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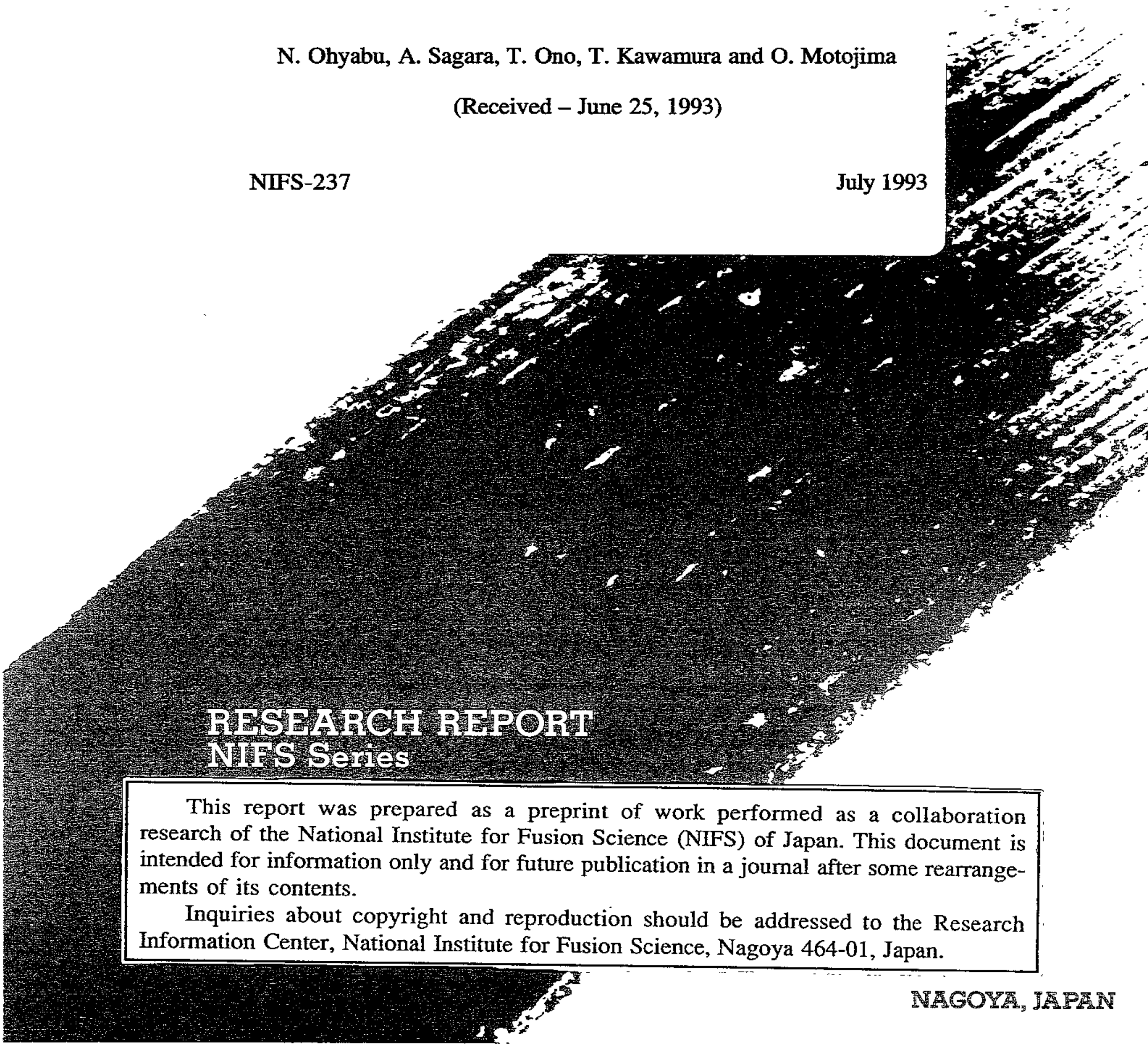

RESEARCH REPORT
NIFS Series

NAGOYA, JAPAN

CARBON SHEET PUMPING

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ABSTRACT. A new hydrogen pumping scheme has been proposed which controls recycling of the particles for significant improvement of the energy confinement in toroidal magnetic fusion devices. In this scheme, a part of the vacuum vessel surface near the divertor is covered with carbon sheets of a large surface area. Before discharge initiation, the sheets are baked up to 700 ~ 1000 C^o to remove the previously trapped hydrogen atoms. After being cooled down to below ~ 200 C^o, the unsaturated carbon sheets trap high energy charge exchange hydrogen atoms effectively during a discharge and overall pumping efficiency can be as high as ~ 50 %.

