Fast XUV 16×16 array hybrid module for plasma imaging applications

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Introduction

Absolute extreme ultraviolet (AXUV) Si photodetectors manufactured by IRD Inc. (USA) [1] are quite popular in plasma research applications owing to high sensitivity, fast response and an almost flat spectral curve in the 30…5000 eV photon energy range [2-8]. Owing to this feature, AXUV detectors are frequently named “silicon bolometers” [2], related as being applicable for the absolute measurements of the photon fraction of plasma radiation loss [2-7].

However, the detector μs-scale response and high sensitivity are frequently more important for plasma imaging applications, than radiation power measurement accuracy, since they provide an opportunity to follow the evolution of MHD and other rapid events [9,10].

Currently there is no commercial manufacturer of matrix XUV arrays, suitable for plasma imaging applications, which would be quite helpful, e.g. for studies of impurity behavior in scrape-off layer, its penetration and accumulation into the plasma core. This task is a main goal of the present work, aimed at the development of a hybrid array approach with the use of SPD photodiodes similar to AXUV Si detectors, designed and manufactured according to Ioffe Institute original technology [11].

Detector array design

In general, the design of SPD diodes is similar to AXUV detectors with an ultra-shallow p-n-junction and extremely thin (5…10 nm) surface “dead” layer. The spectral responsivity of detectors is shown in Figs.1,2.

Getting an optimum compromise between the read-out cycle frequency (frame rate), the spatial resolution (pixel No) and the number of parallel electronic channels, is the main problem to be solved. The task is much harder for XUV plasma diagnostics due to the restrictions related to the in-vessel location: vacuum compatibility, limited number of vacuum feedthroughs, ability to withstand thermal baking at 150-200ºC, wall conditioning procedures, etc. The frame rate of $>2\cdot10^5\ s^{-1}$ together with proper detector and front-end circuit bandwidths are needed for impurity behavior studies, since the characteristic times of rapid events related to impurity propagation in plasma during disruptions, magnetic reconnections, ELMs and other fast processes, are of the 10…100 μs range [9, 10] (Figs.3,4).

These requirements defined the hybrid approach combining the detector array with front-end electronics, and limited total number of pixels in a single module. The basic 16×16 hybrid module is comprised of eight stacked sub-modules with 2×16 linear SPD diode arrays combined with a circuit board containing two 16-channel preamplifiers and four 8-channel fast multiplexers. The pictures of a prototype sub-module, stacked array and simplified front-end circuit are shown in Figs.6-8, respectively. The matrix array front size is 31×31 mm with ~25% filling factor (single element size is 0.88×1.22 mm).

The module has “zero-edge” design providing an option of stacking them into the larger arrays, if necessary. For preliminary testing it is packed into a pinhole camera of 38×38×155 mm size with a variable field-of-view and 50-pin output connector (Fig.8).

Data acquisition system and preliminary test results.

The data acquisition system (DAS) is based on the approach developed for short-pulse plasma diagnostic application requiring fast simultaneous sampling of a number of analog signals (Fig.9). It is comprised of the controller of array multiplexers shown in Fig.7, and eight 4-channel synchronous 12-bit ADC modules with a 40 MS/s upper sampling rate, thus providing ~1 μs minimum time for the array complete read-out. Each channel has a 64 MB on-board memory limiting the duration of the acquired period to 0.8 s at the maximum sampling rate. A common TCP/IP Ethernet protocol is used for the data transmission to main PC operating as a DAS control console, data preview and storage computer.

Preliminary laboratory tests of detector noise and response time were fulfilled with the use of red, blue and UV light-emitting diodes, which provide various light absorption depths relevant to actual UV to X-ray photon ranges in silicon. Satisfactory dynamic performance of the prototype device had been observed, with the 10/90% rise/fall times within 5±2 μs range at 2.5 V bias (Fig.10). Further optimization of the module design to get better temporal resolution is planned after full-scale testing in the T-11M tokamak environment. The development of a proper insertion mechanism is underway.

