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IR reflectivity measurements depending on carbon film thickness

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Abstract: In thermonuclear controlled fusion machines using magnetic confinement, carbonisations are realised to prevent metal impurities to enter into the fusion plasma made with hydrogen elements; it consists in helium glows in which methane gas is injected . The methane molecule is broken and the carbon deposits on all inside vessel surfaces : inner walls as well as optic elements like windows and mirrors . We studied the dependence of the reflectivity of infrared thermography stainless steel mirrors with carbon films thickness in the 3-5 μm bandwidth . The presented results show a decrease of less than 10% of the temperature announced by the camera .

1 . Magnetic fusion :

Thermonuclear controlled fusion [1] research is made in the aim to reproduce solar energy in a controlled way . Fusion principle is to move closer two hydrogen atoms so that they form an heavier atom meanwhile an energetic neutron is released . The energy of this neutron will be recuperated to produce electricity . To bring closer hydrogen atoms, two conditons must be realised . First, confinement is needed . It is obtained in our case with magnetic strength instead of gravity as in stars ; another way is to use inertial confinement [1] where laser or particles beams compress hydrogen atoms . To keep particles magnetically trapped, magnetic lines are closed on themselves forming a torus shape . This is a tokamak machine [fig 1] .

Second, a high temperature is needed to overcome repulsion strength ($>10^8$ °C); at these temperatures, atoms are separated in ions and electrons : they form a plasma which is globally neutral . To reach such high temperatures, additional heatings are used based on neutral particle beams and high frequency waves such as ion cyclotron, lower hybrid and electron cyclotron .

Although plasma particles are trapped in non-material magnetic barriers, atomic collisions appear and diffusion, convection,conduction and radiation phenomena occur; this implies heating of contact surfaces . That is why an infrared thermographic system is developped to measure and survey these heatings which can lead to a failure of one of the plasma facing component inside the tokamak [2] .

2 . IR thermographic diagnostic :

The Tore Supra IR thermographic diagnostic consists, until now, in three endoscopes [fig 2] situated at 120° one from the other on the top of the tokamak; they are remotely controled so that every element inside the vessel can be observed .

Images of objects inside the vessel are captured by a movable stainless steel mirror and returned to an optical system through a sapphire window . This window is necessary to keep

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ultra high vacuum inside the torus vessel . Inframetrics 3-5 μm cameras recuperate images from the optical system which transported them .

Plasma inside the tokamak encounters surfaces made of, or covered with graphite . This graphite is sputtered and redeposited during or after plasma is stopped . Furthermore carbonisations are made to cover metal inner walls of the vessel with carbon so that metal impurities rate inside the plasma is lower . Carbonisation, and its erosion, was extensively studied [3,4,5] but to our knowledge no measure on its effect on infrared mirror reflectivity was carried out . So did we . We deposited carbon layers on our stainless steel mirrors to determine from which thickness mirror reflection is affected .

3 . Experimental apparatus :

Our carbonisation system was installed in a special vessel [fig 3] . To realise carbonisation He or D_2 or H_2 glow plasmas can be used in which few per cent of CH_4 or CD_4 are in addition . Methane molecule is broken by collisions with plasma particles . Carbon atoms deposit on all surfaces . In our case, the plasma was made with helium and methane gas was injected .

Two $\lambda/2$ polished mirrors, set back to back, are supposed to be hidden from carbon deposition and centimeter by centimeter are exposed to the glow (see fig 3) . The deposited layer thickness is indicated by a microbalance diagnostic . The following parameters were established for carbonisation :

$P_{CH4}/P_{He} = 0{,}065$
total pressure (He + CH4) : $P_{tot} = 1{,}15$ Pa
plasma current density : $j = 12\ \mu A/cm2$
carbon deposit speed : $f_C = 1$ monolayer in 10 s
vessel temperature : $T_{deposit} = 150$ °C

The total deposit duration was less than two hours .

