ENERGY GAIN OF PLASMA IONS IN A STRONG HIGH FREQUENCY ELECTRIC FIELD BETWEEN TWO TARGET PLATES

R. Chodura, J. Neuhauser

IPP Garching, EURATOM-Association, D-8046 Garching, Fed. Rep. of Germany

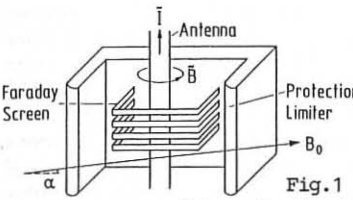


Fig. 1

Introduction. In the past RF-heating at ion cyclotron frequency has proved to be a promising method of plasma heating. Nevertheless, this method suffers from being connected with strong impurity production due to sputtering in the antenna region. The origin of the high energy sputtering ions is not quite clear. We discuss a possible mechanism for creating such high energy plasma ions and show some reults of a numerical model on this phenomenon.

Figure 1 gives a schematic view of an ion cyclotron wave antenna. A high frequency current flows through central conductor loop $\tilde{I}$. The loop is shielded by a Faraday screen of metallic strips which suppress electric field components parallel to the strip direction (and keeps plasma out of the antenna interior). The antenna is protected by a lateral limiter. The current loop is oriented poloidally, the Faraday strips either purely toroidal or nearly toroidal along the main magnetic field B_o (exact parallelism being very unlikely in practice).

Due to the finite inclination α of the magnetic field B_o relative to the toroidal direction, the poloidal RF current $\tilde{I}$ induces a magnetic RF flux through an area bounded by a contour which runs along a magnetic field line nearby to the antenna from a conducting wall to another (e.g. between Faraday strips, antenna limiters or vessel walls) and returns back through the conducting material. Thus, the magnetic RF flux produces a voltage along the magnetic field in the plasma between two material walls. This voltage can be estimated to be of the order of $10^2 - 10^3\ V$ for usual antenna currents of several hundred amperes, i.e. much larger than the plasma sheath potential of $\sim 3T_e/e$ in the antenna vicinity. We are mainly interested in this electric field effects along magnetic field lines rather than the details of launching the fast magnetosonic wave. Therefore we ignore magnetic field oscillations in the following study and replace the induced RF voltage along field lines between material walls by a given potential difference.

Model. In order to study the plasma response to the applied RF voltage, in particular the ion energy gain, an 1D electrostatic Monte-Carlo particle code [1] was used.

The code depends on one spatial coordinate perpendicular to the boundary targets (assumed as infinitely extended plates). The two target plates are assumed to be totally absorbing, the plasma to be collisionless. The loss of plasma particles and energy to the targets is replaced by an ambipolar particle and heat source flux. Between the two target plates a prescribed voltage is applied. The code calculates the spatial distributions of potential, current, density, etc. as well as the local velocity distributions of plasma ions and electrons, in particular at the target plates.