Acknowledgments

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Spectral responsivity of XUV detectors

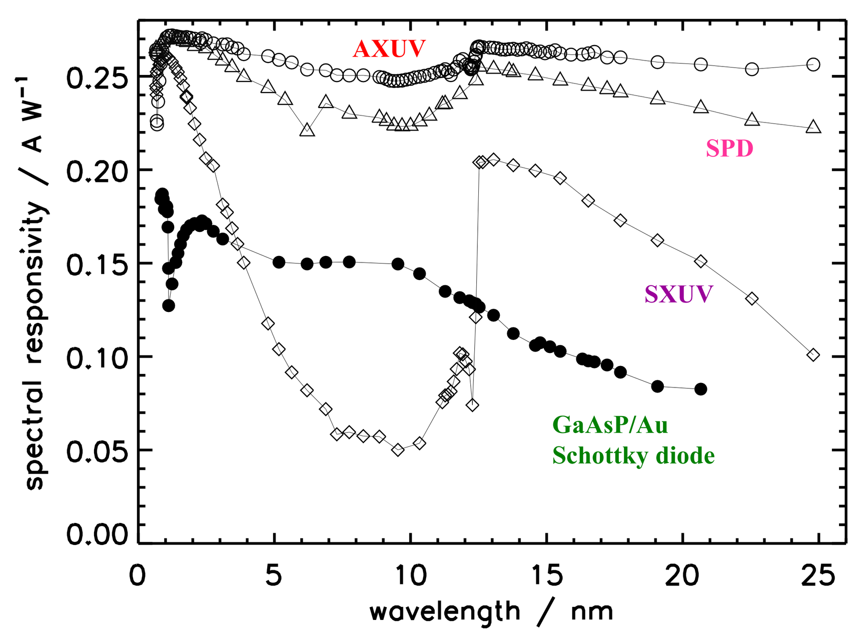


Fig.1. Spectral responsivity of extreme UV photodiodes [8].

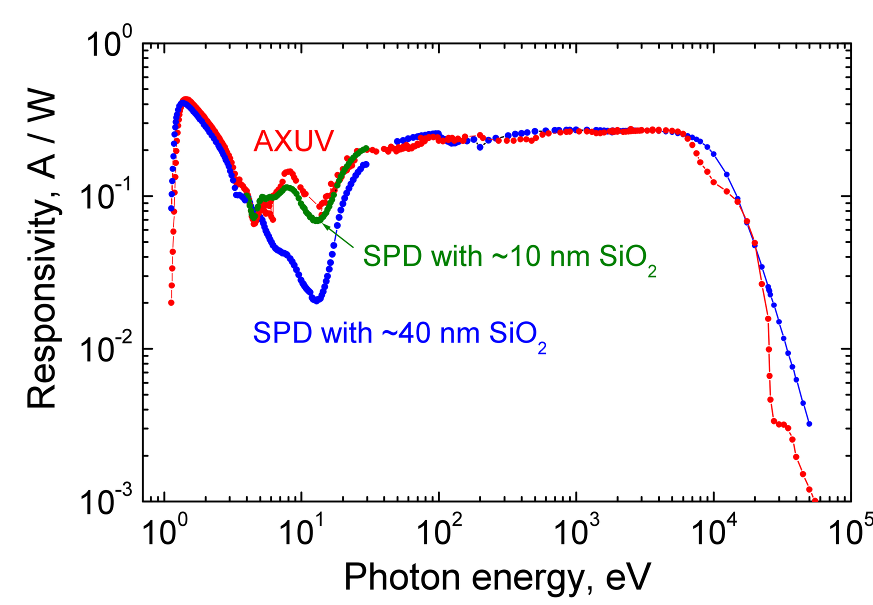
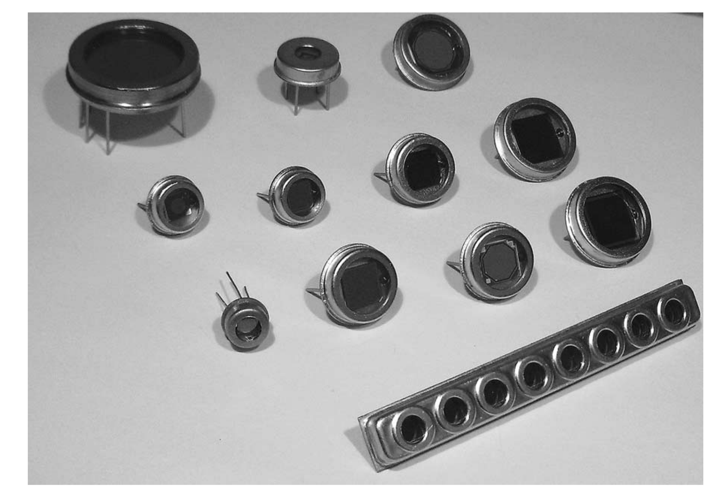


