A NOVEL METAL FOIL IR SENSOR BOLOMETER FOR ADITYA-U TOKAMAK

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Radiation losses in tokamak is a major challenge to heating the plasma at a very high temperature. Line and Bremsstrahlung radiations from fuel and impurity species are the origin of significant radiation losses in tokamaks. Therefore, radiation power loss measurement becomes imperative for power balance, heat load on the in-situ wall, impurity behaviour, MHD activities, disruption mitigations, etc.[1] Bolometers are used to measure the radiation power losses in tokamaks. Resistive bolometers, IRVB, and AXUV bolometers are primarily used in tokamaks.

A novel single-channel metal foil IR bolometer has been developed to measure the total plasma radiation power loss and the toroidal radiation asymmetry in the Aditya-U tokamak. This bolometer has similarities with IR video imaging bolometers (IRVB) in terms of using the carbon-coated Pt foil behind an aperture. However, it is challenging to place multiple IR cameras in a tokamak magnetic field region. Therefore, a new concept is introduced to replace the IR camera with an IR detector, which has a similar spectral range. A mid-wave infrared (MWIR) detector with a transimpedance preamplifier combo unit having a wavelength sensing band in 3-5 μm is used to measure the thermal radiation emitted from the Pt foil. A calibration experiment has been carried out to measure the effective thermal properties of the Pt foil and the IR detector response with blackbody radiation.

An experiment in a vacuum vessel is carried out to measure the thermal diffusivity and the product of thermal conductivity and foil thickness by incident a diode laser on one side and an IR camera observes another side. The heat diffusion within the Pt foil can be given by a 2D heat diffusion equation having a Plasma radiation term and a blackbody term as[2] –

$$\frac{\partial^2 T(x,y,t)}{\partial x^2} + \frac{\partial^2 T(x,y,t)}{\partial y^2} = \frac{1}{\kappa}\frac{\partial T(x,y,t)}{\partial t} + \Omega_{\mathrm{BB}} - \Omega_{\mathrm{Rad}} \qquad \text{...... (1)}$$

Where, $\Omega_{\mathrm{BB}} = \frac{\varepsilon\sigma_{SB}(T^4 - T_0^4)}{\mathrm{k}\, t_f}$ and $\Omega_{\mathrm{Rad}} = \frac{P_{rad}}{\mathrm{k} t_f l^2}$

κ and k are the thermal diffusivity and thermal conductivity of the Pt foil, respectively, ε is the emissivity, σ_{SB} is the Stefan-Boltzmann constant, t_f is the foil thickness, and l is the camera pixel dimension. Thermal diffusivity is found from the foil cooling spatial temperature profile fitting with the Gaussian temperature profile across the central spot, as shown in Figure 1. The slope of the variance of the Gaussian profile variation with time gives the thermal diffusivity, as shown in Figure 2. The incident laser power can be controlled by its software, and it can be varied from 0 to 100 mW. A plot between the foil temperature rise corresponding to different incident laser power is shown in Figure 3. The 1/slope of the curve represents the product of thermal conductivity and Pt foil thickness. A Cranck-Nicolson explicit numerical algorithm is used to find the incident radiation from equation (1)[3]. The spatial and time derivative terms are found from the pixelized temperature values around the central spot and the temperature time evolution within the pixels that have the time resolution given by the IR camera frame rate.

