A simplified technique to measure the plasma electron temperature

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In such thermonuclear machines as ITER the relatively high levels of potentially damaging fluxes at the first wall – neutrons and γ –rays make very problematic the using of any semiconductor detectors placed near the machine. So it is necessary to design the diagnostics without such detectors.

In this paper the simplified technique to measure the plasma electron temperature clear on such limitations is described.

The absorber-foil method introduced in [1] was used to evaluate the plasma electron temperature. This method is based on the fact that the ratio of the signals of two detectors looking along the same chord of the plasma cross section when the entrance of one detector is covered by the filter depends mainly on the peak electron temperature along the chord. The electron temperature T_e can be obtained from comparison of the experimental and theoretical flux ratio. Usually the electron temperature from several hundreds of eV is measured by this method.

The measurements of the soft-X-ray emission with double channel Low-Voltage - Ionization Chamber (LVIC) [2] is proposed. The schematic diagram of the detector is shown in Fig.1. The detector have two identical LVIC.

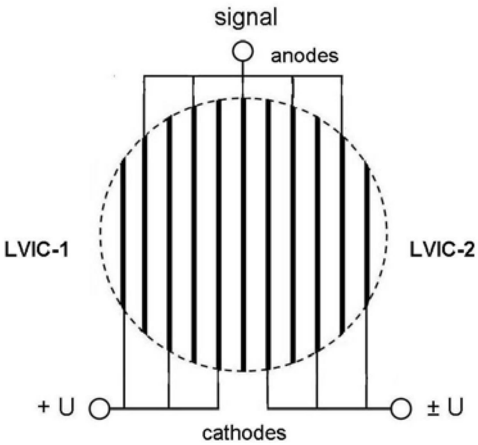

Fig.1. Detector schematic diagram

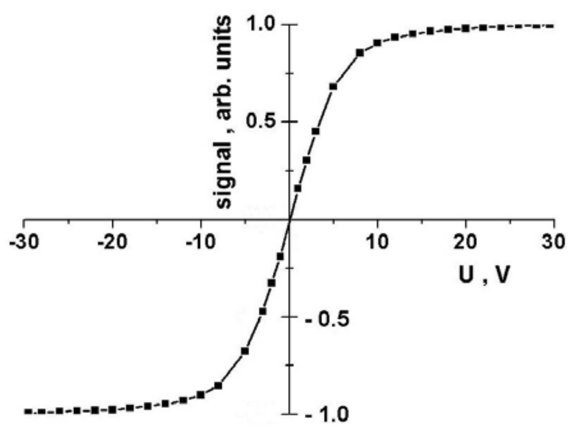

Fig.2. LVIC current-voltage characteristic.

Every LVIC has several flat electrodes with a 3-mm interelectrode distance. Diameter of detector is 60 mm and its length is 65 mm. The anodes of both LVIC are connected together. The entrance of LVIC-2 is covered by Al filter with thicknesses of 10-20 nm. The current-voltage characteristics of every LVIC one can see in Fig.2.

As it follows from this figure the characteristic is symmetric against the sign of applied potential. This fact is principal for this method. The plato regime starts from 10-15 V. The external appearance of the detector is given in Fig.3. The female ring serves as the scale. The bias potential on the one LVIC is DC potential of +15 V, and on the second one is ±15 V meander.

If the signs of bias potentials of both LVIC have the same sign, anode current is the sum of LVIC-1 (I_1) and LVIC-2 (I_2) currents

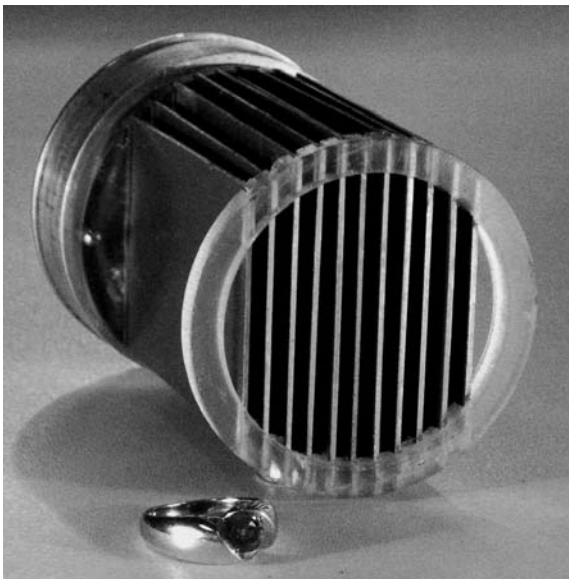

Fig.3. Detector external appearance.

$$I^+ = I_1 + \eta I_2 = I_0(1+\eta) \tag{1}$$

In the opposite case we have

$$I^- = I_1 - \eta I_2 = I_0(1-\eta) \tag{2}$$

where η is the filter transmission and I_0 is the intensity of X-ray flux.

From Eqs. 1 and 2 we can find the filter transparency

$$\eta = \frac{I^+ - I^-}{I^+ + I^-} \tag{3}$$

Radiation of an X-ray tube with a tungsten anode was used to test the detector. The voltage applied to the tube was varied from 5 to 50 kV.

