Experimental and theoretical thermal analysis of CVD diamond window units for the ITER upper launcher

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***Abstract*—An ITER torus window prototype with CVD diamond disks and corrugated waveguides are being investigated by using IR imaging and temperature measuring technique during high power RF microwave loading up to 1 MW at a frequency of 170 GHz at the JAEA gyrotron facility. To evaluate the cooling efficiency of the window design the temperature distribution over the diamond disk area is measured and compared with a theoretical thermal FEM analysis.**

I. Introduction And Background

FOR plasma engineering at ITER, EC launchers will be used at the upper port [1,2,3] and the equatorial port [4,5] levels. The goal of the presented studies is to verify a prototype window design and to evaluate its applicability for a generic concept. The high power RF behavior of the torus window assembly with corrugated waveguides is investigated using IR imaging technique during high power microwave transmission with the intention to reach 1 MW at a frequency of 170 GHz at the JAEA gyrotron test facility [6,7,8]. Experiments with different pulse duration have been performed to determine the temperature distribution over the whole diamond window area and the efficiency of the indirect cooling by a copper cuff for different mm-wave power levels. By Finite Element Modeling (FEM) thermal analysis the measured temperature evolution of the window unit can be explained and quantified. The impact of parasitic higher modes in the microwave beam is demonstrated.

II. Results

The following figure shows the temperature-time dependence in pulsed experiment (15 sec / 320 kW) using the indirect cooling with a water flow of 12.5 l/min. Curves A-F correspond to selected points in the IR picture of the diamond window. The temperature evolution reaches thermal equilibrium and can be described by the following parameter set:

$$T(t) = T_o + T_1 (1 - \exp(-t/\tau_1)) + T_2 (1 - \exp(-t/\tau_2))$$

with the time constants $\tau_1 = 0.94$ s and $\tau_2 = 2.03$ s, respectively and the temperature parameters $T_o = 42.54$ °C, $T_1 = 19.94$ °C and $T_2 = 14.17$ °C [9].

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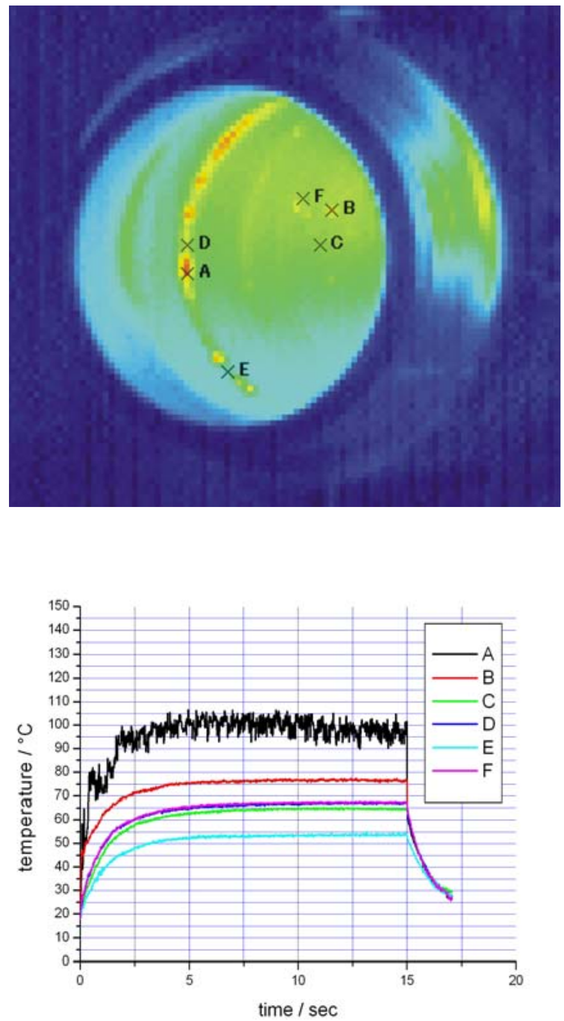

Fig. 1 IR picture (top) and temperature evolution (bottom) on a CVD diamond disk for a 320 kW/15 sec load.

Assuming a Gaussian beam, the steady state FEM simulation yields a temperature of about 60 °C in the center of the diamond disk with the actual window parameters: loss tangent $3.4 \cdot 10^{-5}$ [9], thickness 1.11 mm, disk diameter 75 mm and an aperture of 63.5 mm. These parameters also determine the absorbed microwave load for a given transmitted microwave power. Fig. 2 shows a sectional drawing of the window in rotational symmetry. The Cu cuff with the cooling channels is at a temperature of 40 °C. For 600 kW microwave power the calculated temperature in the center of the diamond disk is 76 °C for the mentioned loss tangent.

