Fast XUV plasma imaging: matrix array detector with 1 Mfps frame rate

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Introduction

Silicon extreme ultraviolet (XUV) photodiodes became quite popular in plasma researches last 15 years owing to fast response (< 1 μs), and high sensitivity (~ 0.1…0.2 A/W) in wide spectral range 1…5000 eV [1-5]. It provides an opportunity to develop multi-channel pinhole camera diagnostics with good spatial and temporal resolution with high S/N ratio in a broadband frequency range [2]. However, a direct 2D plasma imaging with the use of these detectors still is not possible due to limited variety of commercially available versions manufactured mostly in single-element and linear array packages with wide-edge design preventing their assembling into a matrix array.

For this reason, an experimental 16×16 hybrid matrix array detector unit had been developed for the fast XUV plasma imaging with up to 10^6 fps frame rate [4,5]. The detectors were manufactured by the original technology of Ioffe Institute providing the spectral response curves very similar to those of well-known AXUV detectors from IRD Inc. Corporation.

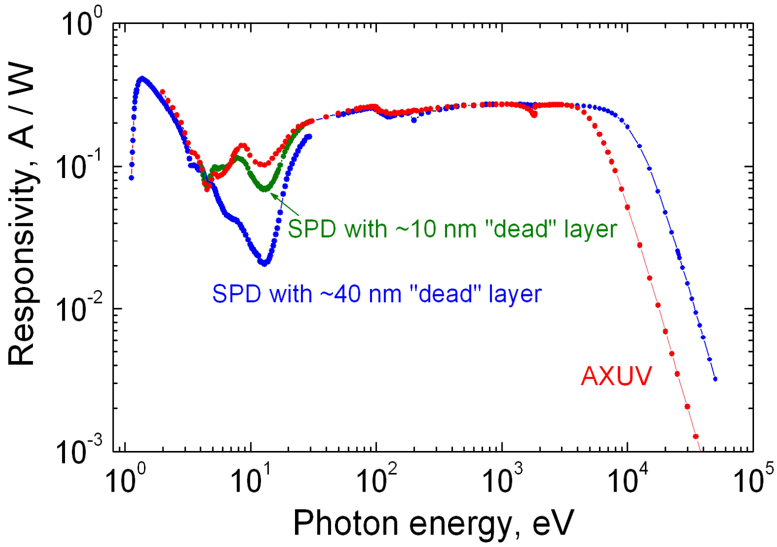

Fig.1. Spectral responsivity of XUV photodiodes

The details of diagnostics design and the first results are present, obtained from this detector array installed into tangential vacuum port of the T-11M tokamak for imaging of fast impurity transport events during the development of plasma MHD instabilities, e.g. major and minor disruptions.

Detector array design

In general, the design of SPD diodes is similar to AXUV detectors with an ultra-shallow p-n-junction and thin (5…10 nm) surface "dead" layer. The comparison of their spectral responsivities of XUV detectors is shown in Fig.1. The details of the calibration procedure are described elsewhere [6,7]. Absolute sensitivities for both detector types are very close, with a small difference depending on the passivation layer thickness.

An optimal choice of the passivation layer type and thickness is a trade-off between the detector spectral responsivity flatness, long-term and radiation stability. A 10…20 nm thick layer had been used in the SPD array detector, which provides an acceptable compromise of the sensitivity drop in 3…30 eV region and the radiation hardness and stability [8]. Another problem to be solved is a searching for an optimum choice between the read-out cycle frequency (frame rate), the spatial resolution (pixel No) and the number of parallel electronic channels. Main difficulty for XUV plasma diagnostics results from the restrictions related to the in-vessel detector location: high vacuum compatibility, limited number of vacuum feedthroughs, thermal baking at 150...200ºC, etc.

The frame rate up to 10^6 s^{-1} together with proper detector and electronic 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 [9-11].

These requirements defined the simplified hybrid approach combining the 16×16 detector array module comprised of eight stacked sub-modules with 2×16 linear SPD diode arrays directly mounted to the ceramic circuit boards with front-end electronics. The matrix array front size is 31×31 mm with ~25% filling factor (sensitive area of a single photodiode is ~1 mm^2). For the plasma diagnostics application it is packed into a pinhole camera of 38×38×155 mm size with a variable field-of-view angle and 50-pin output connector (Fig.2).

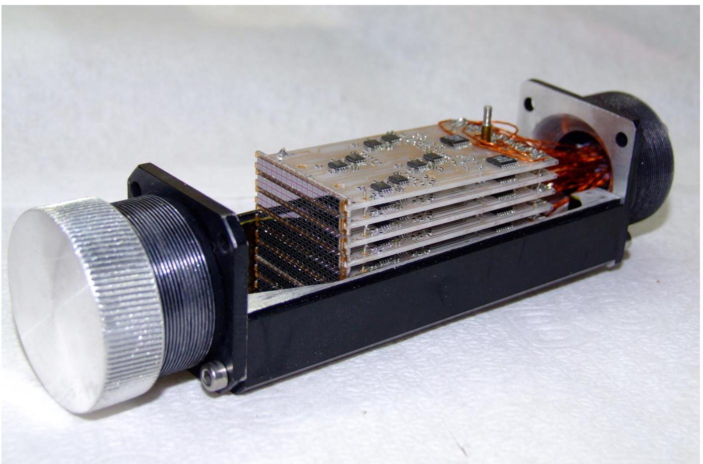

Fig 2. Pinhole camera with hybrid 16×16 matrix detector array

Data acquisition and processing.

