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Three-channel X-ray detection head for diagnostics of plasma in noisy environment

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Abstract A compact, three-channel, noise-resistant detection head based on semiconductor detectors has been built for the diagnostics of X-ray emission from plasmas. It is useful in the energy range of 0.5–20 keV.

Key words high-temperature plasma • semiconductor detector • X-ray diagnostics

Introduction

Semiconductor detectors, sometimes called P-I-N diodes, are often used at diagnosing the hot plasma [1–3]. Multichannel detection systems give the possibility of evaluating the level of X-ray emission at different ranges of wavelength. To have a broadband range of operation detectors of special kind, suitable for the softest and the hardest parts of the considered spectrum, should be applied. In this work, for these extreme parts of spectrum we use special Si photodiodes: the ones of a very thin active layer and additionally of a very thin dead layer, for the range of about 1 keV, and thick detectors, which are intended for registering nuclear radiation [4], for measurement of harder X-ray component up to about 20 keV. Based on the detectors, a compact three-channel detection head was constructed. The head is small-sized and is supplied from a battery, to make it prepared to operation in a noisy environment.

Detectors

Three types of Si photodiodes are used in the head, all fabricated at ITE, Warsaw, Poland. The simplified cross-sections of structures of the diodes are shown in Fig. 1. The shaded areas correspond to the active (depleted) layers in the diodes. The FLM detector [4] is fabricated from a high-resistance material and has a thick active layer (380 μm, when full depleted at the bias above 100 V). It is for measurement of a hard component of X-ray emission up to 20 keV. The BPYP03B photodiode is made of a low-resistance silicon and is characterised by a thin dead layer (about 0.15 μm). The thickness of the active layer in the photo-diode is voltage-dependent, and it can be set to as low a value as 2 μm (at the bias of 20 V). That makes the photodiode insensitive to hard radiation above 5 keV. It is suitable for measurements of a soft component of X-ray radiation in the range of 2–4 keV. The BPYP03A photodiode

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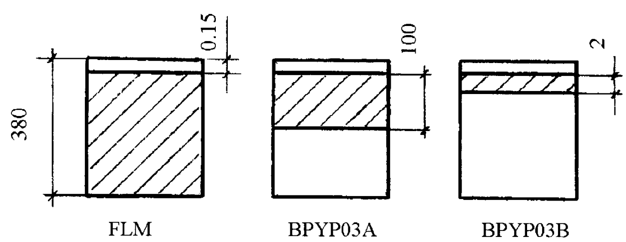

Fig. 1. Cross-sections of the diodes. Dimensions are in micrometers.

is of medium parameters. It is from a 2 kΩ material, and the thickness of active layer can be set at 100 μm. The thickness of the active layers of the detectors determines the sensitivity in recording the harder X-rays, as it can be seen from Fig. 2. The X-ray response in Fig. 2 is a product of the absorption of X-rays in an active layer and the transmission through the dead layer (the influence of the dead layers is small above 1 keV). An adjustment of the sensitivity in the soft energy range can be obtained by the use of a proper entrance filter.

Head description

The head was designed for attaching to an experimental chamber. It is vacuum-tight and is equipped with a clamping connector (Figs. 3 and 4). X-ray filters are located in two places. One common, entrance, thin filter is provided

Fig. 3. Side view of the detection head (without DC/DC converter and after removing the plate that supports filters).

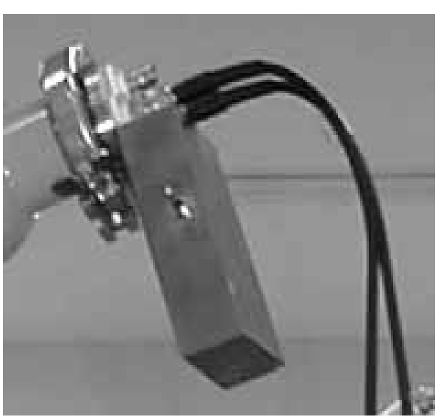

Fig. 4. View of the detection head mounted at the experimental chamber. The attached cuboidal box contains DC/DC converter and battery.

