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Advantages of High Temperature Operation of an Imaging Bolometer

Evgeny A. DRAPIKO
Tomsk Polytechnic University, Tomsk RUSSIA
Byron J. PETERSON, Junichi KODAIRA, Naoko ASHIKAWA
National Institute for Fusion Science, Toki 509-5292 JAPAN

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An imaging bolometer is a new type bolometer which uses a large and thin gold foil which absorbs the incident radiation from the plasma and an IR camera to provide images of the temperature distribution within the foil which corresponds to the plasma radiation. Several theoretically predicted advantages of high temperature operation of an imaging bolometer, such are InSb sensors features, black body radiation intensity, noise equivalent power and others should increase the overall sensitivity. A series of experiments were made to prove this principle. The copper frame which supports the gold foil was heated by 4 vacuum compatible ceramic heaters up to 345 ºC.
For simulating the local foil heating due to plasma radiation we used He-Ne laser. The laser beam was exposed on the foil only for several seconds for each frame temperature step. Also two thermocouples were used to measure the frame temperature. It was experimentally shown that the resulting sensitivity increases with the foil temperature. The sensitivity was measured as a weighted difference in mean signal intensity within a line crossing a laser beam point on the foil for switched off and switch on laser at different frame temperatures.

Keywords: imaging video bolometer, high temperature operation, fusion experiment.

1. Introduction

Imaging bolometers are a reactor-relevant alternative to resistive bolometers for the measurement of total radiated power from a fusion plasma [1]. They rely on a single thin metal foil which absorbs the incident radiation from the plasma as collimated by an aperture. The resulting temperature change of the foil is then measured by an infrared camera located outside the vacuum vessel (Figure 1).

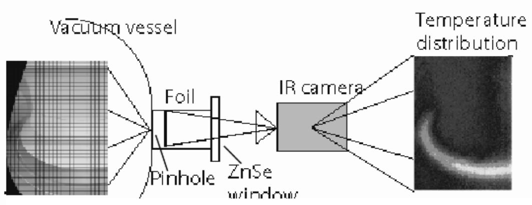

Fig.1 imaging bolometer layout

A possible means to increase the sensitivity of the imaging bolometer is to raise the operating temperature since from Planck's Law it is known that the black body radiation intensity increases and the emitting wavelength decreases as the temperature is raised. For an InSb detector which is sensitive to radiation in the wavelength range of 3 – 5 μm the optimum temperature range is approximately 750 – 1400 ºC. In addition, from the Stefan-Boltzmann Law it is known that the differential increase in the radiated power with respect to the change in temperature increases with the third power of the temperature. Finally, from the derivation of the noise equivalent power of the imaging bolometer given by equation 10 in ref. [2] it is known that the contribution by the blackbody radiation to this noise also increases as the third power of the temperature, but that this term does not become significant compared to the other terms until above around 1000 C. Therefore the sensitivity of the imaging bolometer should be able to be raised by increasing the operating temperature up to the optimal temperature for the InSb detector without raising the noise. This temperature range also corresponds to the operating temperature of the first wall of ITER of about 800 ºC which is where the imaging bolometer foil will be located.

2. Experiment layout

The foil and frame are the same as that used for previous experiments. It was a 2.5 μm gold foil sandwiched between two 2 mm copper frames. The frame itself was mounted to the flange by two bolts through special ceramic washers which provide good thermal and electric isolation of the frame. Both sides of the foil were blackened with graphite. One side of the foil was viewed by an IR camera Phoenix (FLIR) which has the below listed characteristics: wavelength 3-5 μm, spatial resolution 320x256 pixels, signal level resolution 14 bits. We used 4 special vacuum compatible ceramic heaters for heating the copper frame. The maximum temperature which can be

author's e-mail: drapiko.evgeny@lhd.nifs.ac.jp

achieved with these heaters is 500 ºC. For measuring the copper frame temperature we used two thermocouples, placed in the opposite corners of the frame. Part of the frame where one of thermocouple installed, was also viewed by the IR camera for calibration purposes. For viewing the frame and the foil we used the ZnSe vacuum window. To protect the window against an overheating, the frame with heaters were placed at the maximum possible distance from the window of about 27 cm. Heaters were clamped to the frame with bolts to provide good thermal contact. The framed foil is mounted in a vacuum chamber which is then evacuated to less than 1 mTorr to avoid cooling of the foil by collisions with room-temperature molecules and neutral particles. A HeNe laser was used to locally increase the temperature of the foil simulating the plasma radiation. The laser beam was directed into the chamber through three mirrors and one glass window. The measured beam power after all reflections and transitions was 5 mWatts.

