup>

*Institute of Physics of the University, 41000 Zagreb, Yugoslavia, POB 304*

*\* Faculty of Science, 38000 Priština, Yugoslavia*

*\*\* Faculty of Electrical Engineering, University of Zagreb, Yugoslavia*

*+ TEŽ, 41000 Zagreb*

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We measured the distributions of the relative intensities of the mercury and indium spectral lines along and across the plasma of the high-pressure InI-Hg arc. The radial distribution of intensities of mercury spectral lines were obtained by means of the Abel inversion procedure. The temperature distribution was experimentally obtained, and the relevant concentration of neutral atoms and electrons in plasma were calculated for a simple plasma model. The intensity of the satellite band that appears in the red wing of the indium spectral line at 451.13 nm was studied in order to establish the possible correlation with the temperature measured by means of the Boltzmann plot.

### *1. Introduction*

High pressure InI-Hg arcs are usually used as light sources for medical application, since 451 nm indium spectral line causes the destruction of bilirubin molecules on the skin of the newborn children, who suffer from hyperbilirubinemia. In addition, in combination with thalium and sodium iodides, indium iodide is used as the filling of the commercial high-pressure metal-halogen lamps. Two

resonance lines with pressure broadened wings fill the violet and blue-violet spectral regions of the visible spectrum, which is otherwise lacking intense spectral lines.

In this paper we present the results of our investigations of some parameters of the high-pressure InI-Hg arc discharge which burns in argon atmosphere. Basically we measured Hg spectral line intensities and their radial distributions in order to obtain the temperature distributions within the arc plasma. A special attention is paid to the shape of the far quasi-static wings of the indium resonance lines where satellite bands appear due to a spectral type of atom-atom interactions. We were interested whether the intensity of this satellite band could be correlated with the temperature distribution in the arc column. The present studies have a preliminary character, and will be extended to other discharges with other fillings and with more elaborate diagnostics.

## 2. Experimental apparatus

The experimental equipment used for the measurement is shown in Fig. 1. The light source is the high-pressure InI-Hg lamp taken from the normal commercial production but without thallium and sodium iodides. The light beam from

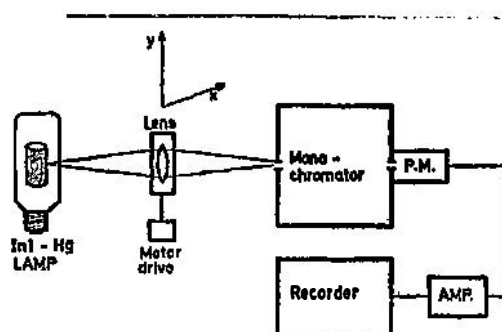


Fig. 1. The experimental equipment.

a certain part of the discharge plasma was focused onto the entrance slit of the monochromator (SPM 2, Carl Zeiss, Jena) by means of the lens, which could be laterally moved by means of the precise motor drive. In front of the entrance slit there is a mask, which divides the slit in equal segments, for easier observation of the plasma column segments at different heights. At the exit slit the sensitive photomultiplier was placed (EMI 9524 B), and after the amplification the signal was recorded on a strip chart recorder. The whole optical system was calibrated by a standard tungsten strip lamp in order to enable the relative intensity measurements. The burner within the lamp was made of a cylindrical quartz tube and filled by InI, Hg and Ar mixture. The filling data of the lamp burner are given in Table 1. The internal diameter of the quartz tube is of 18 mm, with the distance between electrodes of 38 mm. The burner was situated in the lamp bulb. The discharge operated vertically, and was supplied by a 50 Hz alternating voltage with an appro-

prate ballast inductance connected in series. The voltage and current of the discharge are presented in Table 1.

TABLE 1.

Indium iodide	1.0 mg
Mercury	50.0 mg
Argon pressure at filling	25 mbar
Open circuit voltage	200 rms V
Discharge current	3.5 rms A

Data on the discharge tube.

