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# THE EXPERIMENTAL AND THEORETICAL INVESTIGATIONS OF THE ASYMMETRIC SELF-REVERSAL OF THE NEUTRAL COPPER ATOMS RESONANCE SPECTRAL LINE Cu I 327.936 nm UNDER CONDITIONS OF AN IMPULSE DISCHARGE

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**Abstract.** The asymmetric self-reversal of the neutral copper atoms resonance spectral line Cu I 327.936 nm under the conditions of an impulse capillary discharge in the air is investigated experimentally and theoretically for the purposeof the development of the asymmetric self-reversal theory, the estimation of Stark broadening parameters of the spectral line Cu I 327.936 nm and the check of the quantum-mechanical calculations results.

The direct recording of the Stark broadening of the copper atoms resonance spectral lines Cu I 324.7 nm and Cu I 327.4 nm under the conditions of optically transparent plasma presents a difficulty because of their narrowness and strong tendency to the self-absorption and even the self-reversal. For the experimental check of the quantum-mechanical calculations results obtained for the first time by us (Grishina *et al.* 1998, 1999; see also Dimitrijević *et al.* 1996) we have decided to use the asymmetric self-reversal of the Cu I 324.7 nm and Cu I 327.4 nm lines which we have observed under the conditions of an impulse capillary discharge in the air (Fishman *et al.* 1994). Grishina *et al.* (1998, 1999) presented only final experimental and theoretical results for the self-reversal Cu I 327.4 nm line which is the most convenient for investigations because of the small distortion of line wings by weak foreign spectral lines. In this paper some results of our investigations are presented in more detail.

The experimental photographic recording of the self-reversal Cu I 327.4 nm line profiles (simultaneously the hydrogen $H_\alpha$ line profiles have been recorded for the determination of the electron concentration $n_e$) has been carried out on the setup described in Fishman *et al.* (1994). The impulse capillary discharge between the horizontally placed electrodes was used as a source of plasma. The copper atoms have arrived in the plasma from the copper anode through a textolite capillary. The recording of spectra for the plasma cross-section located 0.5 mm from the capillary outlet has been carried out in the current maximum reached in 1.5 ms from the discharge begining with a time resolution of 0.15 ms.

The spectra photographing has allowed to obtain the Cu I 327.4 nm and $H_\alpha$ spectral lines profiles as the plots of the dependence of the intensity $I$ on the wave-length $\lambda$ for the different lines-of-sight with the transversal coordinate $z$ in the investigated plasma cross-section. Figures 1 and 2 show the results for one of spectra for the Cu I 327.4 nm line (the axial values of temperature $T_0$=22000 K and electron concentration $n_{eo}=1.2\cdot10^{18}$ см$^{-3}$).

The Cu I 327.4 nm line has appeared a strong self-reversal for all of the lines-of-sight in the plasma cross-section for which the photographic recording of the intensity has been possible. Figure 1 shows the normalized self-reversal profiles on the wave length scale for two lines-of-sight. All the profiles recorded are asymmetric: the long-wave peak of the intensity has the maximum $I_{max1}$ which appreciably exceeds the maximal intensity $I_{max2}$ of short-wave peak of the intensity. The asymmetry of the profiles becomes apparent also in the different values of the extent on the wave-length scale of the peaks of the intensity relative to the wave-length $\lambda_0$ which gives the position of the minimum of the intensity in the line centre as shown on Fig. 1: the extent $\chi_1$ of the long-wave peak is appreciably larger than the extent $\chi_2$ of the short-wave peak. Grishina *et al.* (1998, 1999) used the parameter of the wings asymmetry $\chi=\chi_1-\chi_2$ for the estimation of the electron half-width $\delta_{eo}$ for the self-reversal Cu I 327.4 nm line which corresponds to the plasma parameters $T_o$=22000 K and $n_{eo}=1.2\cdot10^{18}$ см$^{-3}$.

For the estimation of the plasma structure which is needed for the determination of $\delta_{eo}$ by $\chi$ the plots of the dependences of the intensity $I_{max1}$, the parameter of the peaks asymmetry $I_{max1}/I_{max2}$ and the parameter of the wings asymmetry $\chi$ of the profiles at $I/I_{max1}$=0.1 on the transversal coordinate $z$ have been constructed (see the dots in Fig.2). The plots show that the plasma in the investigated cross-section is close to the axially symmetric plasma. The diameter $2R_0$ of the emission zone where the exited copper atoms on the lower level of the Cu I 327.4 nm line are primarily located approximately equals 2.6 mm. The smooth variation of the dependence $\chi(z)$ in the limits of the emission zone reveals the smooth radial decrease of the electron half-width $\delta_e$ and electron concentration $n_e$ in the limits of the emission zone.

