A photodiode for the measurement of soft x-ray radiation from plasma

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Photodiodes with three layer zirconium, titanium, and aluminum have been used as detectors on the high beta tokamak-extended pulse tokamak for soft x-ray radiation measurement. Signals from the photodiodes show sawteeth instabilities and magnetohydrodynamic oscillations. © *1996 American Institute of Physics.* [S0034-6748(96)05409-3]

Radiation in the soft x-ray range from plasma can provide density, temperature and magnetohydrodynamic (MHD) instability information. Silicon photodiodes have been used as the soft x-ray radiation detectors. Usually, a separately supported aluminum or beryllium thin-film filter is used to cut off the lower-energy photons. The shortcoming of this scheme is that the thin film is very fragile. The problem is even more serious when the plasma temperature and density are not that high so that the thin film has to be very thin.

Photodiodes with Zr/Ti/C thin-film filters deposited directly on the surface have been used on the high beta tokamak-extended pulse (HBT-EP) tokamak as the detectors for the soft x-ray tomography system. This note describes the photodiodes and presents the soft x-ray measurement results using these photodiodes.

HBT-EP tokamak was built to study MHD instabilities during high β discharges.[1] It has a major radius 92 cm, and a minor radius 14–19.3 cm. The plasma current is usually less than 25 kA. The machine runs with a pulse length less than 10 ms. The toroidal field is about 3 kG. The line integrated plasma temperature is about 100 eV. The plasma density is 1×10^{13} cm^{-3}.

One of the unique features of HBT-EP is a segmented conducting shell which consists of 20 segments located at 10 toroidal locations. Each segment is attached to a shell positioner, so that the distance between the shell and the plasma can be adjusted between shots. This unique feature allows us to study the wall stabilization effect on the MHD instabilities. Another unique feature of the HBT-EP tokamak is a set of saddle coils powered by an amplifier provided by the Los Alamos National Lab. The saddle coils are located at different toroidal positions to provide a magnetic filed with $m/n = 2/1$ structure. They allow us to carry controlled feedback studies on the MHD modes.

A soft x-ray tomography system has been designed to study the MHD structures on HBT-EP. The system employs 32 collimated channels of silicon photodiodes manufactured by the International Radiation Detector Inc., as the soft x-ray detector. The photodiodes chosen are AXUV-20's by the International Radiation Detector. AXUV-20 has a sensitive area of 20 mm^2, and a capacitance less than 500 pF. According to the manufacturer, a technique of fabrication of silicon *p-n* junction without creation of a surface "dead region" (no recombination of photogenerated carriers in the doped n^+ region, or at the Si–SiO_2 interface) was used. Furthermore, the SiO_2 layer was reduced to less than 8 nm thickness. Subsequently, these diodes exhibit near-theoretical quantum efficiencies for photons with energy from 6 to 6000 eV. Please refer to Ref. 2 for details of the fabrication process. To filter out lower-energy photons, we ask the photodiode manufacturer to deposit thin-film filters directly on the surface of the photodiodes at the wafer level. Beryllium has been commonly used as the filter material. However, since beryllium is toxic, we designed a three-layer filter consisting of zirconium, titanium, and carbon.

The thicknesses of each layer were varied during the calculation to optimize the response. In the calculation, the transmission coefficients of different materials were experimental data taken by Henke *et al.*[3] The data were downloaded from a Soft X-ray World Wide Web server, http://xray.uu.se/hypertext/henke.html. Based on the calculation, a combination of 100 nm zirconium (Zr), 7.5 nm titanium (Ti), and 100 nm carbon (C) has been chosen. Figure 1 shows the calculated transmission of the Zr/Ti/C filter in the X-UV and soft x-ray range.