### 3. Measurements and results

The temperature distributions of the arc plasma was estimated by means of the measurements of the relative intensities of three mercury spectral lines. All data relevant for the use of the temperature determination via Boltzmann plot are quoted in Table 2. In actual temperature estimation only two mercury lines at

TABLE 2.

$\lambda/\text{nm}$	$E/\text{eV}$	$g$	$A/10^8\text{s}^{-1}$
435.83	7.73	3	0.40
546.07	7.73	3	0.56
576.96	8.85	5	0.61

Parameters of the Hg lines<sup>1)</sup>.

576.97 nm and 546.07 nm were systematically used and the third line at 453.83 nm was occasionally used for the control of the results. At every section of the arc plasma the intensities of the spectral lines were scanned over the discharge profile. The necessary Abel inversion is subsequently performed by means of the Bockasten's method<sup>2)</sup>. The effective excitation temperature is obtained from the obtained radial intensities  $\varepsilon$ , by means of the following equation:

$$T = \frac{E_2 - E_1}{k \left( \ln \frac{\varepsilon_1}{\varepsilon_2} - \ln \frac{g_1 A_1 \lambda_2}{g_2 A_2 \lambda_1} \right)}, \quad (1)$$

where the subscript 1 and 2 refer to the first and the second spectral line, respectively.  $E$  is the energy of the upper level of the relevant spectral line,  $k$  the Boltzmann's constant,  $g$  the statistical weight of the upper level and  $A$  the Einstein's coefficient. Obtained temperature distributions for fourteen sections of the arc plasma are presented in Fig. 2. The measured temperature has of course not the meaning of the temperature in the usual sense of LTE conditions, but rather it gives the feeling of the degree of excitation of the mercury energy levels in the arc discharge with added materials. The temperature distributions were in this

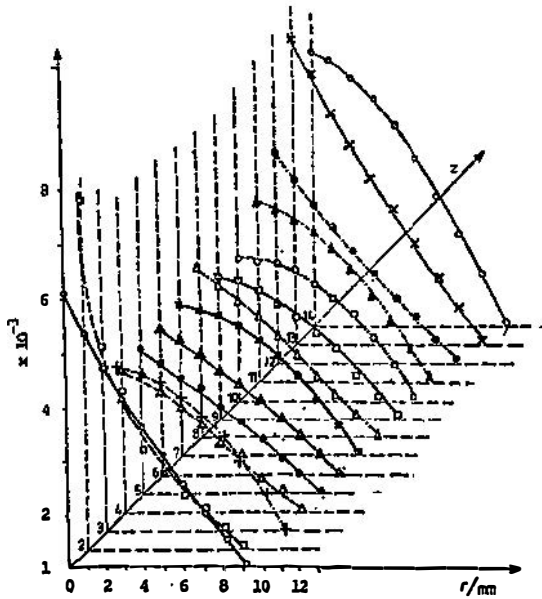


Fig. 2. Radial temperature distribution along the vertical InI-Hg arc ( $z$ -axis) from the lower electrode, LE, to the upper electrode, UE.

way determined up to about half of the discharge radius. The rest of the temperature distribution up to the discharge tube is obtained by means of the following formula<sup>3)</sup>

$$T(r) = (T_0 - T_w)(1 - (r/R)^p) + T_w \quad (2)$$

where the  $T_0$  is the axial temperature in the centre of the arc,  $r$  the distance from the centre,  $R$  the tube radius, and  $T_w$  the wall temperature. The wall temperature was not directly measured, but was rather estimated in accordance with the values given in the literature ( $\sim 1000$  K, Röchlin 1971). The points close to the arc axis were used in order to obtain parameter  $p$  in Eq. (2). The values of parameter  $p$  were ranging from 0.48 up to 2.84.