The data acquisition system (DAS) is comprised of the controller of fast 8:1 multiplexers (located in the detector front-end ceramic circuit board) and 32-channel 12-bit ADC with a 40 MS/s upper sampling rate providing 0.2 μs shortest cycle for the array complete read-out. Actually the cycles below 0.8 μs are not practical due to the data amount and memory limitations Each ADC channel has a 64 MB on-board memory limiting the acquired period to 3.2 s at 1.25 Mfps frame rate. A common TCP/IP Ethernet network is used for the data transmission and the DAS control from/to the remote computers.

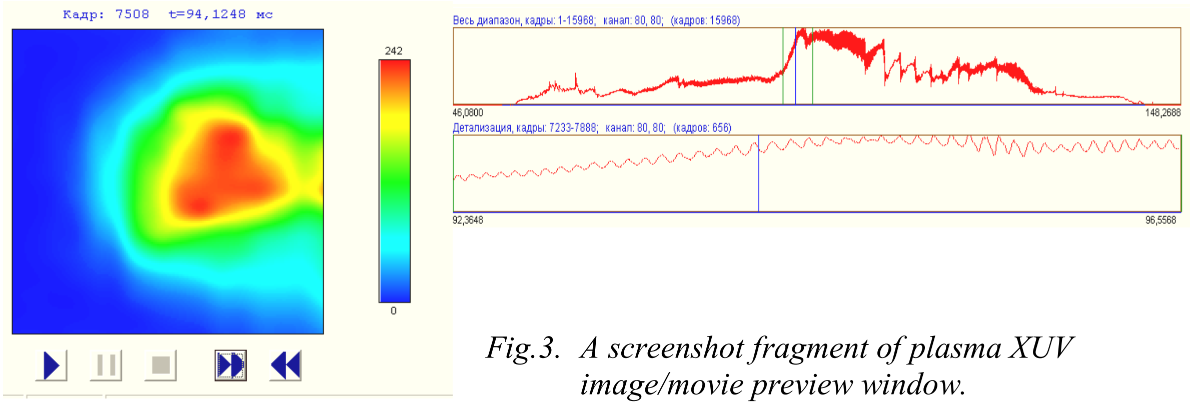

Fig.3. A screenshot fragment of plasma XUV image/movie preview window.

Post-acquisition processing includes the following stages:

1. Calculation and subtraction of the offset levels (“black level” balance).
2. Recovery of the signals of the broken pixels (irregular net interpolation)
3. Image smoothing by interpolation to 160×160 pixels (regular net interpolation)
4. Transformation into the AVI -files and into a specific file format for the combined data imaging software (a sample screenshot is shown in Fig.3).

Detector setup at the T-11M and preliminary results.

The detector has been installed into the equatorial tangential port of T-11M tokamak in order to provide the direct imaging of plasma XUV profile variations in vertical and horizontal directions. The vacuum insertion driver provides L = 500 mm movement into the port for the proper pinhole camera location for the complete observation of plasma profile.

The recent 2010/2011 winter-spring T-11M experimental campaign was devoted to the studies of Li deposition in the SOL with simultaneous use of two rail limiters: the graphite and the liquid Li one [12]. XUV matrix detector data were obtained from more than 100 plasma shots. Special attention had been paid to the animation of fast events - minor and major disruptions, in order to disclose the details of fast impurity propagation across the steroidal magnetic field.

An example of minor (internal) disruption in T-11M shot # 28531 is shown in the set of related XUV image captures (Fig.4).

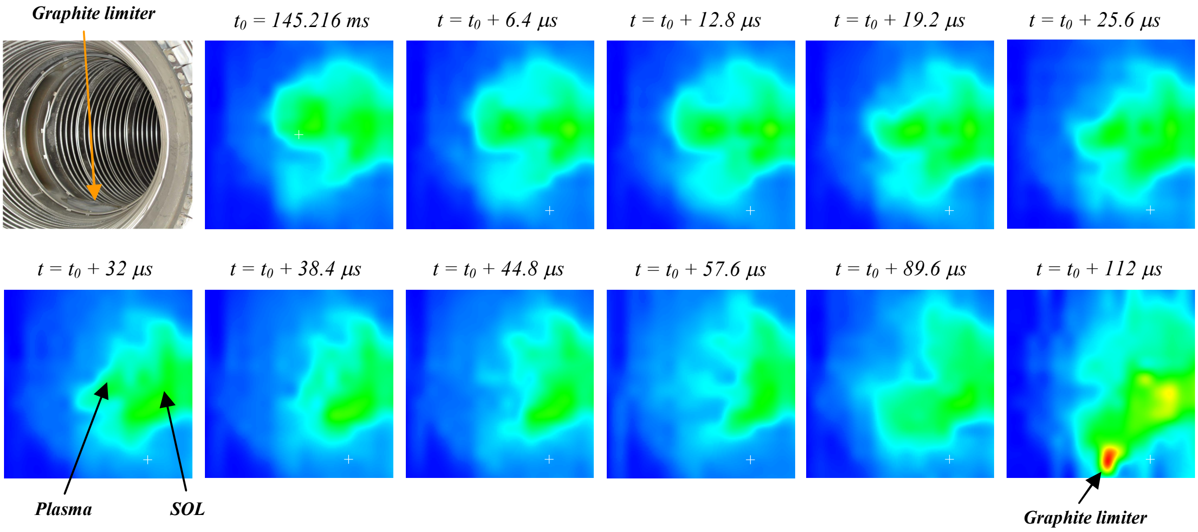

Fig.4. A minor disruption event in the T-11M tokamak

Conclusions

A new diagnostics was developed and tested at the T-11M tokamak for the fast imaging of plasma XUV emission profile evolution with up to ~10^6 fps frame rate. The rapid MHD events of microsecond time scale are clearly seen during the disruptions. Broader applications are planned to other plasma devices equipped with the modern tools for the studies of transient processes (fast plasma guns, pellets, etc). More advanced 32×32 matrix detector array development is under consideration.

Acknowledgments

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