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Measurement of Plasma Resistivity in the Edge of IR-T1 Tokamak

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Abstract— **The Plasma resistivity has been measured in the edge plasma of IR-T1 tokamak. To achive the edge plasma properties (T_e and n_e) using I-V characteristics of movable single langmuir probe. Density and temperature of electron, respectively n_e and T_e, are measured simultaneously for calculating the radial profile of parallel and vertical resistivity. As temperature of plasma raised, resistivity drops rapidly so Reduction of resistivity with increasing temperature could leads to prolonging of the duration of the plasma discharge.**

Keywords-: *tokamaks; resistive MHD; Electron collisions*

I. INTRODUCTION

Any realistic plasma will have a density gradient, and the plasma will tend to diffuse toward regions of low density. We assume that the plasma is weakly ionized, so that charge particles collide primarily with neutral atoms rather than with one another. As the plasma spreads out as a result of pressure gradient and electric field forces, the individual particles undergo a random walk, colliding frequently with the neutral atoms. When plasma consists of just electrons and ions, all collisions are coulomb collisions among charge particle (Trintchouk et al., 2003)(Chen, 1984). If a uniform steady electric field is imposed on plasma this electric field will accelerate the ions and electrons in opposite directions. The accelerated particles will collide with other particles and this fractional drag will oppose the acceleration. Resistivity is determined by the collisional drag on electrons moving against the background of ions. Suppose that an electric field E exists in a plasma and that the current that it drives is all carried by the electrons, which are much more mobile than the ions. Then in steady state the electron equation of motion changes, so that $E=\eta J$ is ohm's low, and η is the resistivity. The transverse or cross field resistivity was calculated by Spitzer as the rate of momentum transfer from electrons to ions through collisions in a resistive magnetohydrodynamics (Trintchouk et al., 2003)(de Blank, 2006) ,

where the electron temperature T_e is in electron volts, Z is the ion atomic mass and $\ln \Lambda$ is the coulomb logarithm. Also parallel resistivity defined by (Mahmoodi Darian et al., 2006)(Goldstone, 1995) ,

$$\eta_{\perp} \equiv 1.03\times10^{-4} T_e^{-3/2} Z \ln\Lambda \;\; (ohm.m) \qquad (1)$$

$$\eta_{Spitzer} = \eta_{\parallel} = 5.24\times10^{-5} \frac{Z \ln\Lambda}{T_e^{3/2}} \;\; (ohm.m) \qquad (2)$$

Impurities in plasma are one of important factors of instabilities. For example impurities prevent plasma from heating. We have defined Z_{eff} as the ratio of the measured plasma resistivity η_p to the theoretical resistivity $\eta_{\parallel}$. For ohmic input power, plasma resistivity is,

$$\eta_p = \frac{r^2 V_l}{2 R I_p} \qquad (3)$$

where V_l is loop voltage, I_p is the plasma current and R is the major radius of tokamak chamber. By definition of Z_{eff} the value of η_p could be calculated. The time evolution of Z_{eff} from a typical discharge of IR-T1 Tokamak has been shown in Figure 1.

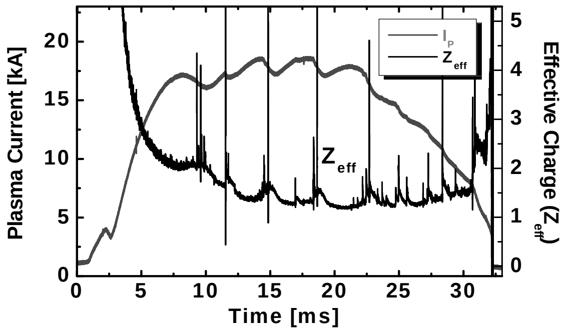

Figure 1. Time evolution of plasma current and effective charge.

II. EXPERIMENTAL SET-UP AND DIAGNOSTICS

IR-T1 tokomak is an ohmically heated air core tokamak with a major radius of R=0.45 m and a minor radius of a=0.125 m defined by two poloidal stainless-steel limiters. The vacuum chamber has a circular cross-section with two toroidal breaks and a minor radius of b=0.15 m. Toroidal magnetic field is equal to B_t~0.6-0.8 T, plasma current is I_p~25-30 kA, averaged electron density in hydrogen is 0.5-1.5×10^{19} m^{-3}, plasma discharge duration is t_d~30 ms and electron temperature is $T_e(0)$~150-180 eV. A single Langmuir probe was used to measure spatial and temporal evolutions of electron temperature and density. The probe is connected to the power supply where its potential is varied continuously over a range from negative to positive potential with respect to the plasma potential to obtain the ion and electron current. The current, *I* is determined as a function of the applied probe voltage V_{app}. This relation $I = f(V_{app})$ is called the probe characteristic or the *I-V* characteristic. The general appearance of the *I-V* characteristic for a Langmuir probe is shown in Figure 2.

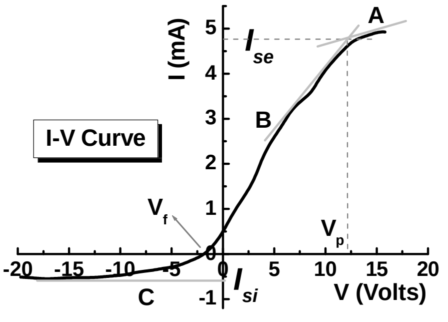

Figure 2. The *I-V* characteristic Langmuir probe during a typical discharge of IR-T1 tokamak.

