Initial Result of TT-1 Plasma Emission Measurements using an AXUV Bolometer

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ABSTRACT

A 16-channel bolometer system based on an Absolute Extreme Ultraviolet (AXUV) photodiode array has been designed, constructed, and installed on the Thailand Tokamak-1 (TT-1). This diagnostic is intended to measure the total radiated power from the plasma, a critical parameter for energy balance and confinement studies. The system's functionality was first validated using a stable plasma from a plasma cleaner device, which confirmed the successful operation of the detector and its custom-built signal conditioning electronics. Following this preliminary testing, the system was installed on TT-1 for its first-light measurements. Initial results from tokamak discharges demonstrate a clear temporal correlation between the bolometer signal and the evolution of the plasma current. This successful operation establishes the AXUV bolometer as a new and crucial diagnostic for radiated power studies on TT-1, paving the way for future investigations into impurity transport and plasma stability.

Keywords: TT-1 Tokamak, Plasma Diagnostics, Bolometer, Radiated Power, AXUV

I. INTRODUCTION

The pursuit of nuclear fusion as a clean, safe, and virtually limitless energy source for the future is a major global scientific endeavor. Fusion energy mimics the process that powers the sun and stars, where light atomic nuclei combine to form heavier ones, releasing immense amounts of energy. The tokamak, a toroidal device that uses powerful magnetic fields to confine a high-temperature ionized gas known as plasma, stands as the most promising configuration for achieving controlled thermonuclear fusion on Earth.

As part of its national strategy to develop domestic capabilities in fusion science and technology, Thailand has embarked on the Thailand Tokamak Project. A key component of this initiative is the TT-1 tokamak, formerly the HT-6M, which was granted by the People's Republic of China and is now operational at the Thailand Institute of Nuclear Technology (TINT). This project represents a significant step towards building national self-sufficiency in a critical high-technology field, fostering a skilled workforce, and reducing reliance on foreign technology.

A fundamental aspect of tokamak research is understanding the plasma power balance. Energy injected into the plasma is lost through several channels, including conduction, convection, and radiation. The total power lost via radiation is a critical parameter for determining the energy confinement time, a primary figure of merit for any fusion device. This radiation originates from several physical processes within the plasma, predominantly Bremsstrahlung (braking radiation) from electron-ion collisions and line radiation from impurity ions that have entered the plasma from the vessel walls. Measuring this radiated power provides invaluable information about plasma temperature, density, impurity content, and magnetohydrodynamic (MHD) stability.

It is important to distinguish this type of measurement from radiological safety monitoring. While other research at the TT-1 facility focuses on characterizing hard X-rays produced by runaway electrons interacting with the vessel walls for personnel safety 3, the work presented here concerns a plasma physics diagnostic. The bolometer is designed to measure the total power radiated from the entire plasma volume as electromagnetic radiation (from soft X-rays to visible light) to understand the plasma's internal energy balance, not the ionizing radiation that may escape the machine's shielding.

This paper reports on the design, fabrication, and initial experimental results of a new Absolute Extreme Ultraviolet (AXUV) bolometer system. This diagnostic was developed entirely through a domestic collaboration between TINT and university partners under the Center for Plasma and Nuclear Fusion (CPaF) network, underscoring Thailand's commitment to building indigenous technological capacity.

II. THE AXUV BOLOMETER SYSTEM

The development of the bolometer system involved the design and integration of the detector, custom signal conditioning electronics, and data acquisition hardware. The design was tailored to the specific physical constraints and experimental requirements of the TT-1 tokamak.

II.A. System Overview and Detector Choice

The measurement system is designed to convert the faint radiation from the plasma into a measurable voltage signal. A high-level block diagram illustrating the signal flow from the detector to the Data Acquisition (DAQ) system is shown in Fig. 1. The core of the system is the radiation sensor, for which a 16-channel silicon photodiode array, model AXUV16ELG, was selected.

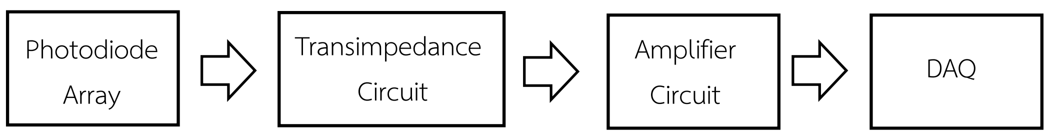

FIGURE 1. Block diagram of the bolometer electronics system.