3. Description of Experiments

To prove the above mentioned statements there were two experiments planned. The first one was aimed at the quantitative characterization of the sensitivity depending on the temperature. The second one considered the qualitative and quantitative characteristics of the local temperature distribution within a laser exposed area on the foil. In the first experiment we were slowly increasing the frame temperature and measuring the mean value of the intensity on a line crossing a laser exposed area through the beam center with the laser switched on and off. The main goal was to show that the same laser power can result in a different signal level change due to the laser power present or absent for different foil temperatures.

The second experiment consisted of measurements of the temperature profile of the laser exposed area on the foil with different frame temperatures (100, 250 and 300 ºC). To exclude the background from the resulting temperature profile we measured it first for the current temperature with the laser switched off. Before each measurement, the temperature was stabilized near the above mentioned values.

4. Experiment results

The results of the first experiment showed that for temperatures from 22 C up to 330 C the sensitivity

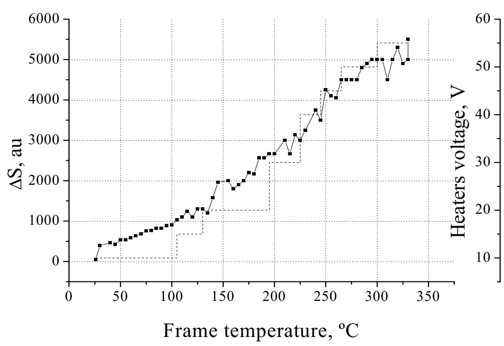

Fig.2 sensitivity over frame temperature

dependency on temperature is close to linear. The fitting polynomial coefficients are following: 892-18x + 0.21 x ^2 For sensitivity we assume the following expression,

$$\Delta S=(S_{l.on}-S_{l.off})/t_i, \quad (1)$$

where $S_{l.on}$ - is the camera signal with the laser on, $S_{l.off}$ - is the camera signal with the laser off, t_i - is the camera integration time. Figure 2 shows how ΔS depends on a frame temperature; also we've included a heaters voltage waveform. It is obvious that the sensitivity increases with temperature growth and the dependence is close to linear.

Figure 3 shows three temperature line profiles for the laser exposed area of the foil with different frame temperatures.

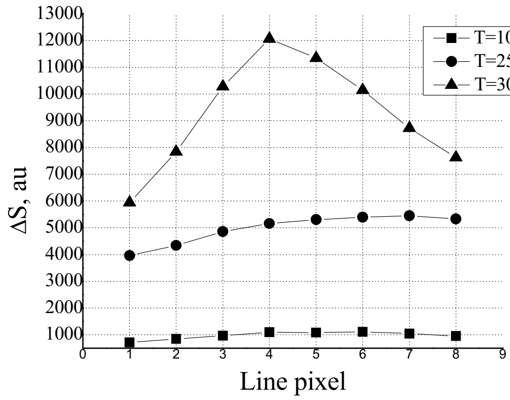

Fig.3 line intensity of a laser spot

5. Discussion

According to the experimental results the advantages of higher temperature operation of an imaging bolometer are clear. According to the first experiment, the resulting sensitivity has the tendency to depend nearly linearly on the foil temperature even up to 350 ºC. So we can state that the integral characteristics of the signal have higher amplitude with increased temperature.

More precise and smooth frame temperature control will help to avoid any voltage step influence to the signal. Due to rapid voltage changes we didn't take in to account the time delay for temperature diffusion from the frame to the foil. So for the best results we should increase the temperature very slowly, or we should provide a temperature stabilization circuit.

As for the differential signal characteristics, the second experiment showed that the local temperature profile on a higher temperature background becomes sharper and higher. In order to achieve the highest possible temperature using the current heaters we pointed the laser beam near the frame in a corner of the foil. which is the location of the highest temperature gradient. So that is why the profile waveforms in Figure 3 have asymmetry. But this fact also verifies that higher foil temperature gives the advantage of higher resulting signals because the background was excluded from the data in these profiles.

5. Future plans

Further plans include investigation of the sensitivity for foil temperatures higher than 350 ºC up to 800 ºC. Also, foil calibration at higher temperatures is planned. For checking whether any foil characteristics change with temperature increase, we should make the calibration procedures described in [3] for two temperatures or more. Control of the temperature gradient on the foil would be good but is too complicated and may be not necessary.

6. Acknowledgments

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7. References

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