In the Figure 2. the region *A* is known as electron saturation and *I* here is equal to the electron saturation current, I_{se},

$$I_{es} = \frac{1}{4} e n_e V_{e,th} A \qquad (4)$$

where n_e is the electron density, $V_{e,th} = \sqrt{8kT_e / \pi m_e}$ is the electron thermal speed. If the potential of probe becomes less than V_p, $V<V_p$, the probe is negative with respect to the surrounding plasma and this causes to reflect part of the impacting electrons (region *B*). Eventually in this potential, *I* reduce to small fraction of saturation current. The total current is zero when $I_i \approx I_e$. This phenomena happen when the probe potential is equal to floating potential V_f. Decreasing the potential further (entering region *C*) probe with constant rate, enable to collected ions. This is ion saturation current, $I=I_{si}$,

$$I_{is} = \frac{1}{4} e n_i V_{i,th} A \qquad (5)$$

where n_i is the ion density $V_{i.th} = \sqrt{8kT_i / \pi m_i}$ is the ion thermal speed and *A* is the probe collecting area. When $T_e >> T_i$, the ion saturation current is not determined by the ion thermal speed, and determined by the Bohm ion current (Merlino, 2007)(Popescun and Ohtsu, 2007) ,

$$I_{is} = I_{Bohm} = 0.6 e n_i \sqrt{\frac{kT_e}{m_i}} A \qquad (6)$$

From above equation, it could be seen that because of $n_e = n_i$ and $m_e << m_i$, the electron saturation current will be much greater than the ion saturation current (Merlino, 2007). Radial profile of electron density and electron temperature has been calculated by Langmuir probe, behind and in front of the fixed poloidal limiter from r =10.5-13.5 cm. The results have been shown in Figure 3.

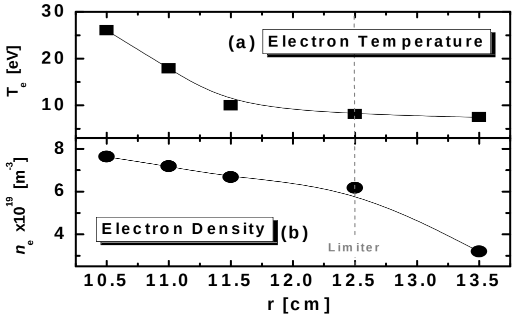

Figure 3. **(a)** The radial profile of electron temperature and **(b)** the radial profile of electron density.

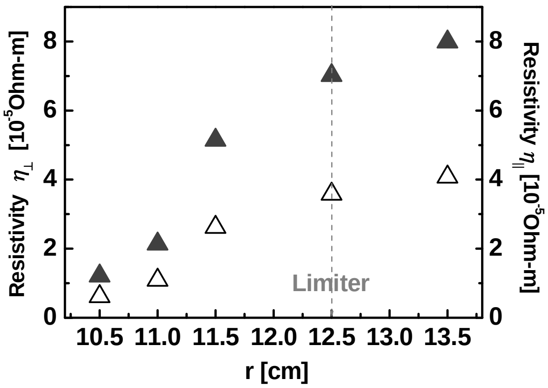

Figure 4. The radial profile of parallel and vertical plasma resistivity.

The radial profile of electron temperature and electron density have been shown in Figure 3. it can deduced that the electron temperature and electron density are increasing from edge to core of plasma, so according to equation 2 the plasma resistivity will decrease by increasing electron temperature. In other hand, when electron temperature increases, the collision frequency is decrease. Collisions between electrons and ions in plasma will prevent the accelerations of electrons in response to an electric field. Without such collisions, electrons would be accelerated indefinitely by an applied electric field, so that an infinitesimal voltage would be sufficient to drive a large current through plasma. Collisions between electrons and ions cause to limit the current that can be driven by an electric field. Also resistivity may be expressed in terms of the electron-ion collision frequency, (Goldstone, 1995)

$$\nu_{ei} = (\frac{ne^2}{m})\eta \qquad (7)$$

So we can deduce from above sentences that when electron temperature increases, collision frequency decrease therefore plasma resistivity decreases. The Figure 4. shows the calculated radial profile of parallel and vertical plasma resistivity it decreased from edge to core. We found that, transverse resistivity for electrons are higher than the parallel resistivity by a factor of 1.96, the results have been compared with other tokamak plasmas and it is similar to TCABR and CASTOR tokamak. In the last, the results have shown that electron density increased from edge to core of plasma column, as the parallel electrical resistivity of the plasma decreases with increasing temperature, this could leads to prolonging of the duration of the plasma discharge.

III. CONCLUSION

In this paper we obtained the plasma resistivity profile using parameters of plasma such as n_e and T_e calculated by *I-V* characteristics of moveable single Langmuir probe in the edge of *IR-T1* tokamak. The results showed that electron temperature decrease from core to edge, as for electron density is. Plasma resistivity is proportional to $T_e^{-3/2}$, so resistivity increase from center to edge of plasma. As temperature of plasma raised, resistivity drops rapidly so plasma at very high temperatures is collision-less i.e. their resistivity is negligible. Reduction of resistivity with increasing temperature could leads to prolonging of the duration of the plasma discharge. Effective charge may be important to measurement of resistivity in high plasma impurity, so that it can prevent the plasma for ohmicaly heating.

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