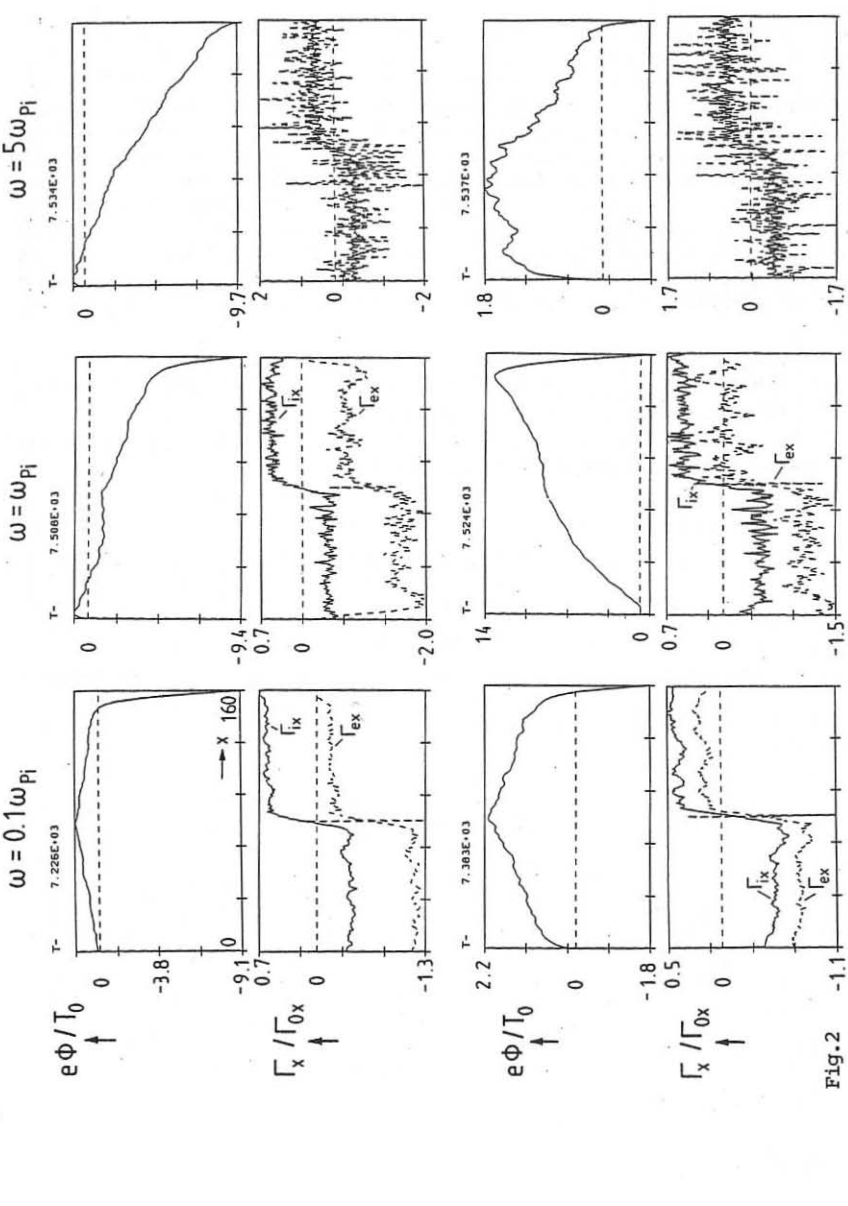
Results. Calculations were done for a prescribed potential difference ϕ between the two target plates at x=0, $\phi(0) = 0$ and x=L, $\phi(L,t) = \phi_o \cos \omega t$. Self-inductance in the circuit was ignored. In the following ϕ_o was chosen as $e\phi_o/T_o = 10$, where T_o is the temperature of ions and electrons entering the system at x=L/2 $\pm d$. The system length L was 160, d=5, in units of Debye lengths with temperature T_o and density $n_o = \Gamma_o/2C_o$. Γ_o is the ambipolar source flux along B_o of ions and electrons entering the system, $C_o = (T_o/m_i)^{1/2}$ the ion sound speed. Of course, the ratio of system length L to Debye length is not realistic but should not change the qualitative behaviour. The magnetic field B_o is assumed to strike the target plates under an angle of $\psi = 60°$ to the normal, and to have a magnitude such that $\omega_{ci}(B_o) = 0.1\omega_{Pi}(n_o)$. In order to save computing time the ion mass ratio was reduced to $m_i/m_e = 100$ (which diminishes the potential jump in the electrostatic sheaths).

Figure 2 shows profiles of potential ϕ and ion and electron fluxes Γ_{ix} and Γ_{ex} at two time steps a quarter period $\pi/2\omega$ apart as functions of the coordinate x perpendicular to the target plates for three different frequencies ω of the applied voltage $\phi(L,t)$. At the small frequency, $\omega/\omega_{Pi} = 0.1$, the potential changes only little within the plasma but exhibits a sharp drop alternatingly at one or the other plate. Electrons coming from the source cannot overcome this potential drop and move to the opposite plate. Ions flow towards both plates but prefer that with the potential drop. The density profile stays nearly constant, only the distribution in the sheaths adjacent to the plates differ. This result is similar to that expected from static Langmuir characteristics.

At the higher frequency, $\omega/\omega_{Pi} = 1$, the potential gradient within the plasma has increased. Additional to the electrons coming from the source, also the displaced electrons from the electrostatic sheaths at the plates, $n\lambda_D\omega$, contribute appreciably to the electron flux, giving rise to the sharp changes of Γ_e at the plates.

At the still higher frequency $\omega/\omega_{Pi} = 5$, i.e. for $\omega >> C_s/\lambda_D$ with C_s the sound speed, even the electrons no more can follow the externally applied potential changes. The potential now drops nearly completely within the plasma, only a small, thermal potential drop across the sheaths at the target plates remains. Ions and electrons now flow ambipolarly and symmetrically to both plates.

