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short-timescale experiments

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Broadband EUV survey spectrometer for short-timescale experiments

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A fast and inexpensive spectrometer system has been developed to record EUV impurity spectra in a magnetic fusion research device. To simplify the vacuum system, light is passed out of the spectrometer's vacuum to the detector using a sodium-salicylate-coated fiber optic coupler. This coupler is positioned such that the focal field is nearly flat over its aperture. The system's detector is a microchannel-plate-intensified, linear, self-scanning photodiode array. The 1024-pixel array covers a bandwidth of over 80 nm and is read out once every millisecond. The readout, which is four times faster than the manufacturer's maximum rating, is fully synchronized to the experiment using a locally-designed control circuit.

Key words: EUV spectrometer, flat focal field, fiber optic coupler, photodiode array, synchronization, control circuit

MASTER

Many modern applications of spectroscopy require millisecond to sub-millisecond temporal resolution combined with a large spectral bandwidth. This is the case in magnetic fusion plasma research. One is often required to measure simultaneously the rapidly-changing intensities of many different spectral lines from impurities in the plasma.

We have developed an EUV impurity monitoring system for use in the Madison Symmetric Torus (MST)¹ magnetic fusion research device. The system is based on a 0.2-meter-focal-length spectrometer with an intensified, linear, self-scanning photodiode array as the detector. The array is an EG&G Reticon product, part #1024SAF-011. While this detector is of a common type, the system as a whole features improvements on past systems: 1) a nearly flat focal field; 2) elimination of an in-vacuo detector assembly; 3) increased time resolution; 4) precise synchronization of the array readouts to external events. The flat focal field minimizes off-center defocussing and is achieved by appropriate positioning of the detection plane (determined by optical ray tracing). A sodium-salicylate-coated fiber optic coupler allows placement of the detector outside the spectrometer's vacuum. Increased time resolution is achieved with a simple modification of the electronics accompanying the array, while synchronous operation is achieved with an inexpensive control circuit. Instructions for the Reticon modification and a detailed schematic of the control circuit are provided in this paper.

Detectors similar to the one in this system were first described by Riegler and More² and later by Sandel and Broadfoot.³ Specific aspects of the arrays alone have been discussed by Talmi and Simpson.^{4,5} Applications of this detector in fusion plasma diagnostics have been described by Bell, Finkenthal, and Moos⁶ as well as by Fonck, Ramsey, and Yelle.^{7,8} Hodge, Stratton, and Moos⁹ as well as Beiersdorfer et al,¹⁰ describe extensions of this type of system to the soft x-ray region of the spectrum.

Our spectrometer is a converted commercial monochromator, the Minuteman 302-VM (see Fig. 1). It utilizes a holographic, aberration-corrected, 1200 groove/mm, concave grating which is rotated on its own fixed axis in order to focus different wavelengths on the exit plane. To match the nominal location of the exit focal plane, the detection plane is tilted relative to the

optical axis at an angle θ . The focal field of this spectrometer has a natural curvature, but defocussing over the detection plane, which is a problem common to all 0.2-meter systems with this type of grating, is largely avoided by optimizing θ and the distance from the center of the grating to the center of the detection plane. Thus, while normal-incidence systems suffer from substantial defocussing at the edges of the detection field,⁷ this system provides a nearly-flat focal field over the detector's aperture. In the central region of the detection plane, the focal field is tangent, while at the edges, the focal field bends away, decreasing the nominal resolution (see below) by less than 0.1 nm. The optimum θ and grating-to-detector distance vary with different central wavelengths. For a θ of 57.8° and a grating-to-detector distance of 185.6 mm, this system is optimized for a central wavelength of 100 nm. While this system can actually operate up to around 300 nm, it is primarily intended for wavelengths between 50 and 200 nm.

The first part of the detector assembly (also shown in Fig. 1) is a fiber optic coupler. One face of the coupler lies in the detection plane and is coated with sodium salicylate; the coating was applied in-house. The coupler passes visible photons to the rest of the detection apparatus, which is located outside the spectrometer's vacuum. This coupler minimizes vacuum constraints and simplifies the system design.

Upon leaving the fiber optic coupler, the visible photons encounter an image intensifier, which is a Varo product, Model 9323. Here, they strike a photocathode and are converted to electrons. These electrons are then multiplied in a micro-channel plate. Finally, the electrons are converted back to visible photons by a layer of P-20 phosphor. The photons are then collected by the fiber-optically-coupled photodiode array. The 25-mm apertures of the coupler and image intensifier are large enough to illuminate the entire array. To maximize efficiency, an optical-coupling gel was applied at the coupler-intensifier and intensifier-array interfaces.

The resulting system bandwidth is slightly under 80 nm (see Fig. 2 for a sample spectrum). Use of the fiber optic coupler and micro-channel plate does not seriously degrade the system's resolution. For an entrance-slit width of 40 μm , the FWHM of a narrow line in the EUV was measured to be slightly greater than 0.3 nm, covering roughly 4 pixels on the array.

Two additional features of this system, both electronic in nature, are of particular note and merit description. See Fig. 3 for a general schematic of the system electronics. The first feature is the quadrupling of the system's speed. The photodiode array is accompanied by two evaluation boards, the Mother board, part #RC1000-011, and the Satellite board, part #RC1001-011. These boards provide signals and video processing circuitry necessary to operate the array and, as shipped from Reticon, allow a maximum clock rate of 250 kHz. Thus, as one pixel is read out with each clock pulse, back-to-back scans of the array result in a pixel integration time (the time between successive readouts of a particular pixel) of about 4 ms. To achieve an integration time near 1 ms, the timescale of many phenomena on the MST, the system must be clocked at 1 MHz. We have found that a simple modification of the Mother board allows operation at 1 MHz. Specifically, one replaces the timing components of three one-shot oscillators (monostable multivibrators). See the Appendix for the specific changes.