Fig.2. Wide-range spectral responsivity of XUV photodiodes [5,8].

SPD photometric detectors



Radiation effects

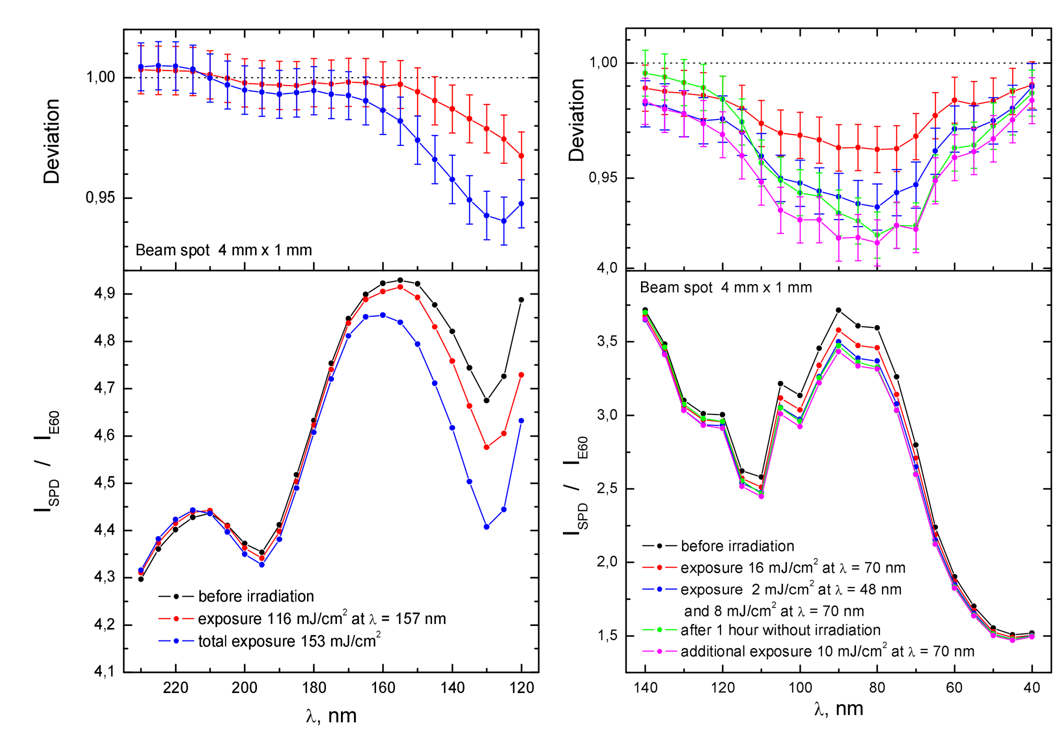


Fig.5. Variation of SPD photodiode response under UV irradiation

Hybrid 16×16 SPD photodiode array module design

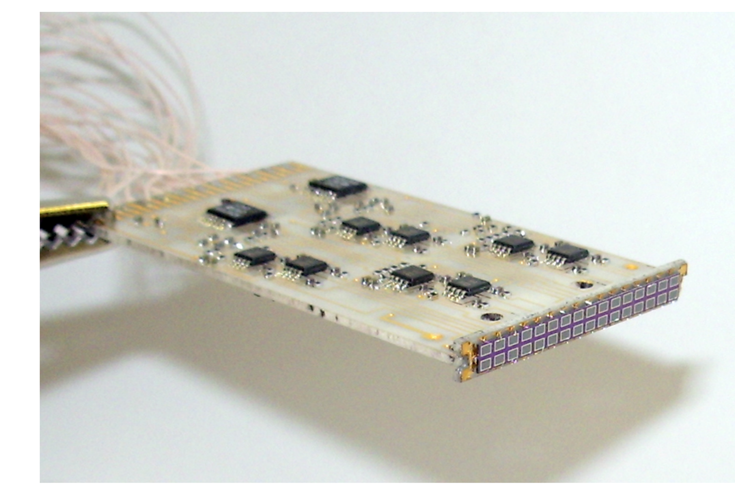


Fig.6. Hybrid sub-module with 2×16 linear SPD diode array.

