MODELING AND OPTICAL DIAGNOSTICS OF AN Ar PLASMA UNDER PLASMA THRUSTER CONDITIONS.

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As it is well known, the functioning of the Stationary Plasma Thrusters (SPT) is based on the ionization of the propellant gas, mostly Xenon, by electron collisions. The electrons are emitted by a hollow cathode, which is situated on the side of the SPT axis and is functioning with the same gas. The formed ions are subsequently driven magnetically and accelerated. The mechanisms of ion creation in electron – atom (ion) collisions, their destruction and their circulation are evidently of principal importance for the SPT study.

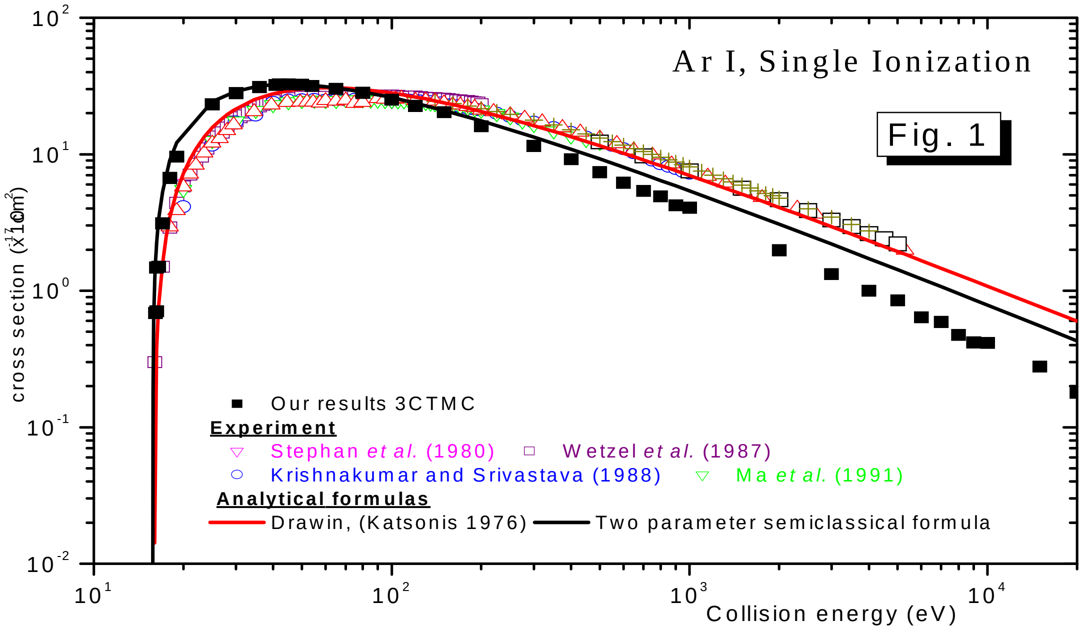
SPT have been developed for more than three decades now, see e.g. [1], and are widely used in varying the trajectories of artificial satellites. Nevertheless, their functioning is not still well understood and their diagnostics and modeling is far from being satisfactory. Among various diagnostics techniques, passive optical diagnostics is an evident choice because it is relatively simple and also it is not disturbing. In applying this method, an Abel inversion is necessary in order to take account of the approximately cylindrical geometry of the plasmas, whenever applicable. Moreover, the plasma is not expected to be in LTE, therefore the populations of the observed transition levels cannot be evaluated by simple use of the Boltzmann law; optical diagnostics necessitates a modeling of the Collisional-Radiative (C-R) type or at least of the simplified Coronal (CO) type. An evaluation of the "cascades" connecting various levels was used occasionally. On the other hand, global modeling of the SPT has as principal aim to describe the circulation of the existing (multi-)charged ions and electrons and their destruction and creation as well. This scheme has to include the electromagnetic fields and the geometry effects coming from the adjacent hollow cathode(s). Whatever the scheme chosen as a basis for the modeling (one-, two-, or three-dimensional, fluid or particle-in-cell (PIC) type) could be, it has also to take correctly into account the presence of the most important atomic processes. This cannot in general be done without a C-R type modeling recourse. Hence, C-R models are ubiquitous in both the diagnostics and the modeling of the SPT. We present elsewhere the essentials of this type of modeling and some related results of interest to SPT study obtained recently [2]. The aim of the present contribution is to illustrate the interest in studying a SPT functioning with Ar as propellant by means of C-R or CO type modeling in conjunction with optical diagnostics.