The X-rays energy distribution in the flux from tube which fall on the detector entrance is

$$\left(\frac{dN_{h\nu}}{dE}\right)_{tube} \sim \left(\frac{U_0}{E} - 1\right)\eta_{Be}, \quad \frac{\text{quanta}}{\text{s}} \tag{4}$$

where U_0 is the tube anode potential, $\eta_{Be} = \exp(-\mu_{Be} d_{Be})$ is transparency of the tube Be window, μ_{Be} is the Be absorption coefficient, d_{Be} is the window thickness. If the thickness of Al filter is d_{Al} and the distance between detector and tube is d_{Air} the signal from LVIC-1 is proportional to

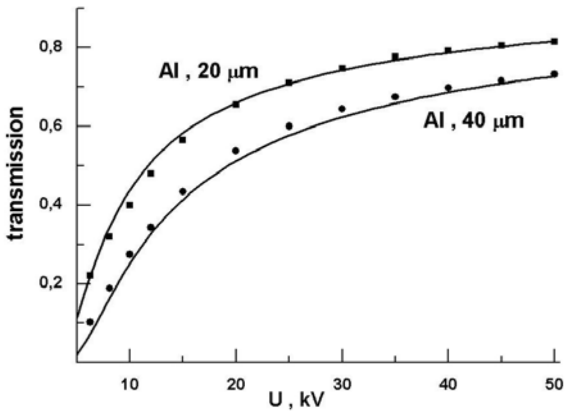

Fig.4. The transmission values for Al filters with different thickness.

$$I_1 \sim \frac{\int_0^{U_0} \frac{dN_{h\upsilon}}{dE} f_{eff} \exp(-\mu_{Air} d_{Air})}{\int_0^{U_0} f_{eff} \exp(-\mu_{Air} d_{Air})} \quad , \quad \frac{quanta}{s} \tag{5}$$

and the signal from LVIC-2 is proportional to

$$I_2 \sim \frac{\int_0^{U_0} \frac{dN_{h\upsilon}}{dE} f_{eff} \exp(-\mu_{Air} d_{Air} - \mu_{Al} d_{Al})}{\int_0^{U_0} f_{eff} \exp(-\mu_{Air} d_{Air} - \mu_{Al} d_{Al})} \quad , \quad \frac{quanta}{s} \tag{6}$$

here f_{eff} is the detector effectiveness of x-ray detection, μ_{Air} and μ_{Al} are the air and Al absorption coefficients. The transmission for $d_{Al} = 20\ \mu m$ and $d_{Al} = 40\ \mu m$ are given in Fig.4. In this figure the points are experimental data and the solid lines were calculated with

$$f_{eff} = \frac{15 + E^{1.6}}{E^2} \tag{7}$$

The X-rays energy distribution of the flux from a plasma which falls on the detector entrance is

$$\left(\frac{dN_{h\nu}}{dE}\right)_{plasma} \sim \frac{1}{E} \exp\left(-\frac{E}{T_e}\right) \eta_{Be} \, , \quad \frac{quanta}{s} \tag{8}$$

Usually the plasma radiation come to the detector through the Be windows with thickness d and the distance between detector and windows is d_A. In this case the detector signal after Al filter is

$$I \sim \frac{\int_0^{\infty} \left(\frac{dN_{h\upsilon}}{dE}\right)_{plasma} f_p \exp(-\mu_{Air} d_A - \mu_{Al} d_{Al})}{\int_0^{\infty} f_p \exp(-\mu_{Air} d_A - \mu_{Al} d_{Al})} \, , \quad \frac{quanta}{s} \tag{9}$$

Taking into account the described equations we can calculate the dependence of the plasma electron temperature T_e on the Al filter transmission η_{Al}. In these calculations the distance between the machine and detector is 10 cm. This relation is given in Fig.5. From this figure one can see that through 10 μm Al filter penetrate 36 % of X-ray plasma radiation and through 20 μm Al filter penetrate 19 % one.

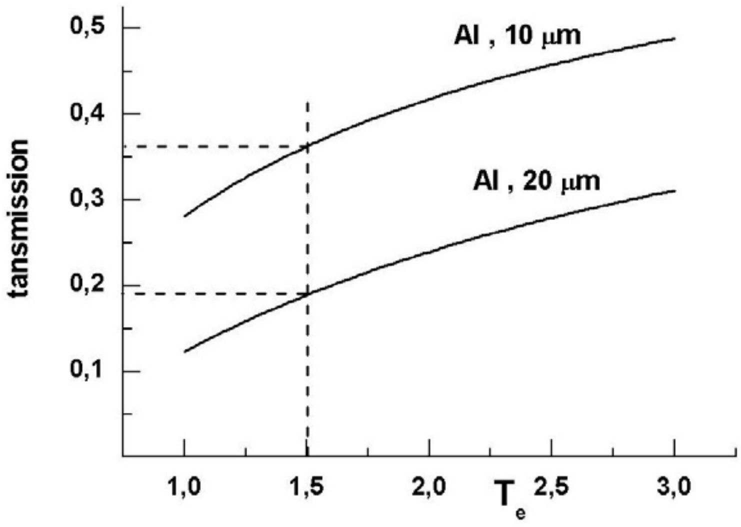

Fig.5. The dependence of the filter transmissions on the plasma electron temperature.

As the spectra of the tube and plasma radiation are different the value of f_{eff} can be different. So *in situ* calibration is necessary. For that it is possible to measure T_e with help of the filters with different thicknesses and calculate the f_{eff} for real experimental conditions.

1. Jahoda, F.C., Little, E.M., Quinn, W.E., Sawyer, G.A., Stratton, T.F. Phys. Rev., v.119, p.843, 1960.
2. Gott, Yu.V., Stepanenko, M.M., Instruments and Experimental Techniques, v. 52, p.264, 2009.