A RAD-HARD, STEADY-STATE, DIGITAL IMAGING BOLOMETER SYSTEM FOR ITER

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ABSTRACT

The concept and design of a new type of bolometer system which can function with excellent spatial resolution and good time resolution in the next generation of long-pulse (or steady-state), harsh-neutron environment, fusion plasmas, is outlined. It uses a cooled pinhole camera design, employing a robust, passive, segmented radiation absorber, cooled from the back-side. Infrared emission from the absorber's front surface is relayed by metal mirror optics to a shielded, high-resolution IR video camera with 0.01 °C temperature resolution. It can make thousands of simultaneous "pixel" measurements at up to 50-60 Hz, without any signal wires through the vacuum interface.

INTRODUCTION

Classical bolometry[1] in a fusion plasma employs discrete thin-foils which are heated by the plasma radiation, and the temperature rise is detected by a metal resistor or thermistor bonded to the back side of the foil, often separated by an insulating film[2-5]. Sometimes a single-channel IR detector has been used to monitor the rise in temperature of the foil instead, so as to provide better electrical noise-immunity[6]. In cases of a short-pulse of plasma radiation, or when studying the energy deposited by by ion, neutral or electron beam, researchers have imaged (in the IR) the backside of a foil or plate target, in order to determine the "instantaneous" distribution of energy in the beam[7]. The problem with using this technique to observe a long-pulse plasma, is that the lateral heat flow in the foil or target plate would spoil the subsequent images, and confuse the measurement. In addition, a foil which is thin enough to have reasonable time response must be cooled over longer time intervals to prevent melting or radiative cooling damage or nonlinear effects from spoiling the measurement. Finally, the detectors must be radiation hardened, to survive the neutron and gamma fluences from a long-pulse DD or DT machine. So-called "silicon bolometers"[8] and pyroelectric detectors have an advantage in that they respond directly to the incident power, but they will not work in this environment. The plasma may have a complex geometry, and multi-channel views (even tomography)[9] are desired for modeling analysis.

DESIGN CONCEPT

The solution to these issues is remarkably simple, and involves a pinhole imaging design, with the plasma radiation striking a compact, segmented, back-cooled “foil”. Each segment of the “foil” corresponds to one imaging resolution element or “pixel”. Each pixel absorber is raised up from the back cooling block (which can be held at a constant reference temperature), and the height of the pixel (and the material thermal conductivity) is designed for rapid axial heat flow compared to the relatively longer lateral heat flow path over to the next adjacent pixel. The passive absorber matrix is imaged in the infrared, via two metal mirrors, which allow the (neutron-sensitive) state of the art, 12-bit digital video IR video camera to be positioned out of the line of sight of the neutron flux from the plasma. Some of the pixels may be positioned outside of the plasma field of view, to act as “background” pixels if necessary. The front surface of the absorbing matrix may be initially be a “blackened coating” (like any other bolometer design), but in the long term, this may change somewhat due to plasma contamination of the surfaces. No wires exit the vacuum interface, which is a distinct advantage for thousands of channels compared to discrete bolometer arrays.

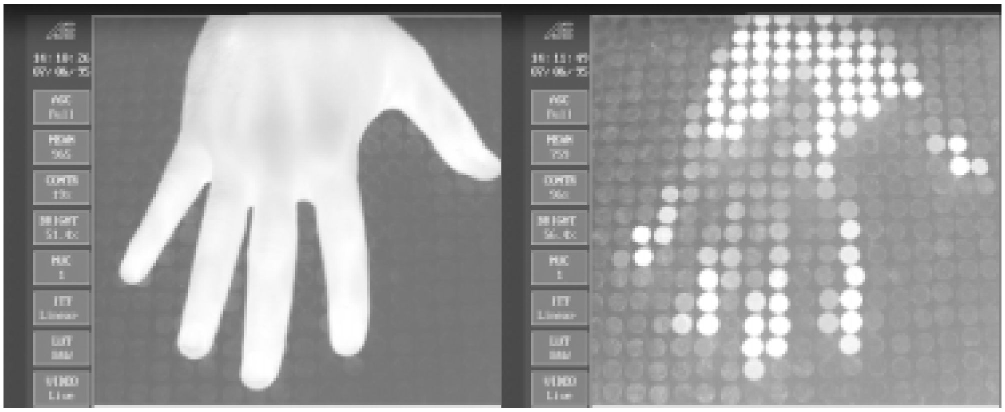

Figure 1: A test matrix (of blackened nails) holds the warmth from a hand, without lateral heat flow degradation.