The accuracy of the effective excitation temperature determination obtained by the method described above is relatively low. The error in the relative line intensities measurements is up to  $\pm 10\%$ , but the Einstein coefficients are known with poor accuracy, only  $\pm 50\%$ . Thus the error in the estimation of the effective excitation temperature could be up to  $\pm 20\%$  at excitation temperatures of about 7000 K.

Self absorption of the Hg lines may be present in our case. We did not check in particular the effect of self-absorption on the effective temperature determination. However occasional check by the 453.83 nm mercury line showed that the uncertainty in the temperature determination is not discernible from the uncertainty in the used atomic transition probabilities which amounts 50%.

In Fig. 3 we present the profile of the self-absorbed indium resonance line at 451.13 nm. On the extended red wing a satellite band appears peaking at about 453.3 nm. The origin of this satellite band most probably is connected with In-Hg interaction, which is concluded by the analogy with the Tl-Hg case<sup>4)</sup>. The blue wing appears in this figure very strong and close to the line centre where is a self-absorbed satellite band which most probably belongs to In-In interaction. This

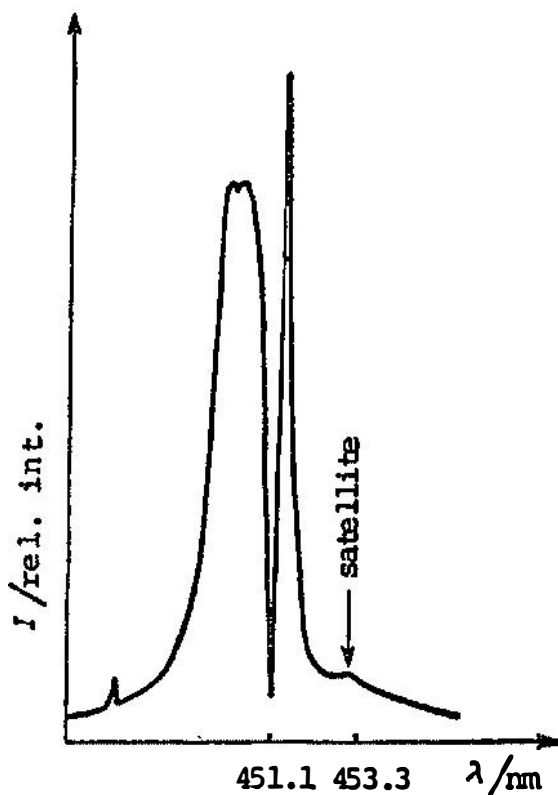


Fig. 3. Experimental profiles of the In-line at 451.13 nm emitted from the centre of the arc.

is also concluded by the analogy with the Tl-Tl interaction case<sup>5)</sup>. In the present study we have used the intensity of the red wing at the location of the satellite band at 453.3 nm, for the comparison with the distribution of the effective temperature on the discharge axis. However in this preliminary study no Abel inversion procedure has been applied for the satellite band intensity.

#### 4. Discussion and conclusion

Our spectroscopic data were time averaged from lamp operated at 50 Hz. Under these conditions the radiation exhibits 100 Hz intensity modulation. The

time averaged spectroscopic information were used for the comparison with the simple model.

In Fig. 4 we present several plasma parameters measured or calculated for the discharge axis. First we have the axial distribution of the effective temperature, which can be also seen in Fig. 2. The effective temperature is elevated in the regions close to both electrodes, and just in the middle of the discharge the effective temperature is somewhat higher. We also present the satellite band intensity distribution, measured in the middle of the arc, but without Abel inversion. There is a slight correlation of the effective temperature and the satellite band intensity, but it has to be proved by means of the appropriate Abel inversion procedure. In Fig. 4b and 4d we present the calculated values for the indium and electron den-