4 . Experimental results :

Six carbon films 1 cm x 3 cm wide were obtained : 50 monolayers, 150, 250, 350, 450 and 550 monolayers thick [fig 4] following the microbalance indication .

The two mirrors present the same visual aspect . A correlation between film thickness and colour was established by J. Winter in his study of carbonisation in Textor tokamak [5] . Using this correlation, we find a good agreement between thickness given by the microbalance and the colour of films deposited on our mirrors .

Reflectivity results for both mirrors are presented below [fig 5] . Reflectivity is constant from 0 to 150 then it decreases from 150 monolayers deposited; as expected the thickest film has the worst reflectivity . We compare the reflectivity of mirrors just beeing polished before deposition and what we call the 0 monolayer situated in a place always under the cache . There is a minor difference between the two which is inside error bars .

Reproducibility of our reflectivity measurements is in the order of +/- 2 % .

Our deposits need special care because of their poor adhesion : we lost part of the thickest deposits by rubbing with a plastic bag . Mirrors surfaces were made very smooth and then it is not so surprising that our films have little adhesion as thick they are . Furthermore, electrostatic interaction may increase this effect . Indeed carbonisation films have quite high electrical resistivity . For example, on Textor samples $1 - 10^6\ \Omega$cm was typically measured [5] .

We observed too that the two films 450 and 550 monolayers show waves . These waves are more important with the increase of thickness . J. Winter observed and measured the same phenomenon [5] . This author says this appears during air exposure . We are not able to

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confirm this because there was no window in our carbonisation vessel where we could see mirrors still under vacuum before air exposure [fig 6] .

Measurement of the 550 monolayers zone where the deposit is and where it peeled, was undertaken . Reflectivity of the undamaged part of the film is the lowest . Reflectivity of the peeled film is half between that latter and that of 0 - 150 monolayers .

If we consider the worst result which means 550 undamaged monolayers deposited, we find that the real temperature is underestimated by less than 10 per cent; this may be dangerous in our application especially at high temperatures : for example, the copper melting point is at 1083°C, with our results the temperature indicated by infrared cameras is around 975°C, but inside the copper 15 bar water circulate to refregirate the plasma facing components which means that with our measurement we wouldn't understand why there is a water leak in the machine; this leak implies no experiment for three months to mend damaged parts and to restart the machine .

5 . Conclusion :

We realised carbonisation with variable thicknessses on two polished stainless steel mirrors used in the infrared 3-5 μm band . Their reflectivity before and after carbonisation was measured, on the different thicknesses of the films formed . Below 150 monolayers the reflectivity does not change . Beyond 150 monolayers, a decrease is observed . If deposit peels, reflectivity is only modified but does not come back to the value with few deposit . Over 450 monolayers the deposit shows waves which show poor film adhesion . The two mirrors have the same results even if they were set back to back for carbonisation, one looking at the anode, the other looking at the opposite . We deduced from these reflectivity measurements that in the case of the thickest deposit the real temperature of the tokamak element is under evaluated by less than 10 % .

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Captions :