The variation of the dependence $I_{max1}/I_{max2}(z)$ for the Cu I 327.4 nm line is very interesting for the purpose of obtaining the information about the Stark parameters of the line broadening (about the sign of electron shift and about the value of the parameter of the relative shift $\eta=\Delta_e/\delta_e$) and the character of the radial variation of the absorbing atoms concentration $n_a$ on the lower level of the Cu I 327.4 nm line. Figures 1 and 2 show that for the central lines-of-sight the asymmetry of the peaks of the intensity of the self-reversal profiles is comparatively small. However for the peripheral lines-of-sight the parameter of the peaks asymmetry $I_{max1}/I_{max2}$ increases sharply and on the boundary of the emission zone the maximal intensity $I_{max1}$ of the big peak is 4-5 times greater than the maximal intensity $I_{max2}$ of the small peak. Such large values of the parameter of the peaks asymmetry $I_{max1}/I_{max2}$ are possible in the case when $|\eta|\geq1$ - such calculation values of $\eta$ have been obtained by us (Grishina *et al.* 1998, 1999).

The theoretical analysis of the complex variation of the dependence $I_{max1}/I_{max2}(z)$ for the Cu I 327.4 nm line calls for the construction of the multiparameters model of the inhomogeneous plasma and the carrying out of the calculations of the self-reversal profiles on the basis of computer calculations of an emission transfer equation for the different lines-of-sight in the plasma cross-section. The calculations have shown that in the given case the most suitable model is the one in which the half-width $\delta_e$ decreases smoothly approximately by a factor of 2 in the limits of the emission zone ($r\leq R_0$) with the increase of the plasma radius $r$ ($r$=0 is the centre in the plasma cross-section) and sharply decreases in the absorbing peripheral zone at $r>R_0$. The absorbing atoms are located primarily in the emission zone and the concentration of the absorbing atoms decreases sharply on the boundary of the emission zone. In Fig. 2 the solid curve C shows the theoretical dependence $I_{max1}/I_{max2}(z)$ with the following model structure: $|\eta|=1$; $\delta_e(r)/\delta_{eo}=\exp[-0.7(r/R_0)^2]$ at $r\leq R_0$ and $\delta_e(r)/\delta_{eo}=\exp(-3)$ at $r>R_0$; $n_a(r)/n_a(0)=\exp[-4(r/R_0)^2]$ at $r\leq R_0$; the absorption parameter $p_o=4$ obtained at the distance between the self-reversal maxima $\Delta_s$ (see Fig.1) in accordance with Il'in *et al.* (1997). The theoretical curve C rather well describes the experimental dependence $I_{max1}/I_{max2}(z)$.

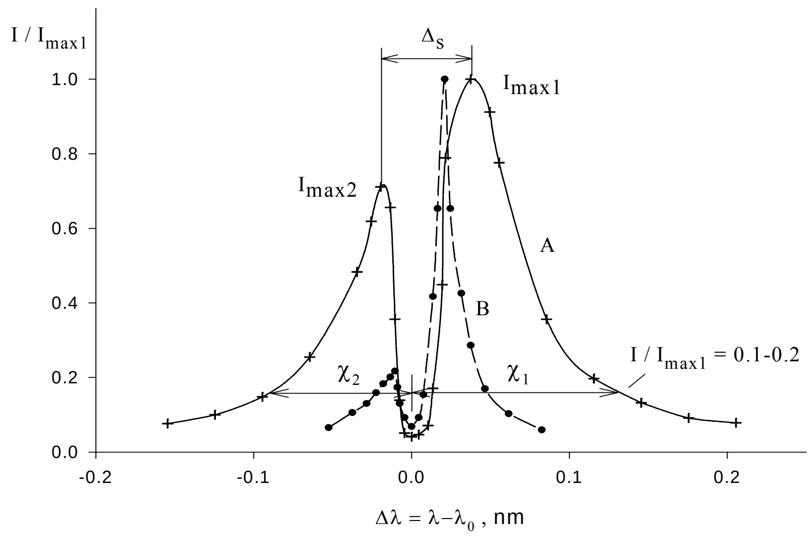


Fig. 1: The normalized self-reversal profiles of the Cu I 327.4 nm spectral line for the different lines-of-sight in the plasma cross-section of the impulse capillary discharge in the air: the profile A corresponds to one of the central lines-of-sight; the profile B corresponds to one of the peripheral lines-of-sight - the positions of the lines-of-sight are indicated in Fig. 2 depending on $I_{max1}/I_{max2}(z)$ (the dots A and B).