The choice of an AXUV photodiode is critical for this application. The "A" in AXUV stands for "Absolute," signifying that the detector possesses a near-constant responsivity (in Amperes per Watt) over a vast spectral range, from soft X-rays through the extreme ultraviolet (EUV), vacuum ultraviolet (VUV), and into the visible spectrum. This characteristic is essential for bolometry, as the goal is to measure the total incident power without needing complex, energy-dependent calibrations for different radiation sources (e.g., line radiation from different impurities or continuum Bremsstrahlung). This property greatly simplifies the conversion of the measured photocurrent into a total radiated power value in Watts. The spectral response of the chosen AXUV16ELG photodiode, as provided by the manufacturer, is shown in Fig. 2, indicating its high sensitivity across a broad range of wavelengths relevant to plasma emission.

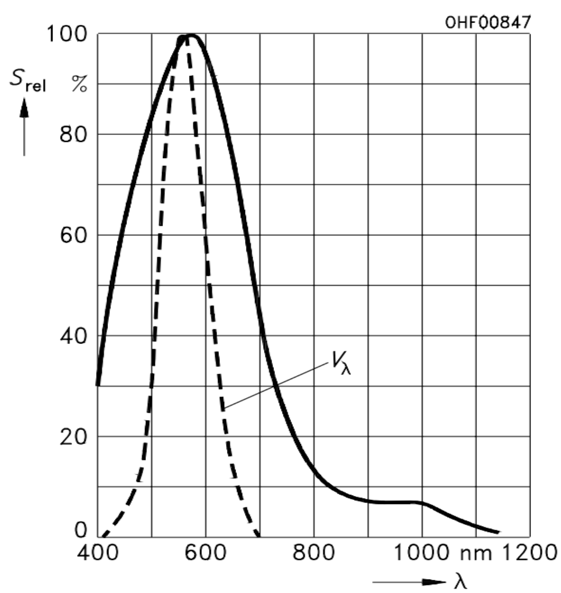

FIGURE 2. Spectral response of the AXUV16ELG photodiode.

II.B. Signal Conditioning Electronics and Hardware

To measure the small photocurrents generated by the detector (typically in the nanoampere to microampere range), a custom multi-stage amplifier circuit was designed and constructed. The design specifically addresses the challenges of acquiring low-level signals in the electromagnetically noisy environment of a tokamak.

The first stage is a transimpedance amplifier, which converts the photocurrent (I_p) from each photodiode channel into a proportional voltage (V_o). The circuit schematic is shown in Fig. 3. The output voltage is governed by the equation $V_o = -I_p R_f$, where R_f is the feedback resistor that determines the gain of this stage. This stage is located as close as possible to the detector head to immediately convert the noise-susceptible current signal into a more robust voltage signal before transmission over longer cables.

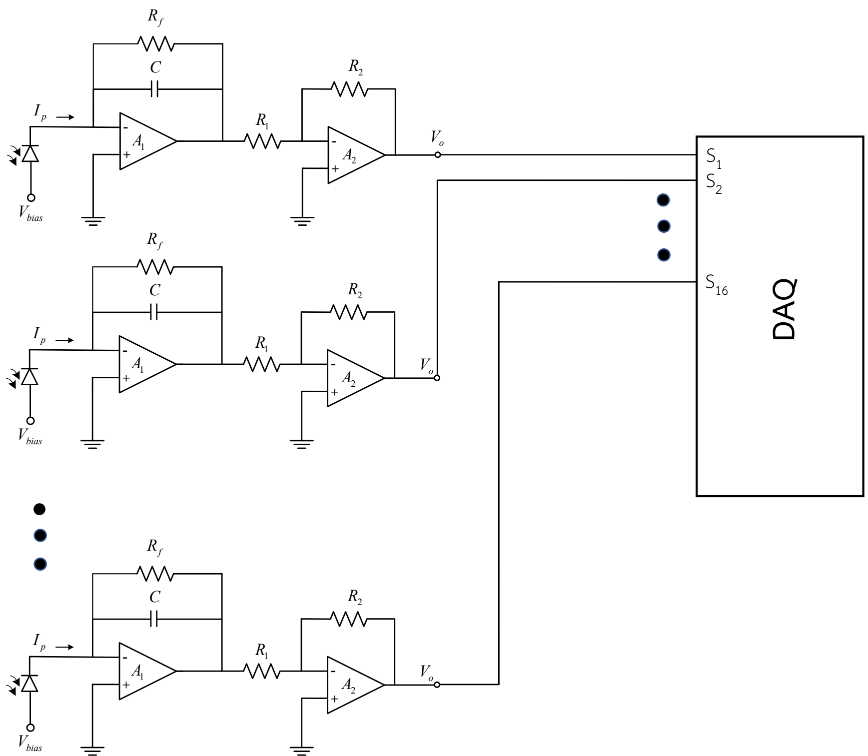

FIGURE 3. Schematic of the transimpedance amplifier circuit for the AXUV photodiode.