Tests of a segmented matrix (20x20 array of blackened, galvanized roofing nails) are shown in Figure 1, where the warmth from a human hand held on the matrix for a few seconds is easily detected 30 seconds later. The matrix of nails was heat-sinked into a pool of water, although the heat decay time is much too long in this prototype to be used for plasma imaging. The images in the 3-5 micron band were taken with a 256x256 element InSb focal plane array (Amber Radiance 1) commercially available 12-bit digital IR video camera.

The overall system will tradeoff sensitivity, speed, and spatial resolution; with the ultimate speed being limited by cooling rates (to erase the previous image) or camera framing rates (which can range from 1 Hz to 1000 Hz with today’s technology). If the luxury of a chopper is available to block the pinhole aperature, then the heating and cooling timescales of the matrix can be different. For use without a chopper, then some amount of integration of the heat from one frame to the next will occur, and it will be necessary to differentiate subsequent frames (in analogy with normal single-channel bolometers), while taking into account pixel cooling, in order to have time resolution limited by the video system . Metal mirrors form an IR relay telescope. The IR vacuum window can be positioned behind neutron shielding.

POINT DESIGNS FOR ITER

Depending on the radiated power density, the desired temporal and spatial resolution, and the plasma access available for diagnostics, one can design a conceptual layout of an imaging bolometer package. A sketch (not to scale) is shown in Fig. 2 below.