The plasmas encountered in the SPT may have various characteristics according to the conditions of their functioning and to the concrete region, which is examined. A notorious case is the plasma inside the thruster's hollow cathode, which has to be studied apart. A three-dimensional cartography of the thruster prototypes in various regimes is necessary in order to get a clear explanation of their functioning and to optimize their characteristics. Consequently, non-perturbing optical diagnostics, either passive or active (optical to VUV spectroscopy, LIF) and multidimensional dynamical modeling are of paramount importance in order to get a sufficient information on the plasma constituents. In so doing, the local plasma characteristics obtainable by detailed optical diagnosis in each non-LTE region separately, can simply be described and evaluated on the basis of a "zero-dimension" modeling of the CO or, better, of the C-R type. A general description of these types of modeling and of their overall application for plasma thrusters is given in the aforementioned contribution [2].

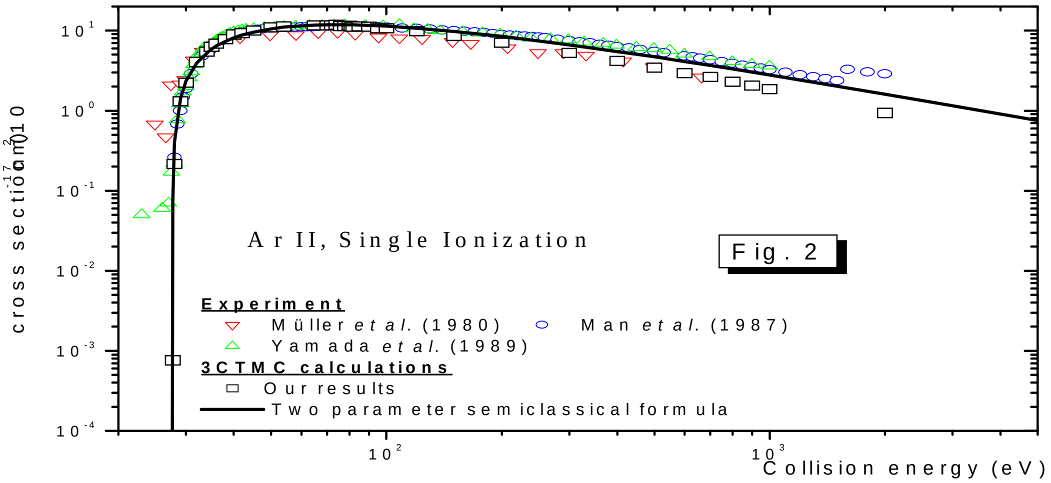
Although the Xe gas appears actually as the main choice for the plasma thrusters feeding, we focus here our interest in modeling and diagnosing a SPT-50 type thruster also when operated with Ar gas. The main purpose of this work is to validate the C-R modeling developed for the study of the plasma thrusters. Such modeling has of course to be based on extensive atomic databases [3]. An important effort has been lately started in order to constitute and to improve such a basis for Xe and its ions [4]. But it has to be stressed that the atomic data base of the Ar atom and its ions is actually in much better status and that significant effort has been dedicated in the past in modeling Ar plasmas [5], even though, as it was reported previously [6], the presence of Ar^{q+} ions which become significant in the few eV energy region of interest here, has been often neglected or insufficiently considered. Therefore, validation of the C-R modeling can take a substantial profit from the existing Ar plasma applications. On the other side, obtaining the optical characteristics of various plasma regions inside the prototype has been proved a very interesting development of diagnostic tools. Moreover, the obtained overall Ar plasma properties have been compared with other plasma applications as Tokamak edge plasmas and arcs in the few eV energy region [7].

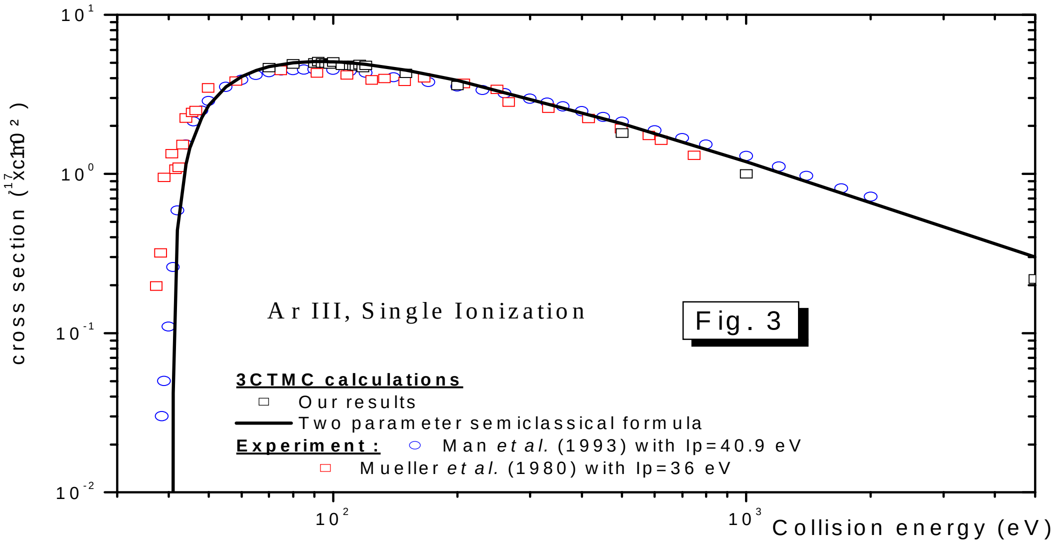
Optical measurements have been done recently in a SPT-50 prototype available at the LPTP Laboratory of the Ecole Polytechnique. This prototype was used previously for studying the possibilities of emission spectroscopy inside the channel with optical fibers passing through holes realized *ad hoc* and the obtained results for pure Xe gas and also for a 90 % Xe – 10% He mixture were discussed and thoroughly documented in [8]. We have first observed the plasma radiation inside the SPT-50 vacuum vessel in various places and orientations for pure Xe plasma. We then started an optical diagnostics of the prototype with pure Ar gas, both in the hollow cathode feeding and in the main discharge. Due to the higher ionization potential of Ar, the voltage needed and for the cathode start up and for the main discharge sustenance was clearly higher, as expected.