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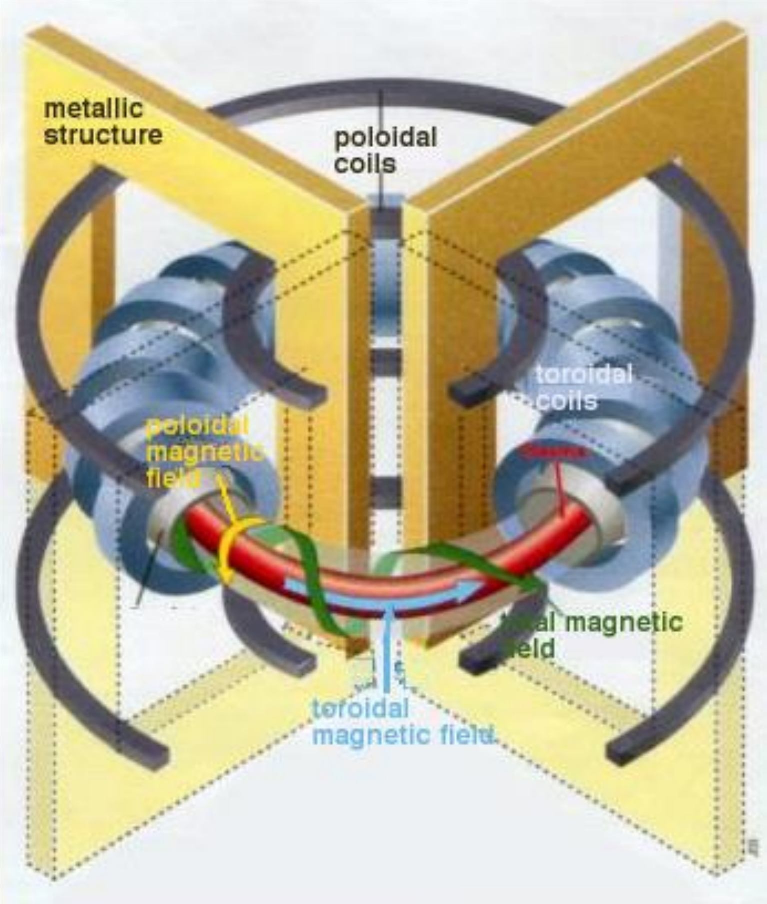