Relative response of the photodiodes with filters to different temperature plasma has also been calculated. In the calculation, bremsstraulung radiation and recombination radiation have been taken into account. A theoretical quantum efficiency of one electron-hole pair per 3.63 eV photons has been assumed for nonfiltered photodiodes. The calculated fil-

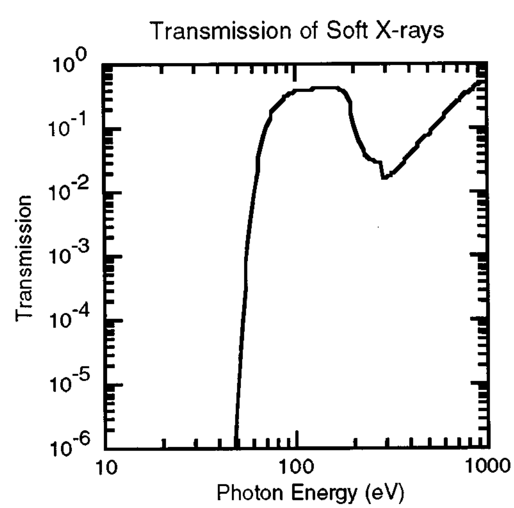

FIG. 1. Transmission of the Zr/Ti/C filter in the soft x-ray range. The thickness of Zr is 100 nm. The thickness of Ti is 7.5 nm. The thickness of C is 100 nm.

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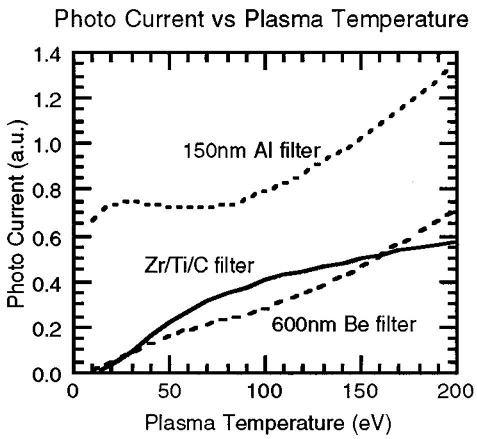

FIG. 2. Relative responses of photodiodes with various filters as functions of plasma temperature.

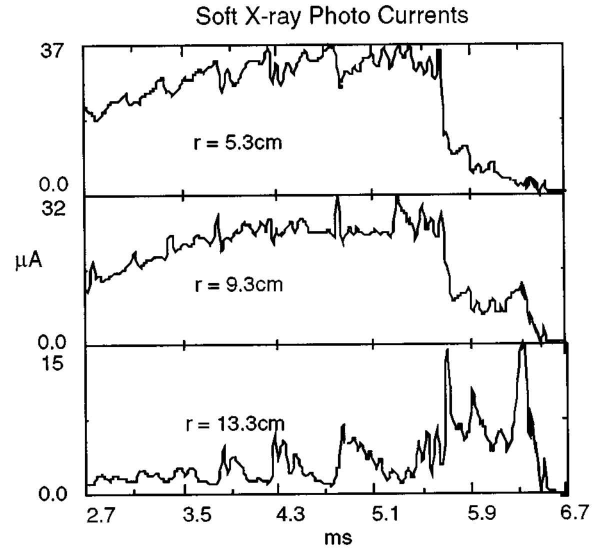

FIG. 3. Soft x-ray signals measured by photodiodes with Zr/Ti/C thin-film filters. The signals exhibit sawteeth and MHD oscillations.

ter transmission was then combined with this theoretical quantum efficiency to get the response of the filtered photodiodes. Figure 2 is the calculated result of a photodiode with the Zr/Ti/C filter as a function of plasma temperature. In comparison, Fig. 2 also shows the relative responses of photodiodes with a beryllium filter and an aluminum filter as a function of plasma temperature.

Figure 3 shows the soft x-ray signals measured by the photodiodes with the Zr/Ti/C thin-film filters in a HBT-EP discharge. Signals along three chords are shown here. This shot is characterized by sawteeth instabilities and MHD oscillations. The signals show the reverse sawteeth on the signal from the channel away from the center. This indicates outward movement of thermal energy during the crash phase of the sawteeth. The termination of the discharge was also accompanied by outward thermal movement. The mode numbers of the MHD oscillations and the exact scenario of the disruption remain to be resolved by future tomography reconstructions.

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