Following the transimpedance stage, a second inverting amplifier stage provides additional gain. This ensures that the final output signal is scaled appropriately to match the input voltage range of the main TT-1 DAQ system, optimizing the signal-to-noise ratio of the final measurement. A photograph of the assembled prototype, showing the detector head and the multi-channel amplifier board, is presented in Fig. 4.

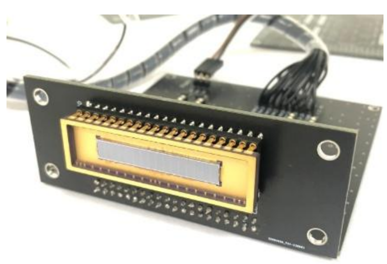

FIGURE 4. Assembled prototype of the AXUV bolometer system.

III. EXPERIMENTAL VALIDATION AND RESULTS

A methodical, two-step approach was used to validate the bolometer system. The first step involved testing on a simple, stable plasma source to de-risk the design, followed by installation and first-light measurements on the TT-1 tokamak.

III.A. Preliminary Validation on a Plasma Cleaner

Before installation on the tokamak, the bolometer system underwent preliminary testing using a plasma cleaner device (Atto, Diener). This device generates a stable, continuous RF glow discharge under an argon atmosphere at a power of 20 W, providing a reliable source of plasma radiation. This test served as a crucial de-risking strategy, allowing for the verification and debugging of the detector, electronics, and DAQ chain (sampling rate of 48000 kS/s) in a controlled environment, completely isolated from the complexities of pulsed tokamak operation such as large electromagnetic interference and complex plasma dynamics.

The results of this validation test are shown in Fig. 5. The plot displays the output signals from four of the bolometer channels during the operation of the plasma cleaner. The signals clearly respond to the presence of the plasma, confirming that the entire measurement chain—from photon detection to voltage output—was functioning as designed. This successful test provided the confidence to proceed with installation on TT-1.

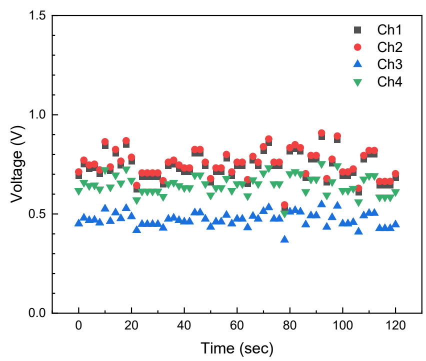

FIGURE 5. Output signals from four AXUV channels during validation on the plasma cleaner.3

III.B. Initial Measurements on the TT-1 Tokamak

Following the successful preliminary tests, the bolometer prototype was installed on a vacuum port of the TT-1 tokamak, as shown in the photograph in Fig. 6. The system was then integrated with the central TT-1 DAQ system to record data during plasma operations.

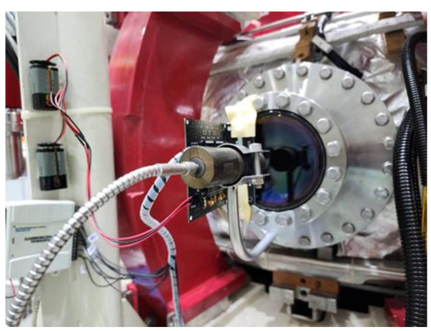

FIGURE 6. Installation of the bolometer prototype on a TT-1 vacuum port.3

The primary result of this work is presented in Fig. 7. This figure shows the time evolution of the signal from a single bolometer channel (right) juxtaposed with the plasma current (I_p) waveform (left) for a typical TT-1 discharge. The data provide unambiguous evidence of the system's successful operation. A clear temporal correlation exists between the two signals: the bolometer signal begins to rise shortly after the initiation of the plasma current. Furthermore, the overall envelope of the bolometer signal closely tracks the shape of the plasma current pulse, increasing during the current ramp-up, remaining elevated during the current flattop, and decaying as the discharge terminates.