fig.1 : Tokamak principle

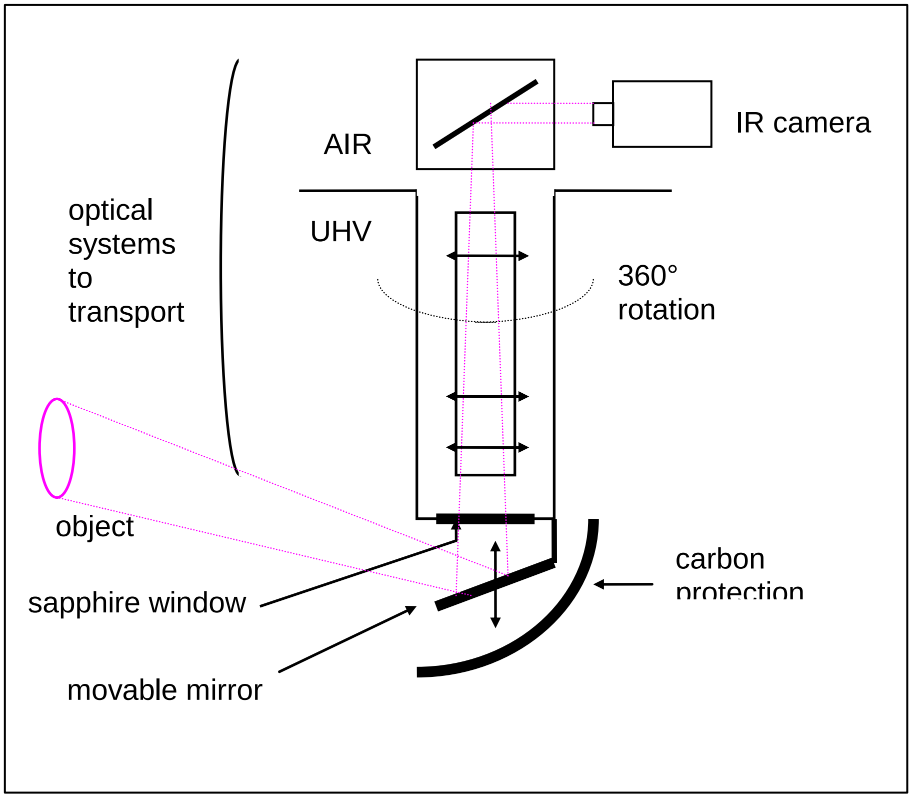

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fig.2 : endoscope principle

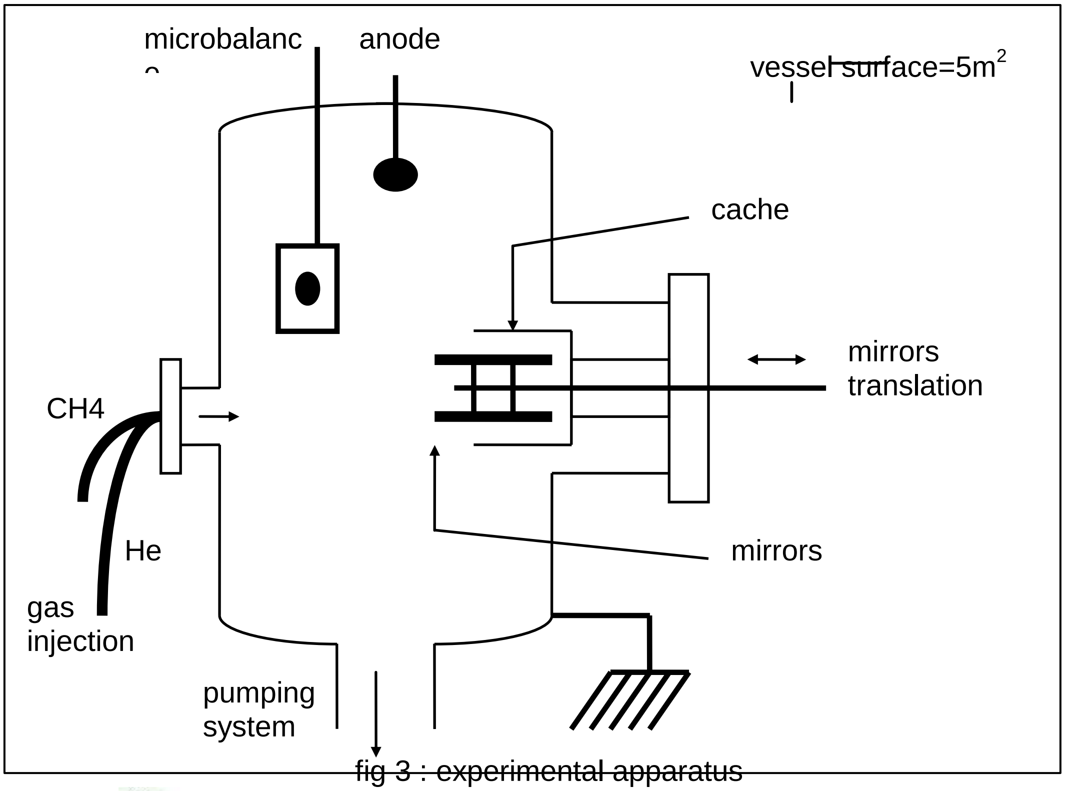

fig 3 : experimental apparatus

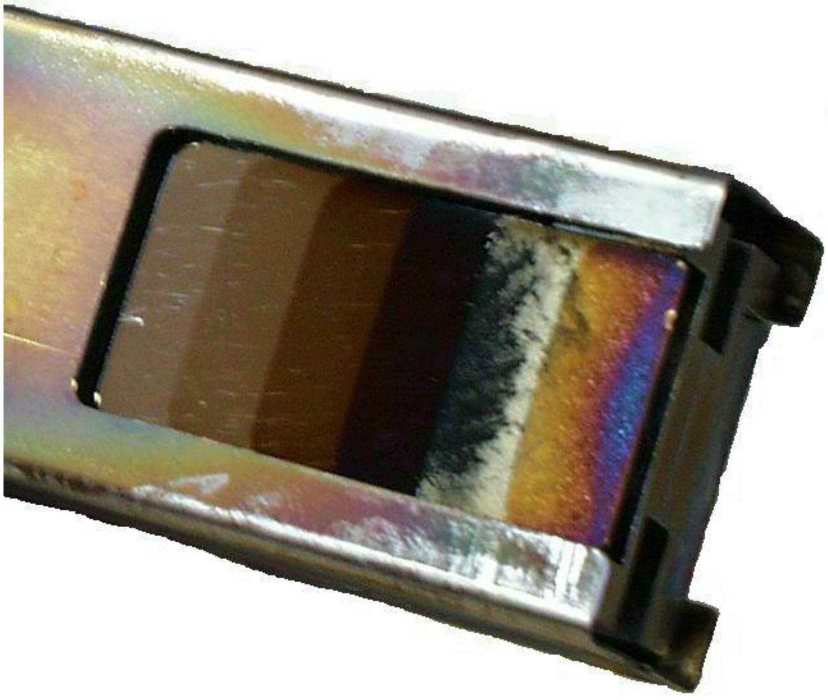

fig 4 : stainless steel mirror after carbon deposition

