23G06

Heat conduction analysis of a composite metal
プラズマ照射された金属複合材の熱伝導解析

Hiroto Matsuura,Ryohei Ohyama,Shotaro Turu, A.Rusinov,Mizuki Sakamoto
松浦 寛人, 大山亮平, 鶴昭太朗,A. ルシノフ, 坂本瑞樹

Res. Org. for Univ.-Comm. Collabo., Osaka Pref. U.,
Gakuen-cho 1-2, Naka-ku, Sakai, Osaka 599-8570, Japan
大阪府立大学地域連携研究機構、〒 *599-8570* 大阪府堺市中区学園町 *1-2*

Absorbed heat flux from plasma to solid target is difficult to determine experimentally. It depend not only on plasma parameters but also on surface condition, which can not monitor in site easily. In this work, a bulk composite target is irradiated by He plasma, and temperature data with an Inferred Camera thermometer and thermocouple are compared. From these data, modeling of heat conduction process are also conducted. For exact heat estimate, heat sink must be treat carefully.

1. Introduction

Sheath heat flux from plasma to solid surface has large impact on the divertor plate of fusion plasma, the substrates in semi-conductor processing, the wall material of space vehicles. It is found from direct heat flux measurement with thermal probes that sheath heat flux depends not only plasma parameters but also the material and surface condition of the probe tips [1]. Tungsten is the first candidate of the first wall material of fusion reactors. Recently, however, it suffers various surface damage under the helium plasma irradiation [2]. So it is important to study the effect of these surface damage on the sheath heat flux. Moreover, surface damages affects Inferred Camera thermometer (IRC) data and surface temperature data with it can not provide absorbed heat content in the bulk material.

In this work, we use a bulk target material with three thermocouples (TC), obtain the temperature data obtained with IRC and TC, and compare them with heat conduction model.

2. Experimental setup and target

Experimental device used here is the compact PWI simulator, APSEDAS [3]. By keeping gas pressure in the chamber as about 35 [mTorr], Helium plasma is produces with a Radio Frequency helical antenna of 13.56 [MHz]. In this work, RF power is 300 $\sim$ 400 [W] and, hence so-called Helicon jump does not occur and plasma density is not so high (order of 10^{16}[m^{-3}].

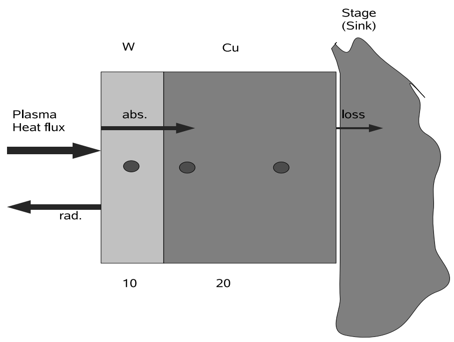

Fig.1: Schematic drawing of composite target. The target consists of Tungsten (1cm thick) and Copper (2cm thick).

Bulk irradiation target is shown in Fig. 1. which is set on the water cooled support stage. This target consists of of Tungsten with the thickness of L_1 = 10.0 [mm] and Copper of L_2 = 20.0 [mm]. Its cross section facing plasma is $S = 30 \times 30 = 9.0 \times 10^2$ [mm^2] and surface temperature is measured with two IRCs (Chino IR–CAQ series) with different temperature range. Bulk temperature is measured with three type-K TCs, which are set at 5.0,12.0, and 22.0 [mm] from Tungsten irradiation surface.

3. Experimental result and discussion

Figure 2 shows an example of target temperature evolution. Plasma parameters measured with a Langmuir probe are $n_e = 5.9\times10^{16}[\mathrm{m}^{-3}]$, $T_e = 10[\mathrm{eV}], V_s = 38[\mathrm{V}], \Gamma_i = 5.7\times10^{20}[\mathrm{He/m^2s}]$, respectively. Surface temperature (IRC data, red line) shows rapid increase to 315[deg.] at discharge start, keeps almost constant during the irradiation, and drops rapidly to 295[deg.] at discharge end. But bulk temperature data (TC1,TC2,TC3) show slow increase and steady state does not establish even at discharge end (90[min.]).