This observed behavior is consistent with fundamental plasma physics. In an ohmically heated tokamak discharge, the plasma density and temperature are strongly driven by the plasma current. Since the total radiated power is a function of density and temperature (e.g., Bremsstrahlung power scales with the square of the density), it is expected that the radiated power will track the evolution of the plasma current. The data in Fig. 7 confirm this expected behavior, validating that the system is not merely detecting light, but is functioning as a true plasma diagnostic measuring a quantity representative of the total radiated power.

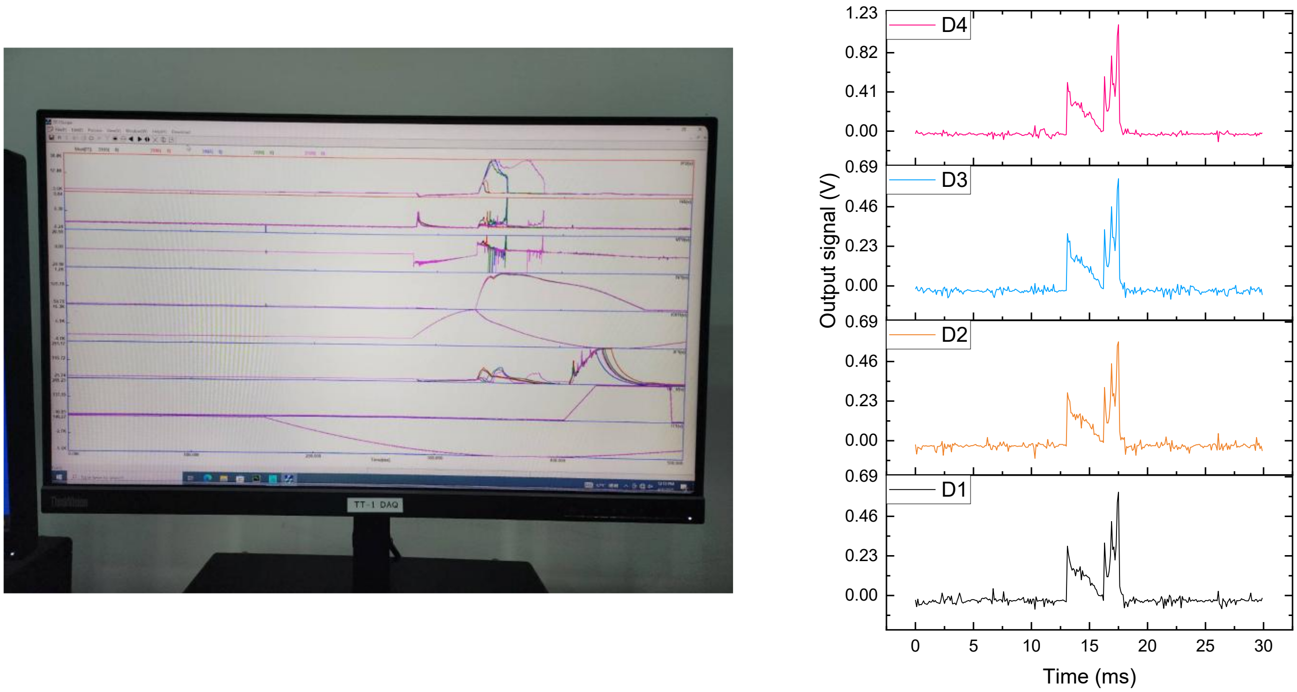

FIGURE 7. (Left) Plasma parameters from the TT-1 DAQ and (Right) the corresponding radiated emission signal measured by the prototype AXUV bolometer during a TT-1 discharge.

IV. CONCLUSION

A 16-channel AXUV photodiode bolometer system has been successfully designed, fabricated, and deployed on the TT-1 tokamak. This work was conducted as a domestic collaboration within Thailand's national fusion research program, representing a key step in developing indigenous diagnostic capabilities. Initial tests on a plasma cleaner validated the instrument's design, and subsequent first-light measurements on TT-1 have demonstrated its capability to measure radiation emitted from the plasma. The strong correlation between the bolometer signal and the plasma current confirms the system is operating as a valid plasma diagnostic for radiated power.

ACKNOWLEDGMENTS

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