Radiation hardness test of mica bolometers for ITER in JMTR

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1. Introduction

Maximum radiation loss without disruption is essential to extend the maintenance intervals of ITER and following fusion reactors. The strong radiation distribution at the divertor must be known in fine detail to control such discharges. The corresponding reference diagnostic uses metal resistor bolometer cameras for detailed tomographic reconstructions of the radiation distribution [1]. The radiation hardness of the detector had been identified as the main question concerning the reference design. We report on the results of a Japanese/European collaboration (under ITER task T492) achieving the first in situ neutron irradiation tests of present day bolometers have been performed. A neutron dose equivalent to 0.1 dpa was reached, corresponding to the fluence between two maintenance periods at the bolometer locations behind the first wall elements or in the divertor under full load conditions of ITER-FEAT.

2. Experimental set-up

We used a former JET high temperature bolometer [2], derived from the ASDEX-Upgrade [3] version by replacing the kapton foil with a Muscovite mica foil of 20 μm thickness and reducing the resistance to 200 Ω. The bolometer was connected with gold plated spring contacts to external connection wires arranged in twisted pairs and inserted in a metal tube to be installed into the Japan Materials Testing Reactor (JMTR) in Oarai. This reactor has a maximum thermal power of 50 MW and a maximum fluence of thermal neutrons of $4 \cdot 10^{18}$ n/(m^{2}s). The bolometer was placed inside the reactor for three 25 day reactor cycles to a total dose of 0.1 dpa (10^{24} n/m^2, E> 1 MeV) at a thermal neutron fluence of $1.5 \cdot 10^{18}$ n/(m^{2}s). A thermocouple was installed next to the bolometer to monitor the temperature. The tube was filled with helium at 0.3 Mpa. During the irradiation, resistance measurements were performed as well as electrical calibration measurements, to determined the sensitivity and the time constant of the bolometer. The principle of the electrical calibration (fig. 1) is to step up the supply voltage to the bolometer and monitor the temporal evolution of the consequent signal voltage while the additional electrical power heats up the bolometer. The DC calibration of the sensitivity was also done by measuring the current to voltage characteristic of the bolometer. The sensitivity is here defined as bridge output voltage per bridge supply voltage per incident power.

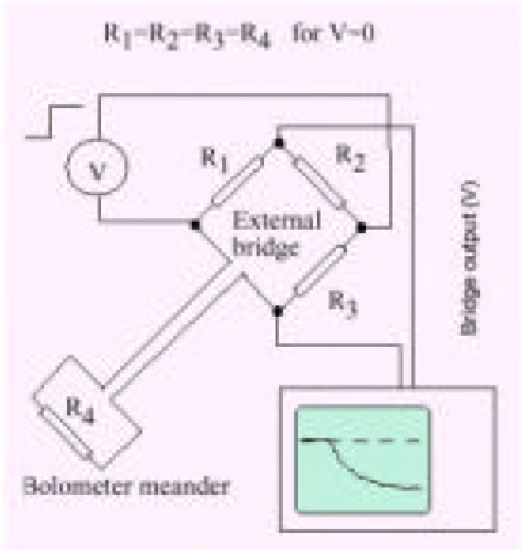

Fig. 1: In situ calibration set-up.

3. Experimental results

The resistance of the gold meanders increased significantly during the experiment. During the ramp-up of the power in one day, the resistance follows closely the evolution expected from the heating up to 100°C (fig. 2). Only after the full power of 50MW is established for 2 more days a clear additional rise of the resistance of 5% is noticed. This trend continued (fig. 3) with an almost linear rise to 390 Ω at the end of the first cycle. During cool-down of the first cycle one meander broke in a process which showed at first a gradual small increase of the resistance during 1 minute and then a sudden increase to double the value indicating a rupture of the circuitry on the foil itself. Four hours later and two hours after reactor shutdown all connections went open circuit after the resistances had decreased to 315 Ω leaving a residual resistance increase of 90 Ω. Some resistance measurements recovered on start-up of the second

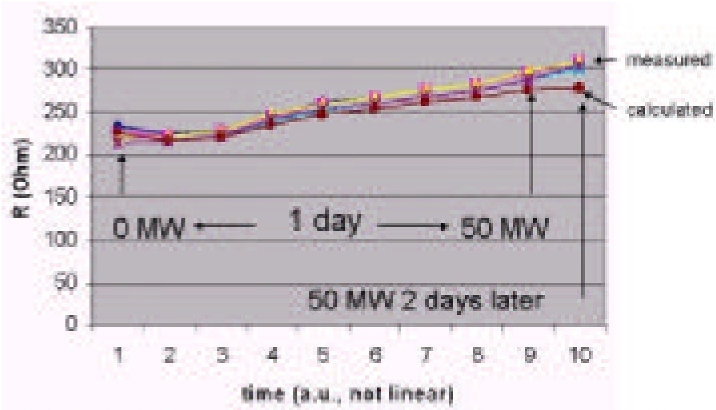

Fig. 2: Resistance during start-up (4 bolometer + 1 thermocouple)

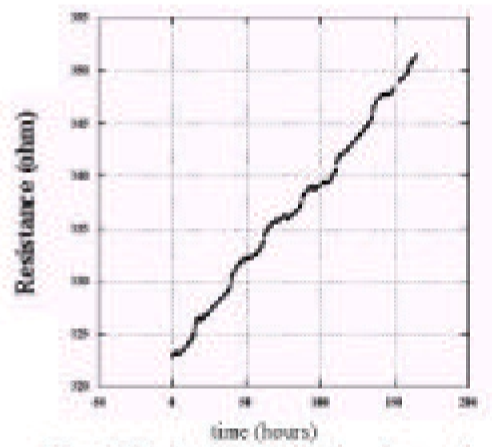

Fig. 3: Resistance rise during first cycle

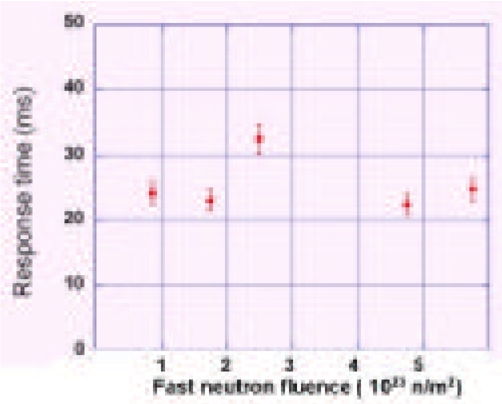

Fig. 4: Time constant measurements.