Clocking the array at 1 MHz (from the MST's master clock) with only this modification did not affect the linearity of the array response, as was verified with a set of neutral-density filters. However, the saturated-signal level from the array dropped by a factor of about 2.5. To offset this drop we use a Lecroy 8100 as a preamplifier (see Fig. 3). We also installed a BUF-03-FJ as a line driver to better drive the array data into 50- Ω coaxial cable.

External synchronization of the array readout to our experiment is also required, and we have designed and implemented a control circuit (see Fig. 4 for a detailed schematic), the second electronic feature, to achieve this end. In contrast to past Reticon systems¹¹ the current system provides for relatively simple external control of the array readout. One merely sets two jumpers on the Mother board (see the Appendix) to bypass the board-generated clock and Mstart pulses. One Mstart pulse is needed to begin each readout of the array. The control circuit provides the Mstart pulses, as well as the triggers necessary for the system's digitizer, a Lecroy 8210, while carefully synchronizing the array readouts to each plasma discharge in the MST. Refer to the Appendix for a circuit startup procedure necessary to ensure internal synchronization of the different circuit sections. In order to collect all of the data in a typical 60 ms discharge, the

control circuit is designed for continuous or back-to-back scanning of the array. The functions of the control circuit are described below.

The array requires 1028 (the number of pixels + 4) clock cycles between Mstart pulses in the continuous-scan mode. Thus, the control circuit produces a Mstart pulse every 1.028 ms. The control circuit also provides triggers, the Data-Strobe and the Stop, to the Lecroy 8210. The 1 MHz Strobe pulses, each of which causes a pixel datum to be recorded and digitized, are input at the external clock port of the digitizer. To avoid recording pixel-to-pixel switching noise, the Strobe pulses are phased relative to the clock pulses such that a datum is recorded only when it is stable. The Stop trigger, which causes the 8210 to exit the digitizing mode, is generated at the end of a complete data-taking cycle. In the design shown here, Stop pulses are available at 32, 64, and 128 ms after the start of the plasma discharge.

One other circuit function is to use MST-generated triggers to initiate readout of the array, at pixel #1, precisely at the beginning of each plasma discharge (fully-synchronized readout). The relevant MST triggers are called Preset and Start. The Preset trigger, which one sets to arrive 3-4 ms before the discharge, allows the circuit to prepare itself and the array for the Start trigger, which arrives precisely at the beginning of the discharge. Immediately after the Start trigger, a Mstart pulse is generated. The array readout, which stops at pixel #1024 after receipt of the Preset trigger, then begins again at pixel #1. Readout continues until the next Preset pulse, even though data-taking ends with the Stop pulse.

Exact timing of the Preset pulse relative to the Start pulse is not critical; nevertheless, it is somewhat constrained. The array readout ceases between the two triggers; thus, if the time between the two pulses is too long, dark signal will build up on the array, resulting in the contamination of the first array scan after the Start pulse. The time must be long enough, however, to allow the readout in progress when the Preset pulse arrives to finish. 3-4 ms is a good range for the time between pulses.

The design of this control circuit has many advantages. It is relatively simple and inexpensive to build. It uses standard TTL-based components and can be constructed using the

wire-wrap method. The circuit has a minimal dependence on external signals, limiting its susceptibility to line noise. Past designs for similar circuits (e.g., ref. 11) utilize the end-of-scan pulse, generated by the Reticon evaluation circuitry at the end of each array readout, to trigger each subsequent readout. The circuit here is independent of such external signals.

The combination of a nearly-flat focal field, fiber optic coupler, fast photodiode array, and synchronous operation make this EUV system a simple and effective means of monitoring line radiation in short-timescale experiments.

Appendix

To allow 1 MHz operation, the changes to the Mother board, using Reticon's board notation, are as follows:

Chip U11(2): R40 becomes 5 k Ω ; C58 becomes 270 pF;

Chip U12(1): R41 becomes 5 k Ω ; C59 becomes 180 pF;

Chip U12(2): R47 becomes 5 k Ω ; C88 becomes 68 pF.

To bypass the Mother-board-generated Mstart and clock pulses, one sets jumpers E2-E3 and E8-E9, respectively.

To ensure proper circuit operation, the following circuit startup procedure is necessary: 1) apply power (+5V) with the external clock connected and the debounced switch Enabled; 2) apply a Start pulse; 3) Disable then re-Enable the circuit using the debounced switch. When Enabled, output A of the debounced switch (Fig. 4) is at ground, while B is at +5V. When Disabled, the polarities are reversed.

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Figure Captions

Fig. 1. The layout of the EUV spectrometer. The angle θ between the optical axis and the focal plane is 57.8° . The distance from the center of the grating to the center of the focal plane is 185.6 mm.

Fig. 2. Single spectrum from the EUV spectrometer. The central wavelength is 116.0 nm.

Fig. 3. Block schematic of the EUV system electronics. Note that the preamp, digitizer, and memory modules are housed in a local CAMAC crate.

Fig. 4. Control circuit schematic. Section 1 uses the Preset and Start pulses from the MST trigger generator to synchronize the array readout to the plasma discharges. Section 2 produces Stop triggers for the 8210 digitizer. Section 3 provides the Data-Strobe pulses for the digitizer. Most of the remaining circuit components are dedicated to producing an Mstart pulse after each cycle of 1028 clock pulses.

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Fig. 1

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Fig. 2
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Fig. 3
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Fig. 4, B. E. Chapman, Applied Optics: Optical Technology

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