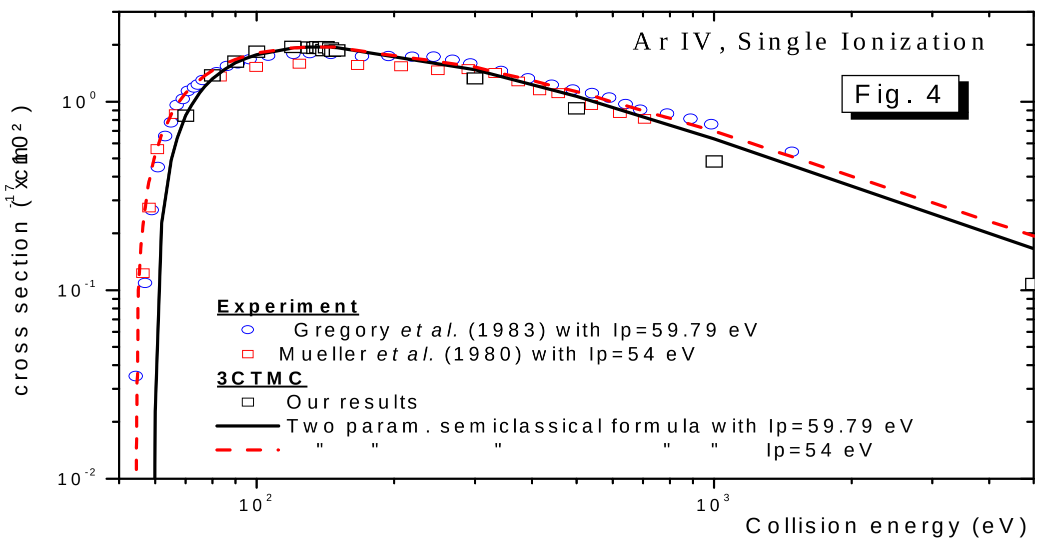
Taking advantage of the rather low gas density (10^{12-14} cm^{-3}) and electron temperature (a few eV, assuming maxwellian distribution) we are proposing here a simplified zero dimension coronal model in order to obtain an overall description of the SPT characteristics and of the basic parameters of the plasma approximately. As is explained in [2] this model (referred as Ar I - V), is conceived to include only the Ground Level (GL) of the first five ionisation species with the Electron collision Ionization (EI) of species I – IV and the Radiative Recombination (RR) of II-V. The cross sections of the former (σ_{EI}) were calculated with a two-parameter formula, the values of which are coming from our CTMC calculations and evaluated by taking into account the available experimental and some theoretical results [9 - 17]. σ_{EI} values are shown in Figs. 1 to 4.