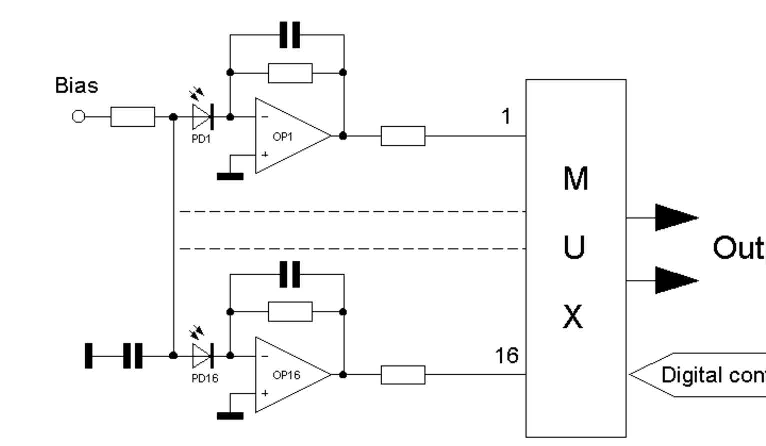


Fig. 7. Simplified detector front-end circuit

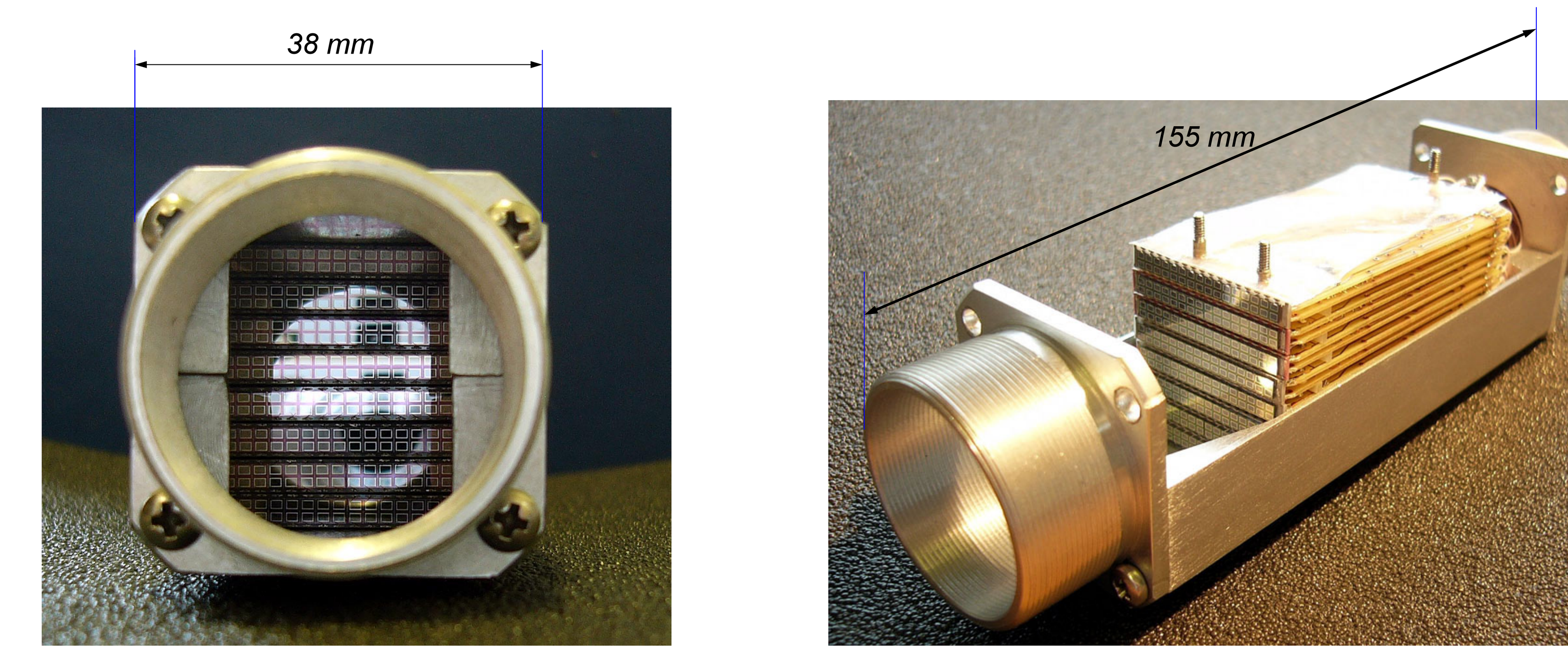


Fig.8. Prototype 16×16 hybrid array module packed into the test pinhole camera.

Fig. 9. Synchronous 32-channel × 40 MS/s data acquisition system with