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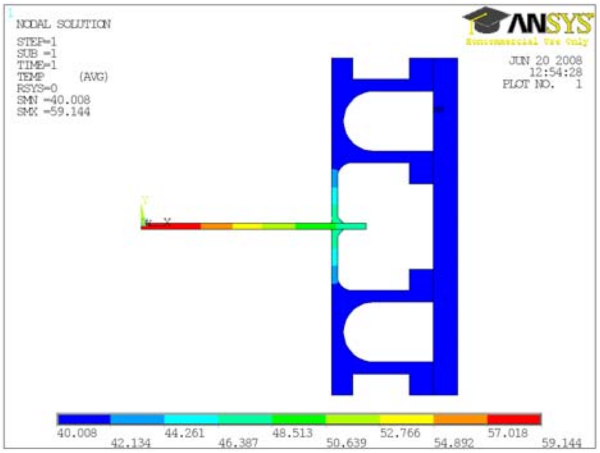

Fig. 2 Steady state ANSYS FEM analysis of the diamond window assembly for 320 kW microwave power.

To compare the time constants of the simulation and the experiment a transient analysis for 320 kW and 50 sec pulse length shows the dependence in Fig. 3.

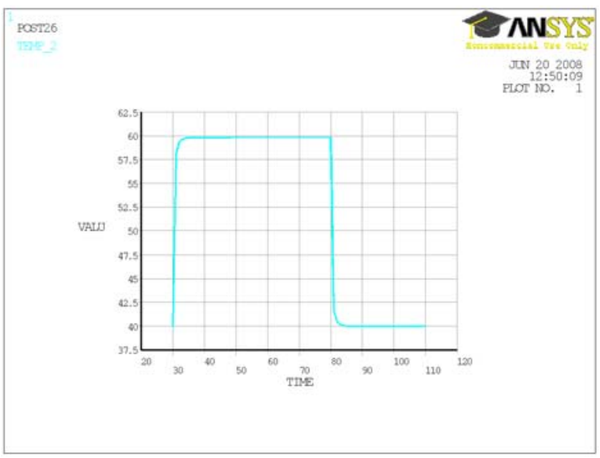

Fig. 3 Transient analysis of the diamond window assembly for 320 kW/50 sec microwave power.

The time constants obtained from a least square fit with the same temperature-time function are τ_1 = 0.2 s and τ_2 = 2 s, where τ_2 coincides with the observed value. However, τ_1 is in a model description much shorter. Most likely reason is the deviation from Gaussian beam profile caused by higher order modes in the incident beam. The distribution of the temperature and the electrical field is non-radial symmetric. Higher order modes are generated by several mitre bends in the transmission line from gyrotron. Higher modes in the structure change the power load profile.

For measurements with pulse length > 15 sec (Fig. 4) the diamond disk temperature reaches thermal equilibrium. The small decrease during the pulse is due to the slight variation of the gyrotron output power. Also in the IR image of the window, there are some "hot regions" at the disk border and at the transition gaps between the SS structure and the copper cuffs on both sides of the diamond disk (e.g. B). The gap between copper and steel is about 100 µm. In given case of a mode mixing in the microwave beam additional parasitic cavity heating can be expected and is an obvious source for additional heating of the housing.

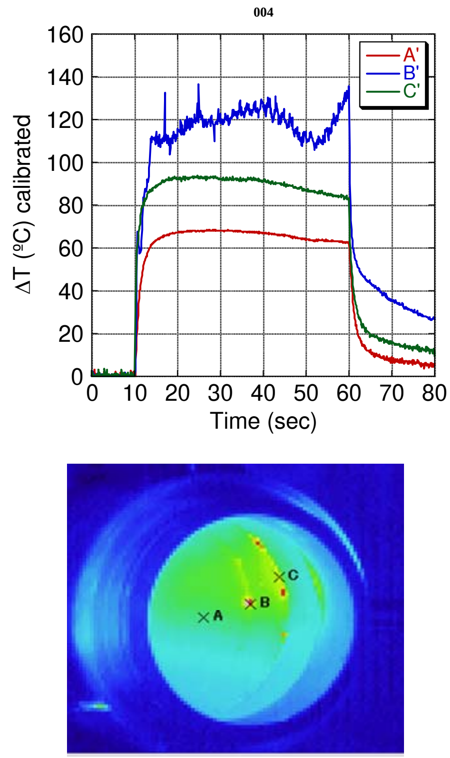

Fig. 4 Temperature-time dependence on a CVD diamond disk for a 320 kW / 50 sec power and the corresponding IR picture. Additional heating by parasitic cavities (mode mixing) can be observed.

III. Conclusion and Outlook

High power RF measurements at 170 GHz have been performed at the JAEA gyrotron facility by means of IR thermography. The disk reaches thermal equilibrium and shows values consistent with the modeling. The microwave beam provided by a 40 m waveguide system with several mitre bends is not purely Gaussian. Also no arcing effects were observed. The higher order modes apparently cause parasitic heating effects. This is because they penetrate into the cavities neighboring the diamond disk and into the gap between the copper cuffs and the SS structure. The influence of the exact mode composition in the microwave beam is subject to further investigations.

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