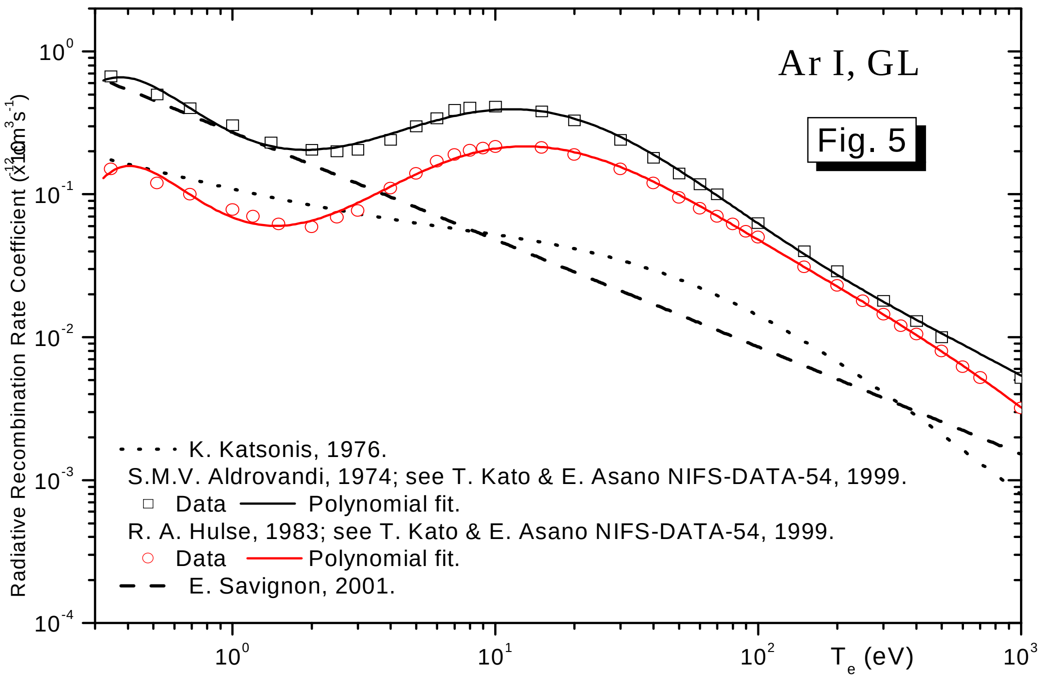
Ar I, Single Ionization
Fig. 1
cross section (x10^{-17}cm^2)
Collision energy (eV)
Our results 3CTMC
Experiment
Stephan et al. (1980)
Wetzel et al. (1987)
Krishnakumar and Srivastava (1988)
Ma et al. (1991)
Analytical formulas
Drawin, (Katsonis 1976)
Two parameter semiclassical formula


Ar II, Single Ionization
Fig. 2
Experiment
Müller et al. (1980)
Man et al. (1987)
Yamada et al. (1989)
3CTMC calculations
Our results
Two parameter semiclassical formula
cross section (10^-17 cm^2)
Collision energy (eV)


Ar III, Single Ionization
Fig. 3
3CTMC calculations
Our results
Two parameter semiclassical formula
Experiment:
Man et al. (1993) with Ip=40.9 eV
Mueller et al. (1980) with Ip=36 eV
cross section (10^-17 cm^2)
Collision energy (eV)


Ar IV, Single Ionization
Fig. 4
Experiment
Gregory et al. (1983) with Ip=59.79 eV
Mueller et al. (1980) with Ip=54 eV
3CTMC
Our results
Two param. semiclassical formula with Ip=59.79 eV
" " " " " Ip=54 eV
cross section (10^-17 cm^2)
Collision energy (eV)

The cross sections of the latter (RR) are still under evaluation. The situation for Ar^+ recombination is illustrated in Fig. 5, where on can see theoretical results [18 - 21] available in the literature, together with our previous calculations in quasi-classical approximation [5].



The fractional ionizations obtained from the CO Ar I – V model are shown in Fig. 4 of [2]. Furthermore, in order to be able to compare the theoretical predictions with our approved results, we have developed a Coronal-Radiative (CO-R) model including additionally a number of excited states. These for the Ar I species are consisting of 4*s*, 5*s*, 4*p* and 3*d* levels. For these levels, EI and Electron collision Excitation (EE) have been evaluated for the moment with Drawin's formula [22]. The inverse processes were calculated using the detailed balance principle [5]. Further evaluations are underway.

The experimental part of this study started with collection of the light emitted from a plasma jet region, using an optical fiber which was placed behind a chamber view-port. It was then connected to a 15 cm focal length spectrograph operating in Czerny-Turner configuration and with spectral resolution of 0.4 nm. The signal detection was made using an intensified CCD camera (512 x 512 pixels) with 19µm x 19µm pixel size. It needs to be emphasized that such a configuration of the experimental set-up enabled only global (with no spatial resolution) observations of the plasma. This first step was meant mainly to recognize the spectral lines that can be useful to include in elaborating a CO-R model adapted to our SPT device. Next, an experimental setup with appropriate spatial and spectral resolutions will be put in place, aiming to a detailed cartography of the SPT plasma. It will allow for the experimental verification of results coming from a two-dimensional plasma modeling (see [2], § 5).

Latest achievements of our Ar modeling in conjunction with the SPT optical diagnostics development will be given in the Conference, together with a comparison with existing measurements. Also, results obtained by other types of modeling and even for various plasma cases, which may not be directly related with SPT, will be presented. The obtained conclusions and the possibilities of completing and extending the present work will also be discussed.

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