ICRF – VOLUME CHARGE – ANTENNA EDGE INTERACTIONS IN THE TORSATRONS U-3M AND U-2M
Part 2. VSC – RF ANTENNA INTERACTION

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The influence of the electron emission and metal impurity emission from the antennas, including the U-3 torsatron antenna, on the RF-discharge has been analyzed. The both effects are the results of the antenna surface bombarding with ions being accelerated in the self-consistent field of the volume-space charge (VSC).

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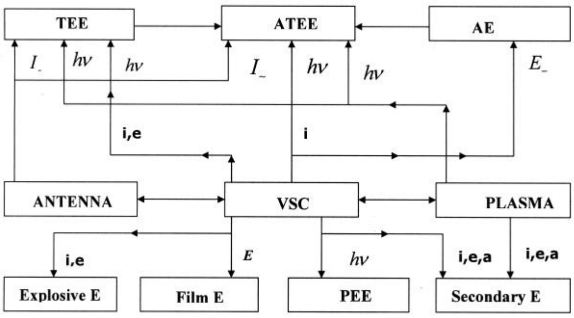
INTRODUCTION

An onset of every gas discharge is the development of an electron avalanche [1]. A “spark” for the avalanche formation are phonon electrons. Free electrons in the plasma facilities with electrodes arise due to the emission from cathodes. In U-3M and U-2M torsatrons the working gas ionization is provided by the alternating electric field E_0 of an RF pulse [2]. The absence in U-3M and U-2M of a preliminary ionization and comparatively slow ionization by the alternating electric field suggests the participation of electron beams in this process. A possibility of electron beam generation with cold electrodes by VSC energetic ion bombarding is shown in [3, 4]. An unwanted effect of the RF antenna bombardment with energetic ions is a heavy impurity emission into the plasma [5]. This effect decreases the efficiency of plasma heating in the ion-cyclotron region of frequencies (ICRF) applied in U-3M and U-2M. These processes are investigated in the present paper.

1. ELECTRON EMISSION FROM THE ANTENNA SURFACE

The electron emission from the U-3M and U-2M antennas can occur by several channels. The thermal electron emission (TEE) takes place at elevation of the temperature in the case of RF current passing, irradiation with electromagnetic waves from the plasma, bombardment of a surface with neutral particles, electrons and ions from VSC. Autoelectronic emission (AE) consists in the electron extraction from the metal by the VSC quasi-electrostatic field (field emission). Autoelectronic thermal electron emission (ATEE) develops if TEE and AE exist independently at $T \neq 0^0$ C and in the presence of the extraction electric field. In this case their joint action occurs. The photoelectron emission (PEE) can arise due to the antenna surface irradiation with monochromatic radiation at a sufficient quantum energy $h\nu > e\varphi$. Quantum absorption increases due to the surface erosion caused by the energetic ion bombardment (sputtering and arc formation processes). In the intense electromagnetic field PEE was observed at quantum energy which is lower by a factor of 2…7 than the energy of medium atom ionization. [8]. A secondary emission (SE) can occur as a result of the direct electron knocking-out from the antenna surface with VSC accelerated ions [9] excited by atoms and even by electrons [10]. A film emission can arise due to the formation of oil and other films. They can be formed in the process of gas and oil vapor adsorption and dielectric element atom redeposition. The emission electrons from the metal surfaces get the underside of films and the VSC bombarding ions fall on the topside of films, and part of them can deposit on the film surface. As a result, the films will be charged and will create local electric fields. The intensities of these fields can be sufficient for production of emission electron currents [9]. In the process of ion bombarding the microasperities are formed on the antenna surface. After six months of U-3 operation the erosion of the antenna surface caused by these processes was observed [11]. On the asperity ends the electric field increases. When the electric current passes through the asperities they withstand intense ohmic heating, melting and evaporation of the metal. Neutral particles in the near-antenna region are ionized by the emission electron flow and form a dense plasma cloud. Quasi-constant electric field extracts the electrons from this cloud which in this process plays a role of a virtual plasma cathode. This variant of ATEE is named an explosive emission [9]. A part of ionized impurity atoms can be accelerated by the VSC field in the antenna direction. Due to this feedback the antenna surface undergoes the avalanche bombardment with heavy ions. A contribution from a single electron emission mechanism can be insignificant. However, almost all mechanisms are interconnected (Figure) and enhance each other.

The emission electron beams can exert influence on the dynamics and parameters of the plasma under conditions of the RF discharge in the magnetic filed and strong nonlinear ICRF-VSC-RF-antenna interaction The electron flows emitted from the antenna compensate the ion loss in VSC due to the hydrogen atom ionization in the near-antenna region. Approximately 0.1 % of energetic electrons can double the VSC voltage, and several percents can increase the potential by a factor of 10 [12]. A part of electrons from the flow pass through the VSC creating the additional plasma ionization in the confinement region. At the start phase of the discharge the ionization can be changed into the avalanche process [13].



