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Heating of an argon Inductively Coupled Plasma after a period of recombination

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To investigate the excitation mechanisms in an argon inductively coupled plasma (ICP) we pulsed the 100 MHz RF plasma generator. It appears that the response of the various levels can be classified globally in three groups.

I The levels determined by the electron ruled Saha balance of ionization and three particle recombination,

II the levels determined by the electron ruled Boltzmann balance of excitation from and deexcitation back to the ground state, and

III levels for which electronic transitions are less important.

Response of type I is found for levels with high excitation energy such as Ar and H levels, response II is typical for levels in metallic systems, whereas the response of type III applies to levels sensitive to charge transfer in noble gas– alkali mixtures.

In this contribution we confine ourselves to the Saha response (type I), contribution [1] deals with the Boltzmann response (II), while [2] is devoted to the response of charge transfer (III).

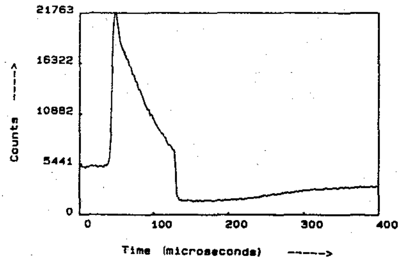

Figure 1. Response of Ar(4p) to pulsation

A typical time dependent behaviour of a Saha ruled level is given in fig. 1. It shows a rapid upward jump (in about 10^{-6}s) as a response to the cooling of electrons to the heavy particle temperature T_h, followed by a relatively slow decline (10^{-4}s) which is related to the recombination. The onset of the RF– generator manifests itself in a more or less complementary way; a downward jump (10^{-6}s) related to heating is followed by ionization (10^{-4}s).

In contrast to the response to cooling no attention has yet been paid to the response to heating. If we assume that the levels are ruled by the Saha balance, and that this balance instantaneously follows the changes in the plasma conditions due to the onset of the RF generator, we may use the Saha equation to derive the intensity jump. The functional dependence of the jump due to heating is the same as the jump due to cooling [3] and reads

$$\ln I/I^* = 3/2 \ln \gamma^* + E_{pi}(\gamma^*-1)/kT_e^* \qquad (1)$$

where $\gamma^* = T_e^*/T_h$ is the ratio of the electron temperature T_e^* after the onset and T_h just before the onset for which we assume that it equals the heavy particle temperature.

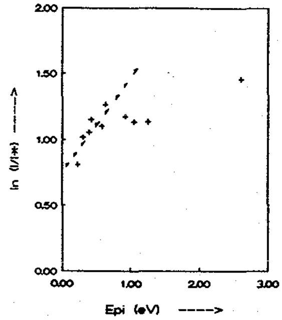

Figure 2. Relative jump as a function of E_{pi}

Figure 2 gives the heating jump for several Ar lines as a function of the ionization potential, E_{pi}. According to eq. 1 intersection of the ln I/I* axis gives 3/2 $\ln\gamma^*$ so that for this plasma region the relation $\gamma^* \simeq 1.8$ holds approximately. This is substantially larger than $\gamma = T_e/T_h$ related to cooling for which we found $\gamma \simeq 1.4$.

The measurements are carried out 5 mm above the load coil at a lateral position of 4 mm from the central axis of the plasma (cf. fig. 1 in [1]). The fact that the lower levels are not on the dotted line determined by the least square fit of the highly excited levels is related to the fact that the former are not populated according to Saha. This is closely related to the ionizing character of the plasma just after the switch on. In order to generate a stepwise ionization flow over the system of excited levels which is needed to rebuild the plasma, the lower levels have to be overpopulated with respect to Saha; i.e. ionization must exceed recombination.

This promising technique will a.o. be used to investigate γ^* as a function of the switch off time.

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[1] F.H.A.G. Fey, W.W. Stoffels, P. van der Linden, J.A.M. van der Mullen, D.C. Schram, 'On the response of analytes in a pulsed argon Inductively Coupled Plasma', ESCAMPIG 1990

[2] F.H.A.G. Fey, W.W. Stoffels, J.A.M. van der Mullen, D.C. Schram, 'On the response of charge transfer sensitive levels to the pulsations of a plasma generator', ESCAMPIG 1990

[3] K.-P. Nick, J. Richter, V. Helbig, J. Quant. Spectrosc. Radiat. Transfer, vol 32, no. 1, 1 (1984)