By using Tungsten thermal diffusivity $\alpha_1 = \frac{\lambda_1}{c_1\rho_1} = 0.695\times10^{-4}[m^2/s]$, heat diffusion time for characteristic length of $L_1 + L_2$ is $\tau_1 = \frac{L^2}{\alpha} = 12.95[\mathrm{s}]$. By using Copper value, τ_2 is about 70%. So if plasma irradiation is longer than one [min.], temperature profile is expected to reach steady state. But Fig. 2 contradicts this prediction. The stage temperature is also monitored with TC and shows similar behavior. (Ideally, this temperature should be kept constant.) So the characteristic length must be much larger than $L_1 + L_2$.

Recently we obtain an analytical solution of heat conduction for a composite slab [4]. One example is shown in Fig. 3. This solution is obtained for large characteristic length $L = L_1 + L_2 + L_{ex}$, where this expanded length L_{ex} denotes the heat resistance between the target and the stage. If $L_{ex} = 0$, the stage acts as a perfect sink. In the real APSEDAS experiment, L_{ex} must be very large and steady state hardly establishes.

After irradiation phase, three TC data and IRC data are identical within the experimental error and the decay constant is about 750[s](12.5 [min.]). Since the heat capacity of sample target can be estimate as $(c_1\rho_1L_1 + c_2\rho_2L_2)\times S = 72.5[\mathrm{J/K}]$ and temperature increment just before discharge stop was 190[deg.], total heat loss was $72.5\times10^4\times190/750 = 18.4[\mathrm{W}]$. If this heat loss occurs only through heat conduction to the stage, heat flux density along normal direction was $20.4[\mathrm{kW/m^2}]$ and temperature drop in W layer is estimated to be about 1[deg.], while in Cu layer it is similar value.

Unfortunately, TC2, and also TC(stage), show a small drop (a few degree) at discharge start timing and recover at stop timing. So in order to check above estimation, direct measurement of temperature gradient will be necessary for farther improved experiment.

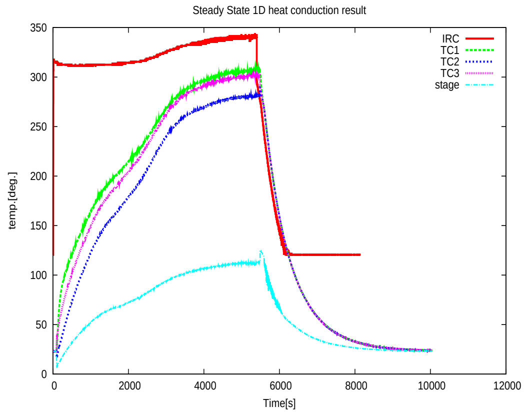

Fig.2: Example of temperature evolution. RF power for plasma production is about 400[W]. Discharge duration is 90 [mini.].

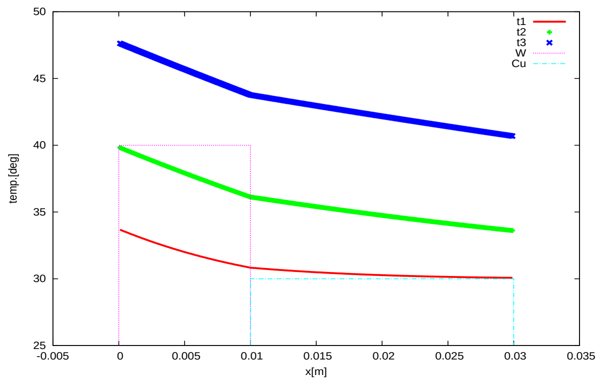

Fig.3: Calculated temperature profile. Initial temperature is assumed to be 30 [deg.], plasma irradiation starts at $t = t_0 = 10$ [s], and three profiles for $t - t_0 = 1.0, 10.0$, and 50.0 [s] are plotted. $L_{ex} = 100L_1$ is assumed.

Acknowledgements

This work was supported in part by the Collaborative Research Program of Research Institute for Applied Mechanics, Kyushu University.

References

[1] H.Matsuura *et al.*: Proc. 2nd Int. Forum. Heat Trans., Tokyo, 2008.

[2] S.Takamura *et al.*: Plasma and Fusion Research 1, 051(2006).

[3] Y.Higashizono *et al.*: Plasma and Fusion Research 4, 043(2009).

[4] M.Ishihara: private communication.