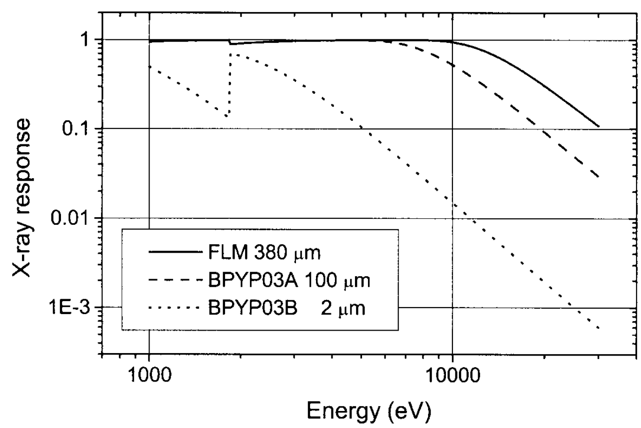

Fig. 2. X-ray responses of the detectors employed in the head (without entrance filters).

for mounting at a great distance from the head (as a separate mechanical part), to avoid capturing possible X-ray fluorescence, and the three others are mounted close to the detectors. These close filters are attached with the use of magnets and can be easily replaced by others.

To make the head resistant to the noise produced by the plasma-generating facilities special means were used. All the inside electronics is insulated from the enclosure including the output connectors. As the head can be additionally insulated as a whole from the experimental chamber, a double shielding is possible with the use of a double shielded coaxial output cable. The head is of small dimensions and of tight construction, which lowers the sensitivity to noise as well. The compactness of the head was achieved by the use of electronic components (photodiodes, charge-bank capacitors) in the form of bare chips (without casing), and by the use of the shortest connections possible. To make the electrical shielding more efficient, the head is supplied from a battery. A small DC/DC converter is provided (supplied from a 9 V battery) to deliver high voltage (up to 330 V).

The electrical scheme is shown in Fig. 5. The steady dark current of the detectors is very low, in the range of some nanoampers, so the loading of the power supply is low as well. The separating resistance of a great value (1 MΩ) can be used to attenuate noises. During the registration of an X-ray pulse the detector takes current from the 4.7 nF capacitor. The DC/DC converter (Fig. 6) was designed to obtain the longest operation possible without battery changing. It is based on a high-voltage BSS125 MOS transistor. Owning the low loading of the battery (about 2 mA), the equipment can operate for 100 hours (or 200 hours, when using an alkaline battery).

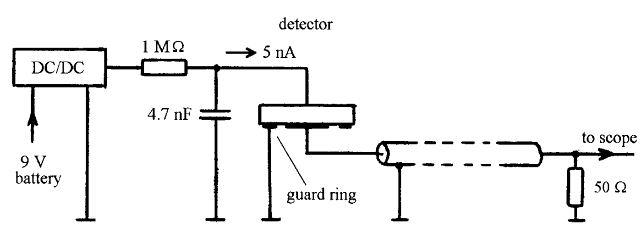

Fig. 5. Electrical circuit of detector connection.

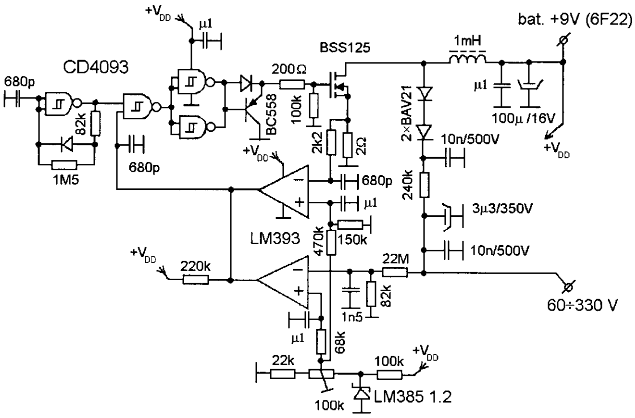

Fig. 6. Electronic scheme of the high-voltage DC/DC converter.