Figure 3 shows for the same frequencies as Fig. 2 the time history of the potential $\phi(L)$ across the 2 plates, the potential at the midplane in the plasma $\phi(L/2)$, the ion and electron fluxes Γ_{ix} and Γ_{ex} and the energy fluxes Q_{ix} and Q_{ex} per ion and per electron carried to one target plate. The plasma potential in the midplane essentially stays positive even during the half cycle of negative external potential as was found also experimentally in [2]. The fluxes are strongly oscillating for $\omega < \omega_{Pi}$ and become nearly stationary for $\omega >> \omega_{Pi}$.



ω = 0.1ω_pi
ω = ω_pi
ω = 5ω_pi
eΦ/T_0
Γ_x/Γ_0x
Γ_ix
Γ_ex
x
7.226E+03
7.508E+03
7.534E+03
7.383E+03
7.524E+03
7.537E+03

Fig.2

Conclusions. The results clearly show that at least for $\omega \lesssim \omega_{Pi}$ (and hence for a typical Alfven and ion cyclotron range of frequencies) there is a significant nonresonant ion acceleration by sheath rectification of the induced electric field parallel to magnetic field lines. As a consequence significant sputtering is to be expected wherever these field lines intersect material walls, e.g. at the antenna screen, the antenna limiters or even at more remote structures, depending on the actual antenna and wave field distribution in the edge region. Assuming a sputtering coefficient in the percent range, a total ion flux of a few times $10^{20}\ s^{-1}$ into the antenna region is required in ASDEX to explain typical impurity influxes during ICRH [3]. This is only a small fraction of the total recycling flux and hence quite realistic. From the basic process it is clear that antenna optimization (Faraday shield, dipol antenna, etc.) minimizing the induced field along field lines intersecting material walls could significantly reduce the impurity inflow.

References.

[1] R. Chodura, Phys. Fluids **25**, 1628 (1982); J. Nucl. Mat. **111&112**, 420 (1982).
[2] L.I. Grigor'eva et al., J. Nucl. Mat. **128&129**, 317 (1984).
[3] J. Roth, G. Janeschitz et al., Impurity production and transport in the divertor tokamak ASDEX, submitted to Nuclear Fusion.

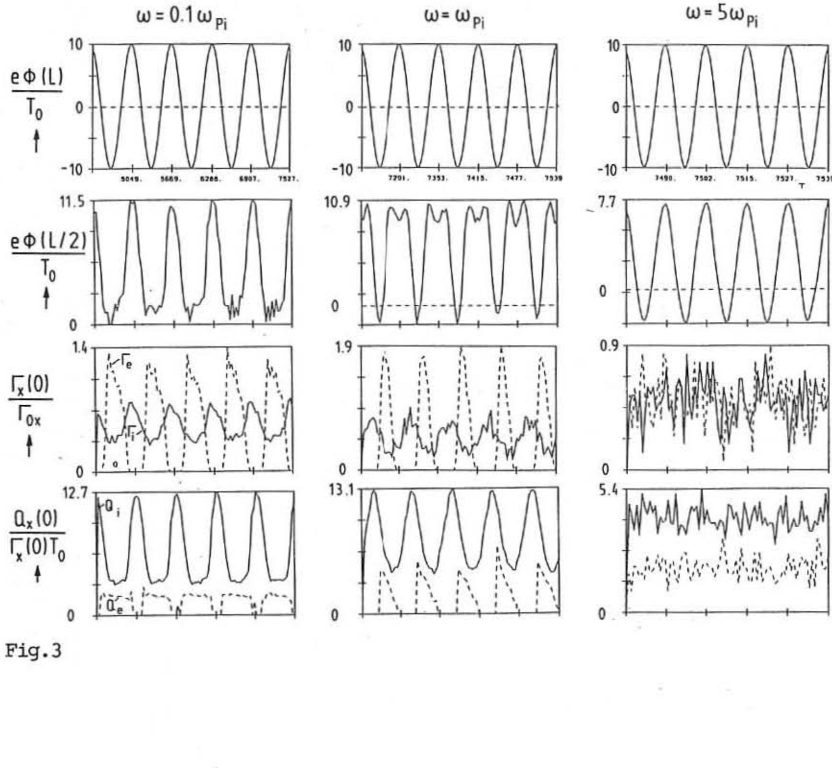


Fig.3