The results presented show that there are strong possibilities for a rather good simulation of the asymmetric self-reversal of the Cu I 327.4 nm line under the conditions of the impulse capillary discharge in the air used by us and for obtaining the reliable information from the self-reversal line. The simulation has shown that for the central line-of-sight ($z$=0) $\delta_{eo}\approx\chi(0)/3$ which gives in the present case at $\chi(0)$=0.05 nm the electron half-width $\delta_{eo}$=0.017 nm with the plasma parameters $T_o$=22000 K and $n_{eo}=1.2\cdot10^{18}$ см$^{-3}$. With such plasma parameters the quantum-mechanical calculation (Grishina *et al.* 1999) has given $\delta_{eo}$=0.030 nm. The experimental value of the electron half-width $\delta_{eo}$=0.017 nm obtained from the asymmetric self-reversal of the Cu I 327.4 nm line is approximately by 1.7 times lower than the theoretical value.

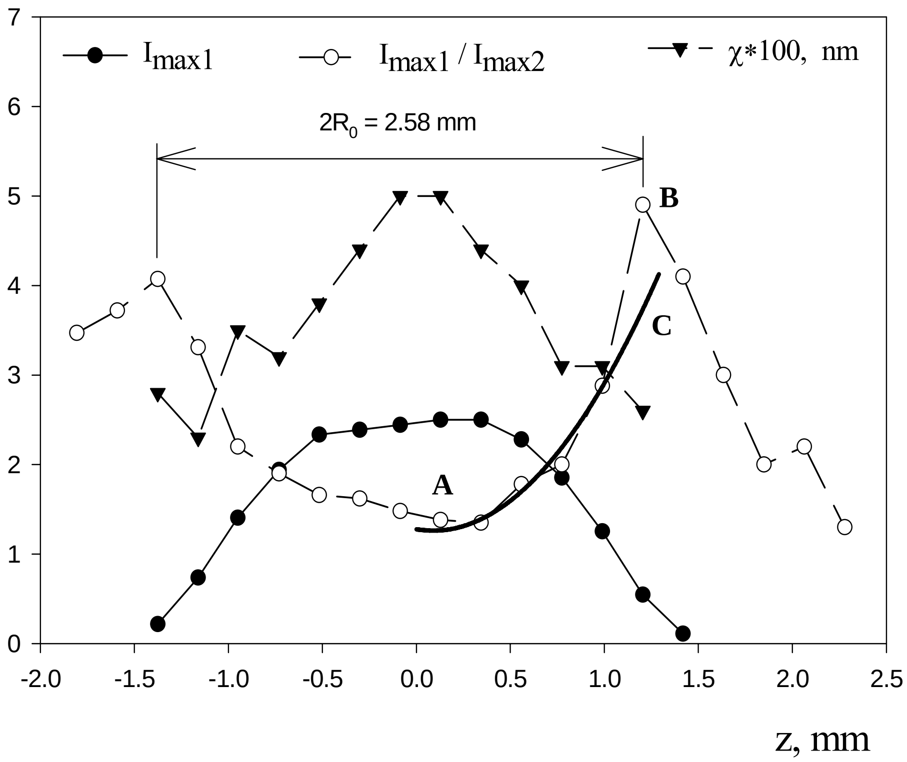


Fig. 2: The plots of the dependences $I_{max1}(z)$ (the intensity $I_{max1}$ is given on the relative scale), $I_{max1}/I_{max2}(z)$ and $\chi(z)$ (the dots) for the Cu I 327.4 nm spectral line. The self-reversal profiles in Fig.1 correspond to the lines-of-sight pointed at the dependence $I_{max1}/I_{max2}(z)$ as the dots A and B. The solid curve C is the theoretical dependence $I_{max1}/I_{max2}(z)$.

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