Simplified circuit of interconnection between different types of electron emission from the antenna in the RF discharges

If the VSC field exceeds the critical Dreicer field ($E_->E_D$) a part of accelerated beam electrons can turn into the runaway electrons. In U-3M this condition is usually fulfilled and is indirectly confirmed experimentally [4]. Runaway electrons phenomena could be one of the reason in rising of the losses of energy [14]. In the strong electromagnetic field the fast electron emission can excite the current plasma turbulence [15]. Then a part of electrons can obtain an additional heating that leads them to the two-temperature values. By the way, in U-3M the two-temperature state of ions was recorded experimentally [2].

2. HEAVY IMPURITY EMISSION

Very negative consequence of the antenna bombarding with accelerated ions is a heavy impurity emission into the plasma confinement volume [4]. In the experiments on the behavior of impurities, during plasma RF-heating in the torsatron U-3M, the metal impurity flows into the plasma from the RF-antenna and from the helical coil sheaths were found out [11]. In this experiments the RF power P_{RF} =450 kW is supplied to the antenna with titanium nitride (TiN) coating. A main cause for the increase of impurities Ti and Fe is the sputtering from the surfaces of the antenna and helical winding sheaths. It has been suggested that the surface sputtering occurs because of bombarding the surfaces with ions accelerated by a quasi-constant positive potential up to the energies of ≈ 300 eV. Such a potential arises in the case of VSC positive ion formation near the antenna and, probably, in the case of a lower value of the potential near the helical winding sheaths. By operating with a stainless-steel antenna the estimated average velocity of chromium atoms CrI in U-3M was $(2\ldots3)\cdot 10^6$ cm/s, that is characteristic for the processes of arc formation [16]. By operating with the TiN coated antenna the estimated velocity of atoms TiI was $\sim 5\cdot 10^5$ cm/s that is characteristic for the sputtering processes. A quantity of metal impurity atoms from the antenna is higher by a factor of 3 than that of impurity atoms from the helical winding sheaths and from the inactive antenna [4, 11, 16].

The increase a high-Z impurity contained in the plasma exerts influence on the *L* and *H* modes and internal transport barriers (ITB). It means that even insignificant impurity sources may be problematic for the hot plasma [12]. Therefore, many investigations are aimed to the problem of heavy impurities, in particular, metal impurities [12, 17-20]. It is shown, that the impurity sources can be, for the most part, antennas, as well as, Faraday screens, protective antenna elements, limiters and internal walls of discharge chambers. The volume-space charge which causes the metal surface sputtering can be formed by means of a far antenna field E_0 and surface wave field on the elements distant from the active antenna. Some part of Ti impurity migrates from the antenna throughout the chamber and adsorbs on the limiters by providing the secondary Ti source. A similar effect which occurs, most likely, in U-3M provokes the transport of Ti atoms from the active antenna onto the helical winding casings and other inactive antenna.

In the TFTR tokamak the Ti influx from the antenna Faraday screen [18] into the plasma core was investigated in [18]. In this experiment the Farady screen was coated with TiC. Redeposition of Ti on other metal surfaces and subsequent resputtering were observed too.

CONCLUSIONS

Many investigations have given a single-valued result for the impurity influx from the metal surfaces in the plasma facilities with RF discharges. A cause of the metal impurity influx into the central plasma region is the VSC formation, especially near the RF-antenna surface, and the subsequent bombarding of its surface by energetic positive VSC ions. The volume-space charge is an integral structure of low-pressure RF-discharges. Therefore, at present, it is impossible to remove the effect of metal impurity emission. This effect might be only weakened. The impurity quantity was decreased by the additional protection and coating of the antenna surface with a refractory metal (Ti, Co, Mo, W), however, in this case the average Z of impurity in the plasma volume was increased. After coating the *TiN* RF-antenna surface in U-3M the amount of the Ti impurity entering into the plasma was significantly decreased and, as a result, the plasma electron temperature was increased to 1.3 keV [9, 16]. A more effective method for the protection from the impurity is boronisation. In this case Z was decreased by a factor of 3 due to the heavy metal impurity decrease. A grave disadvantage of this method is a short life of the boron coated films – from tens to several thousands discharges. So, in the boronisation process a cycling is required.

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КРАЕВЫЕ ВЗАИМОДЕЙСТВИЯ ICRF – ОБЪЁМНЫЙ ЗАРЯД – АНТЕННА В ТОРСАТРОНАХ У-3М И У-2М ЧАСТЬ 2. ВЗАИМОДЕЙСТВИЕ ОПЗ – ВЧ-АНТЕННА

В.Л. Бережный

Проведен анализ влияния на ВЧ-разряд эмиссии электронов и металлических примесей из антенны, в том числе из торсатрона У-3. Оба эффекта являются результатом бомбардировки поверхности антенны ионами, ускоряющимися в самосогласованном поле объёмного пространственного заряда.

КРАЙОВІ ВЗАЄМОДІЇ ICRF – ОБ'ЄМНИЙ ЗАРЯД – АНТЕНА В ТОРСАТРОНАХ У-3М ТА У-2М ЧАСТИНА 2. ВЗАЄМОДІЯ ОПЗ – ВЧ-АНТЕНА

В.Л. Бережний

Проведено аналіз впливу на ВЧ-розряд емісії електронів та металевих домішок з антени, у тому числі з торсатрона У-3. Обидва ефекти є результатом бомбардування поверхні антени іонами, що прискорюються в самоузгодженому полі об'ємного просторового заряду.