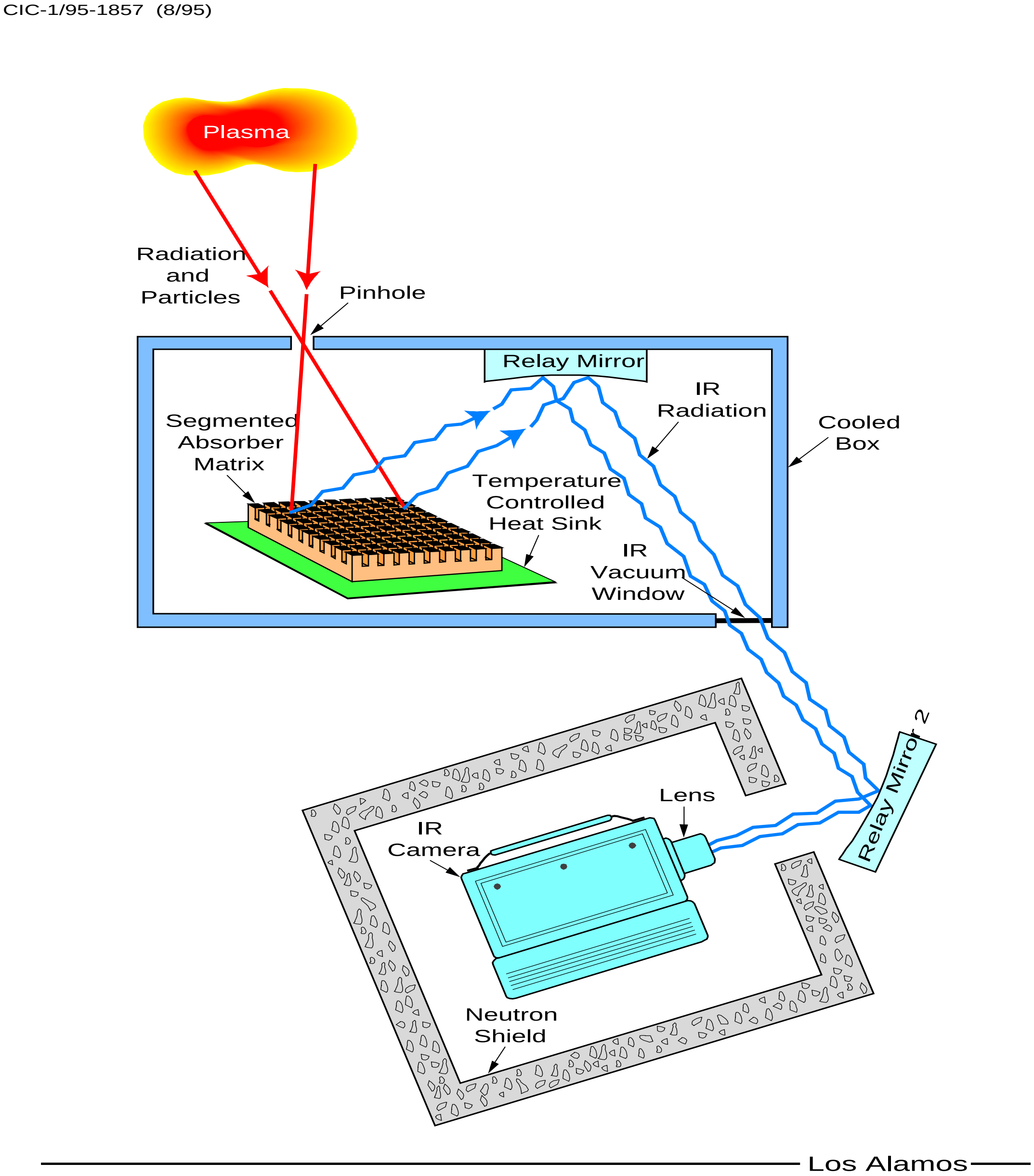

Figure 2: Components of the rad-hard, steady-state, digital imaging bolometer system.

Design choices for pinhole size, demagnification (radial or tangential viewing), target matrix size and number of pixels, location of vacuum interface, distance to IR imager and amount of neutron shielding, must all be made. A sample design point with a 100° viewing angle is shown in Table 1 , assuming an aluminum absorbing matrix, and a pixel spacing 1.1 times the pixel diameter. The possibility also exists to bond a different absorbing material to the "end" of each pixel, thereby allowing various choices for the cooling substrate. There is a potential problem with infrared radiation from hot objects (ie, the inner wall or divertor plates) directly in the field of view, that could be 500-1000 degrees hotter than the segmented matrix in the bolometer itself. These hot objects will radiate ~1000x more strongly in the 3-5 micron band, due to blackbody emission. This light could contaminate the IR coming up off of the segmented matrix. If this is a problem, then either the matrix itself could be run hot, or in the worst case, a design whereby the matrix is viewed from the backside, while cooling is applied from the sides of each pixel could be employed. This would have the advantage that plasma light would never be a problem.

Table 1: One possible design point for an imaging bolometer on ITER.

Plasma Device: ITER	Parameters	Comments
Plasma Volume	2500 m^3	
Radiated Power	600 MW	0.01-1.0 MW/ m^3 core 100-300 MW/ m^3 X point and Divertor
Plasma distance	4 m	average for core; smaller in divertor
Pinhole aperature (diameter)	0.5 cm	
Demagnification	50x	for core system, less in divertor
Distance to back plane (matrix)	0.08 m	larger, if willing to sacrifice compactness
Pixel size (diameter)	0.5 cm	array is 22 cm x 22 cm in size
Number of resolution elements	40x40	25 cm spatial resolution across diameter (could be easily improved 2-4x)
Radiated power at each pixel	10-40 mW/cm^2	1×10^{-7} solid angle at pinhole
Temperature decay time desired	20 ms	
Height of each pixel	~ 5 mm	Distance above cold block, depends on material and desired time constant.
Max temperature rise (target)	10 °C	minimum resolvable 0.01 °C

SUMMARY

A new type of imaging bolometer is presented, which is both robust and flexible, and can operate in the long-pulse and harsh radiation conditions expected to be encountered in ITER. This work is supported by US DOE contract W-7405-ENG-36.

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