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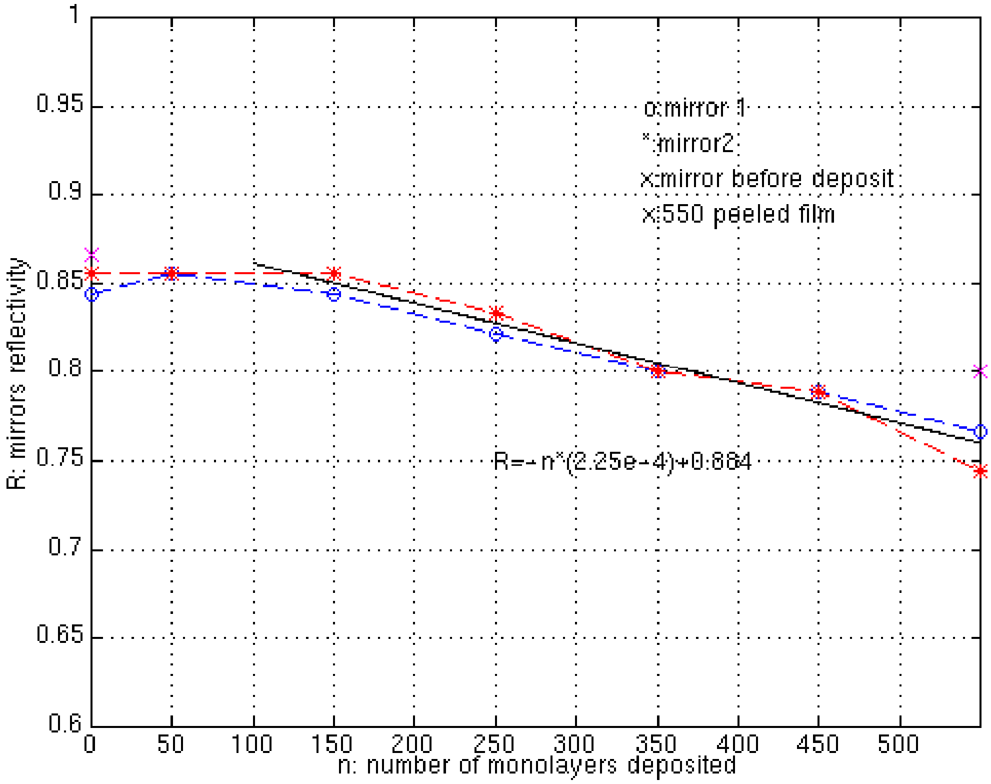

fig 5 : stainless steel mirrors reflectivity depending on the carbon thickness

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fig 6 : mirror macrophoto showing waves for the two thicker deposits 450 (right) and 550 (left) . on the upper part scale is shown : two black lines are separated by 1 mm .