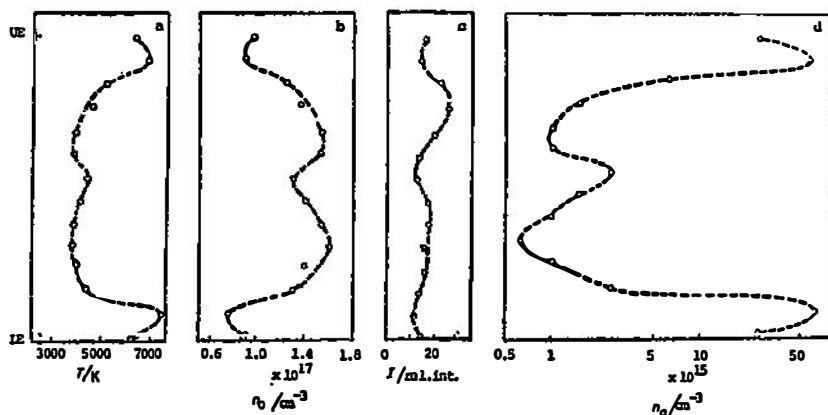


Fig. 4. a) The temperature distribution along the axis of the arc from the lower electrode, LE to the upper electrode, UE. b) Distribution of the neutral indium atom density,  $n_0$ , between the electrodes. c) Distribution of the relative intensity of the red satellite peak at 453 nm of the In-line, between electrodes. d) Distribution of the electron density,  $n_e$ , between electrodes.

sities from the simple model of the discharge plasma. Since the indium ionization and excitation potentials are smaller than those of mercury, in our simple model we have considered only indium in the plasma composition calculations. For the dose of InJ about  $0.1 \text{ mg/cm}^3$  the estimated partial pressure of indium is  $7700 \text{ Pa}^6$ . For this given pressure the neutral indium and electron densities have been calculated for the certain number of the axis temperatures and plotted in Fig. 4b and 4d. One may see that there is a slight direct relation between Fig. 4b and Fig. 4c, i. e., the concentration of neutral indium and the intensity at the red satellite peak. Our aim in the present study was to observe the direct correlation of the axis temperature distribution with the intensity distribution of the satellite peak. In this preliminary study we found only a weak trace of such correlation. The idea to use the satellite bands in the quasi-static line wings for the rough estimation of the plasma parameters has to be checked on the other systems and with the better diagnostic methods. Only those satellite bands, which are not effected by the self-absorption can be eventually used for this purpose. We have seen that in the blue wing there was the In-In satellite which should depend on the square of the indium density and therefore should be even more sensitive for the diagnostic purpose. However it is strongly affected by the self-absorption.

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SPEKTROSKOPSKA STUDIJA InI-Hg VISOKOTLAČNOG LUKA  
TUŠ GEGAJ\*, VIŠNJA HENČ-BARTOLIĆ\*\*, GORAN PICHLER, JADRANKA  
RUKAVINA<sup>+</sup> i TIHOMIR ŠETINČ<sup>+</sup>

*Institut za fiziku Sveučilišta u Zagrebu, Jugoslavija, P. P. 304*

*\* Prirodoslovno-matematički fakultet, 38000 Priština, Jugoslavija*

*\*\* Elektrotehnički fakultet, Sveučilište u Zagrebu, Jugoslavija*

*+ TEŽ, Zagreb*

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Mjerili smo raspodjelu relativnih intenziteta živinih i indijevih spektralnih linija duž i poprijeko plazme visokotlačnog InI-Hg luka. Radijalna raspodjela intenziteta živinih spektralnih linija bila je dobivena postupkom Abelove inverzije. Temperatura raspodjela dobivena je eksperimentalno, a odgovarajuće koncentracije neutralnih atoma i elektrona u plazmi bili su računati za jednostavni model plazme. Bio je proučen intenzitet satelitske vrpce koja se pojavljuje u crvenom krilu indijeve spektralne linije na 451,13 nm u svrhu postavljanja moguće korelacije sa mjerenjem temperature pomoću Boltzmannovog dijagrama.