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THE ELECTRON NUMBER DENSITY OF ARGON-NITROGEN ATMOSPHERIC PRESSURE PLASMA

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Abstract
In this study, the influence of nitrogen gas addition on argon plasma electron number density was investigated. The plasma source is a wall stabilized direct current arc burning in argon at atmospheric pressure with continual water aerosol supply. To the argon gas carrying water aerosol a variable amounts (4, 8 and 11%) of nitrogen was added. The addition of the molecular gas was carried out by increasing the flow rate of the N_2 and decreasing that of Ar, so that the total flow rate of the mixed gas was constant 2.7 $Lmin^{-1}$. The arc was operating in the current intensity range 4 to 11 A. The electron number density was calculated from the measured *Stark* profiles of H_β 486.13 nm spectral line at the arc axis, for different arc currents. The radial distribution of electron number density was obtained from the measured radial profiles of H_β □ line. The addition of the molecular gas to the argon plasma resulted in considerable changes in electron number density.

Results and discussion
The electron number density have been obtained from measured radial profile of *Balmer*- H_β spectral line (486.13 nm) using a program proposed by Zikic *et al* [1]. The method was chosen because it does not require local thermodynamic equilibrium (LTE) condition to be satisfied. Plasmas consisting of mixtures of species including molecules are more complex than pure noble gas plasma. In our case, the situation is additionally complicated by the presence of large density and temperature gradients in radial direction. In order to describe the state of plasma we need to know the spatial distribution of temperature, pressure and composition. Although the assumption of LTE is often used in the modeling and diagnostics of atmospheric-pressure plasmas, the assumption of LTE is valid only for relatively high electron densities, at temperatures above approximately 10,000 K. Under such conditions the rapid collisions between charged and neutral particles, the large Coulomb cross section for collisions between charged particles, and rapid three-body recombination all tend to promote equilibration.

Figure 1a illustrates the influence of the arc current on the electron number density in argon plasma with three different nitrogen contents. In Fig 1b the influence of gas composition on a radial distribution of electron number density for the arc current of 7A is presented.

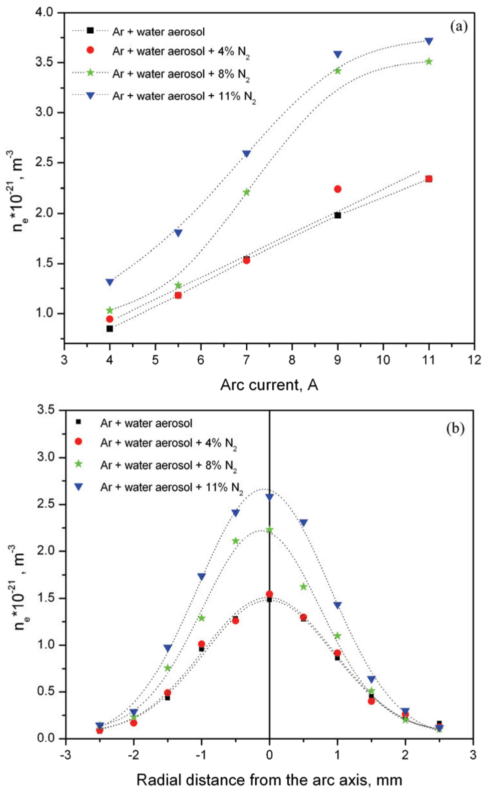

Figure 1. Variation of electron number density in argon-nitrogen plasma with: a) arc current and b) radial position for 7A arc current.

For all three gas compositions the increase of the arc current results in an increase of electron number density, but to a variable extent, Fig. 1. The increase of n_e with the increase in arc current is linear for small N_2 content and almost the same as for pure argon plasma. Increased content of molecular gas resulted in large n_e increase especially for the arc currents above 7 A. For a fixed arc current, measured at the arc axis, the small addition of nitrogen has almost negligible influence on n_e and the increase in n_e is considerable for larger N_2 additions. From the Fig. 1b it is seen that the largest influence of the variable gas composition on n_e is in the arc core region while when moving from the arc axis toward the plasma periphery the effect is lessening.

Direct current argon arc plasma is characterized by a large n_e and temperature gradients in radial direction. The addition of molecular gas is expected to influence the energy transport trough the discharge which will influence the fundamental plasma properties (electron temperature, electron number density and gas temperature), the bulk plasma characteristics (thermodynamic functions and transport coefficients including diffusion coefficient, viscosity, thermal conductivity, and electrical conductivity) and radiation properties (net emission coefficient) of the plasma. For instance, the thermal conductivity of the argon-nitrogen plasma will differ from the thermal conductivity of pure argon plasma. The thermal conductivity of argon increases monotonically with temperature while that of N_2 rises to a peak at about 6500 K, falls to a minimum at approximately 9000 K and then increases again with higher temperature. In the case of Ar-N_2 mixture, each plasma constituent will influence the transport properties according to its amount present in plasma. The changes of thermal conductivity will certainly result in changed temperature and electron number density distributions. On the other hand, the effect of demixing [2] does not seem to be important for Ar-N_2 mixtures as ionization potential of nitrogen is similar to that of argon (14.53 and 15.76 eV, respectively) and at higher temperatures both argon and nitrogen are ionized to the same extent. The increase in n_e may thus be explained by changes is plasma temperature as the number of charge carriers is closely correlated to temperature. The result is interesting since it implies increase in plasma temperature in spite of energy utilization for dissociation of nitrogen molecules and increased energy losses due to changed plasma composition.

Conclusions

The addition of easily ionisable elements or molecular gases [3] to argon plasma is a common spectrochemical practice in order to improve excitation conditions of the source or to minimize matrix effects. Because argon-nitrogen arc plasma may provide unique spectrochemical results, investigation of its operation and properties have been conducted. The obtained results may be important in analytical applications of this plasma source. For three different nitrogen contents we have measured the influence of the arc current on the electron number density variation and the radial distribution of the electron number density for a fixed current. The results have shown that the changes in N_2 content considerably influence the changes in electron number density through changes in plasma temperature and thermal conductivity.

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