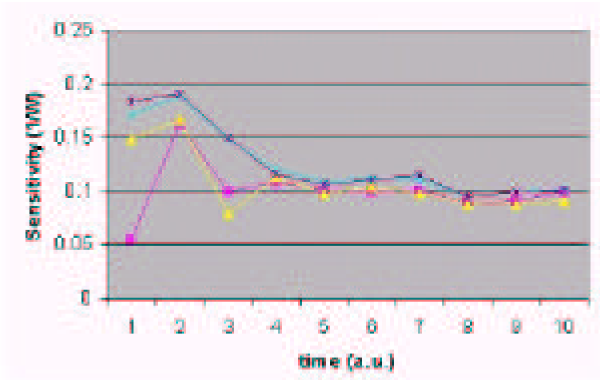

Fig. 5: Sensitivity during start-up of 4 bolometers (time axes as in fig. 2).

cycle, allowing to continue with the measurements during the second cycle. Later in the second cycle some more connections were re-established to the meanders but one connection remained open, although not the one which which failed first. After 2/3 of the second cycle all contacts were definitively lost. The total permanent resistance rise had been about 75% of the initial value for a dose of 0.055 dpa. During the ramp-up phase of the reactor, the time constant rose from 25 ms to 32 ms, and then stabilised around 30 ms where it stayed throughout the rest of the experiment (fig. 4). This value is considerably lower than the time constant in vacuum (160 …230 ms). The sensitivity measurements showed some fluctuations during the startup phase (fig. 5), but soon settled to a stable value of 0.1 1/W. To investigate the influence of high pressure He atmosphere on the bolometer, laboratory measurements were performed at Tore Supra with a similar bolometer at various pressures (fig. 6) which quantitatively confirmed the reduction of the time constant and also agree well with the sensitivity data from the irradiation experiment.

4. Discussion

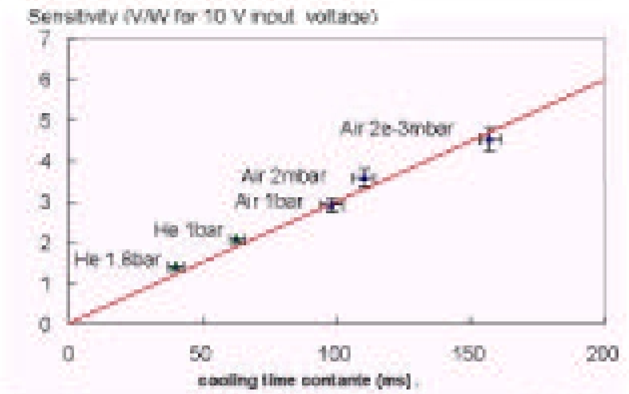

Fig. 6: Sensitivity and time constant measurement at Tore Supra.

One plausible explanation for the large permanent increase in resistance is, that the substrate becomes distorted due to radiation swelling, and hence a strain gauge effect causes the resistance to rise. This seems to be excluded by the previous JMTR investigations [4], which indicated an expansion of the mica substrate of less than 0.3% for 0.01 dpa, but seems possible in the light of other investigations [5] reporting an appreciable distortion after a fission reactor irradiation at 10^{-3} dpa. During the latter experiment water was present and the foil was supported in a frame, whereas in the former experiment this was not the case. It is however also known that H_2O may form in mica under irradiation [6]. Another candidate to increase the resistance is in principle the formation of point defects by atomic displacements. But the experience of JMTR is that Cu which has similar defect properties as gold, does not show an appreciable increase of resistance under similar conditions. Finally the resistance may increase due to nuclear transmutation of Au to Hg, which is a few % in 1 cycle from fast neutrons. Loss of contact at cool-down may be related to radiation induced embrittlement causing the gold meander to be less ductile on cool-down and possibly breaking. The observed variations of the time constant and the sensitivity at start-up may reflect changes of the conductivity of the surrounding atmosphere during start-up. Since the helium does not have a forced flow in and out of the tube but only past the tube in which the bolometer is held, a change of the composition, pressure and temperature is possible, all of which may influence the thermal conductivity and thus the time constant and sensitivity. Other explanations are also possible, e.g. the initial loss of sensitivity can partly be explained by the normal loss of sensitivity with rising temperature. The following plateau should therefore probably be somewhat lower than actually found. The difference might be explained by a degradation of the heat conductivity in the insulator and the metallic heat conduction layer.

5. Conclusions

Until Post Irradiation Examination (PIE) has been performed, the causes for the problems with the resistance of the meanders and their stability are speculative. From the present understanding it may be better to replace the gold meanders with platinum ones. Mica remains for the moment a valid substrate candidate. However it is considered advisable to continue the development of alternative substrates using radiation resistant materials such as Al_2O_3 or AlN at least until a similar experiment has be done under vacuum conditions. Today’s standard bolometers seem suitable for ITER start-up, and with reasonable further development should become usable also for the highly active phase.

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