multiplexer, TCP/IP Ethernet controller and power supply units. Each 12-bit ADC comprises 64 MB on-board memory.

16-channel AXUV monitor at T-11M tokamak

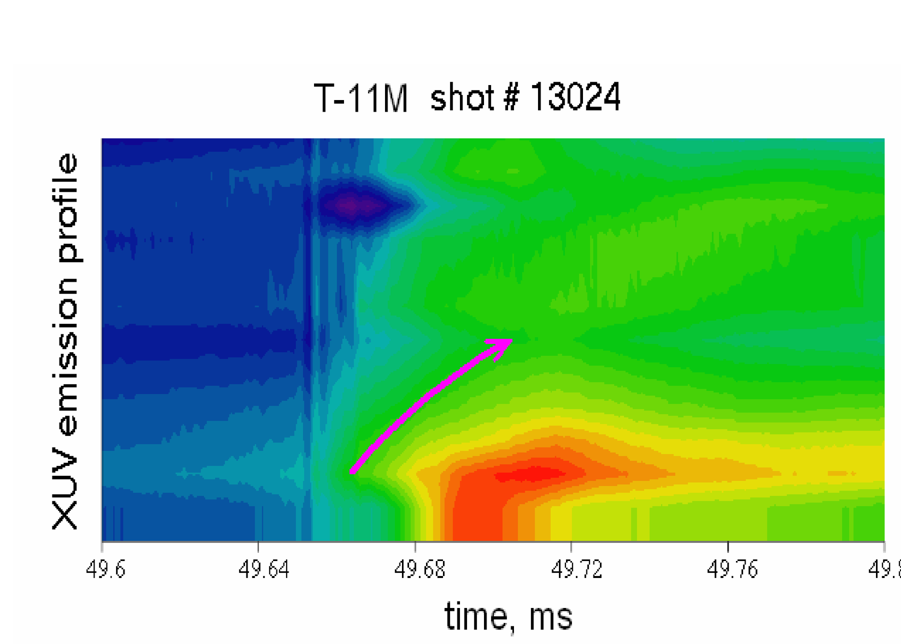


Fig.3. Fast penetration of Li impurity into the plasma core during the disruption [9].