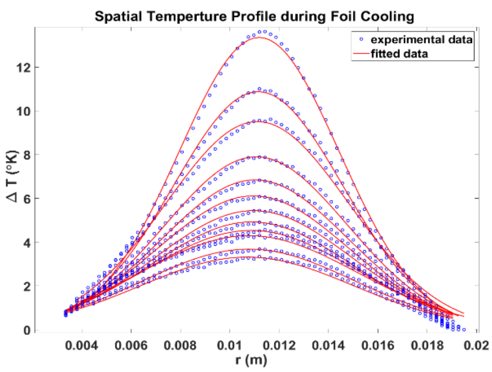

Figure (1) Spatial temperature Gaussian Profile in the cooling phase

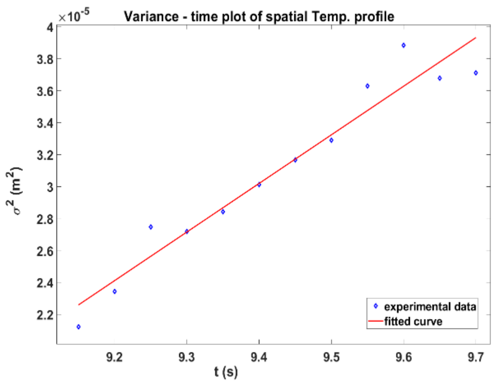

Figure (2) The variance-time curve slope imparts the thermal diffusivity of the Platinum foil

The retrieved radiation power profile from the Cranck-Nicolson numerical algorithm is created by using equation (1) as shown in figure (4). The blue dashed line shows the incident radiation pulse, and the red sold line shows the retrieved adiation power profile, which shows a marginal error of a maximum of 2 mW.

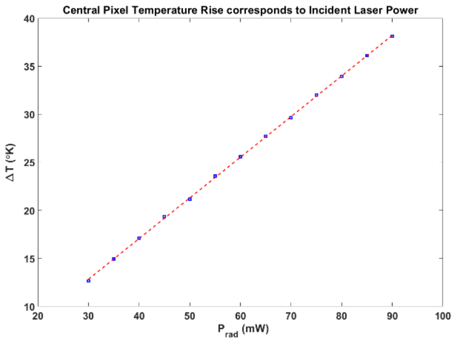

Figure (3) Temperature rise of the Pt foil with incident laser power

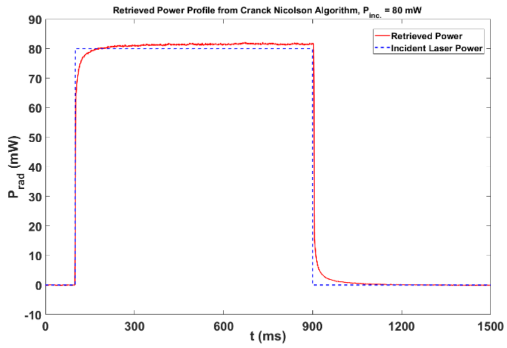

Figure (4) Retrieved radiation profile for Pt foil by Cranck-Nicolson numerical method

The power retrieval of the incident laser depicts the verification of correct values of effective thermal properties of the Pt foil. This metal foil IR sensor bolometer will be mounted on Aditya-U tokamak in the upcoming campaign. A number of these bolometers will be mounted on the various toroidal locations to measure the toroidal radiation asymmetries during the disruption mitigation experiments.

An uncooled IR detector with a spectral range of 3-5 μm is being used for this purpose. An experiment is carried out to calibrate the IR detector with a blackbody source. The IR detector responses are recorded for a range of blackbody temperature values starting from 30 °C to ending at 100 °C, which is the expected range temperature rise of the Pt foil in Aditya-U plasma. The temperature versus detector response data is fitted with a model equation that originated from the Planck's spectral radiance equation.[4] The IR detector response curve with temperature is shown in Figure 5.

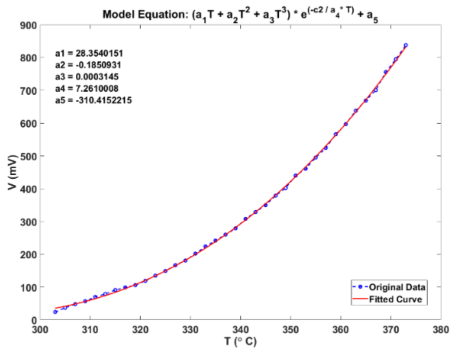

Figure (5) IR detector response fitted curve with Blackbody temperature

Therefore, an indirect relation between incident temperature and corresponding Pt foil temperature rise and the IR detector response with temperature rise will give the relation between the incident plasma radiation onto the foil and the IR detector response. The experimental outcomes of the metal foil IR sensor bolometer will be briefly discussed in the paper.

References:

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