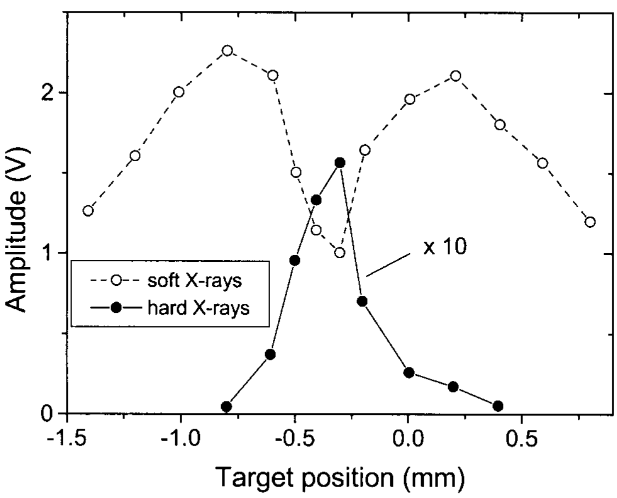

Fig. 8. Example of measurements of X-ray emission from a picosecond plasma (hard and soft components).

Testing of the head

The head was checked with X-ray pulses from a cold-cathode X-ray lamp and later on with a picosecond laser system in Warsaw and as well as with the Prague Asterix Laser System (PALS). The clean output signals from BPYP03B and from FLM detectors, obtained when using the head at the picosecond laser, are shown in Fig. 7. The long tail in the upper trace is due to a high capacitance of the BPYP03B photodiode. As the detectors operate in an integrating mode, the amplitudes are proportional to the charge generated in detectors' active layers and the voltage sensitivities are proportional to the values of a detector capacitance (enlarged by a stray capacitance). An example of investigation of the dependence of X-ray emission on the position of a target (in relation to the position of the optical focus) confirming the proper behaviour of the head is shown in Fig. 8. The data presented are for an Au target. The point on the X-axis that is labelled 0.0 corresponds to the case of sharp focusing as measured by the use of a somewhat inaccurate optical method. The two-humped curve in Fig. 8 is due to the soft component, and the single-peaked curve is from hard radiation. The same typical dependencies have been registered at the PALS.

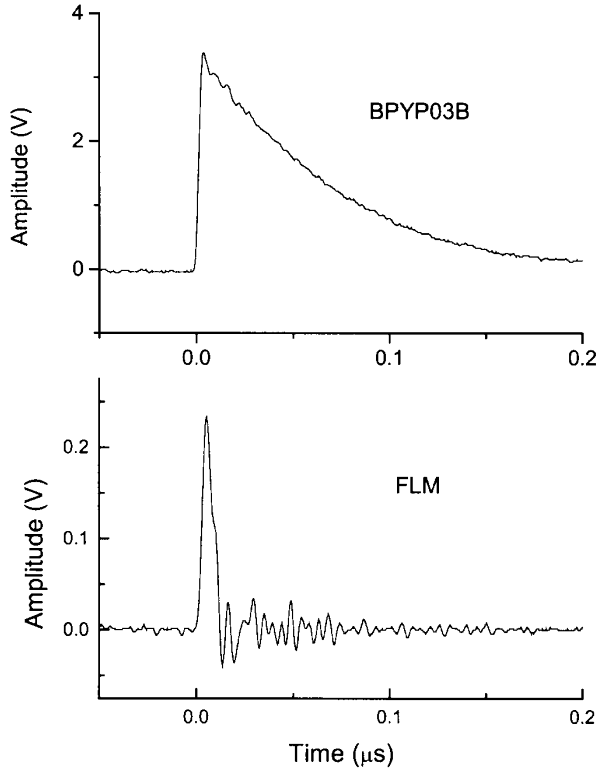

Fig. 7. Output signals from BPYP03b and FLM detectors.

Summary

A X-ray detection head intended for recording radiation from hot plasma in three spectrum channels spreading from 0.5 to 20 keV was designed and fabricated. The possibility to operate in such broad range of energy was obtained by the use of new generation high quality specialised detectors. The configuration of filters in the head is flexible giving the possibility of changing the width of the spectrum channels. The head is supplied from a battery and is easy to handle under experimental conditions. The head was designed to be resistant to noise and that feature was proved at laser experiments.

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