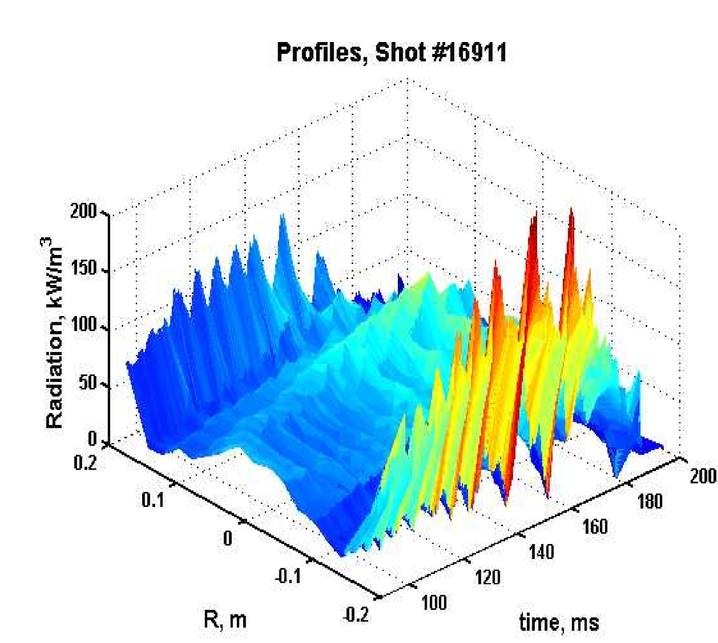


Fig.4. Ionization-condensation instability in the plasma edge at high Li impurity efflux from the Lithium limiter [10].

Transient response

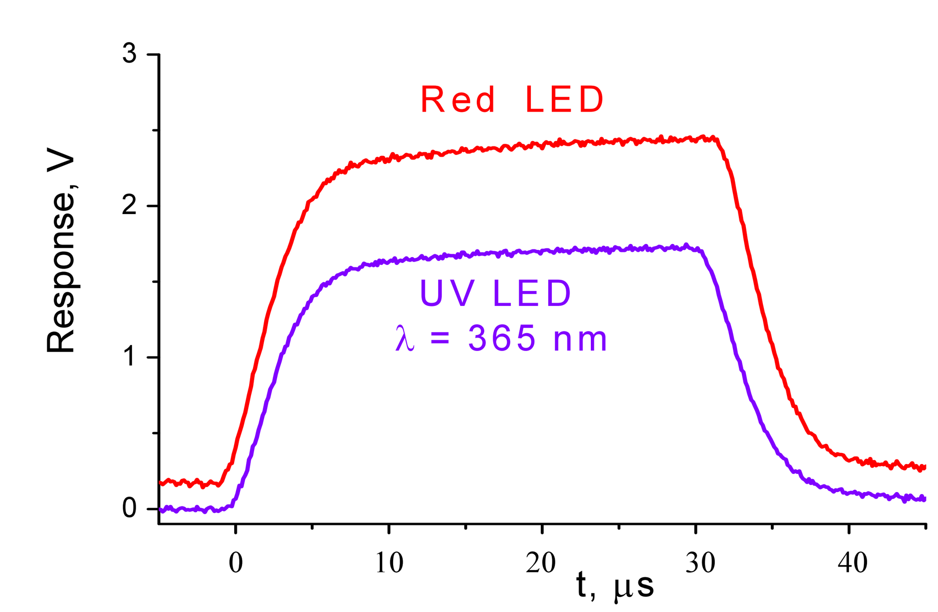


Fig.10. Transient response of SPD array detector with front-end circuit shown in Fig.7 to UV and red LED pulse.

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