Keywords:
carbon wall, hydrogen pumping, divertor, recycling control,
confinement enhancement, charge exchange,

Improvement of the energy confinement is the major issue in the magnetic fusion research. Several discharge modes with improved confinement have been achieved such as H-mode [1], supershot [2], pellet mode [3], counter-beam injection [4]. The common feature among these modes is lower recycling at the divertor plate or limiter, compared with non-improved discharges with comparable average densities. As the extreme operational mode of this type, N. Ohyabu has proposed high temperature divertor plasma operation [5,6], in which highly efficient pumping allows low recycling and hence high divertor plasma temperature of 5 ~ 10 keV. The resultant high edge temperature is expected to lead to a significant improvement in the core energy confinement. This operation requires highly efficient pumping of 20 ~ 50 % which lasts during a discharge, i.e., 5 ~ 10 seconds.

For this purpose, we have proposed a carbon sheet pumping scheme in which high energy charge exchange hydrogen atoms are implanted into the carbon sheets (two dimensionally weaved carbon composites) placed on the vacuum vessel. Overall pumping efficiency can be as high as ~ 50 %. The idea originates from A. Sagara's proposal to a small tokamak program " carbon limiter with external heater". Normally a carbon surface is saturated with hydrogen atoms and thus has no further trapping of hydrogen. This saturation level, however, decreases with increasing temperature. Figure 1 shows saturated deposition profiles of hydrogen atoms at two different temperatures, 30 C^0 and 700 C^0 [7]. This means that most of hydrogen atoms in the saturated carbon surface at low temperature will be released easily when the surface is heated up to 700 C^0, otherwise difficult. Thus after this treatment, a "cold" carbon limiter becomes a good absorber of impinging hydrogen ions and will influence tokamak discharge performance. (The basic data on hydrogen trapping-desorption properties of carbon are to be published elsewhere [7]). Unfortunately this proposed experiment was not executed.

The main drawback of this approach, if it is applied to large devices, is a short limited time of the pumping because the temperature of limiter or divertor plate surfaces exceeds ~ 700 C^0 very quickly. Instead of pumping plasma ions impinging on the small surface area of the divertor plate or limiter, carbon sheets which cover a significant portion of the vessel surface, as shown in Fig. 2., are used to trap charge exchange neutrals for hydrogen pumping. In this case, surface temperature of the carbon sheets can be maintained below 200 C^0 (acceptably low temperature for this purpose) for ~ 10 seconds, typical discharge duration time for the present large devices. We have estimated pumping efficiency of this scheme for the DIII-D divertor geometry [9] shown in Fig. 2(a), using the DEGAS code [8]. Equal number of neutral hydrogen atoms are emitted from two inner and outer divertor legs and their movements are traced until they are ionized in the plasma or trapped by the carbon sheets placed on the lower half of the vessel surface. The dominant atomic processes of hydrogen neutrals in this estimation are ionization by plasma particles and charge exchange with plasma ions. The hydrogen trapping rate of carbon depends on the energy of the impinging hydrogen atoms. The pumping efficiency, defined by a fraction of the atoms emitted from the divertor legs being trapped by the sheets, increases with increasing edge plasma temperature, as shown in Fig.2(b). The efficiency can be as high as ~ 50 % when the edge plasma temperature is greater than a few keV. High pumping efficiency at the high edge temperature is due to the fact that the ionization probability of neutral hydrogen particles relative to the charge exchange probability decreases with increasing plasma temperature. Furthermore, the hydrogen trapping rate of the carbon is high, close to 90 % at the incident energy greater than 1 keV. The pumping capacity is also high at high edge plasma temperature. This is because the average energy of the charge exchange hydrogen atoms is high and thus they penetrate deeply into the carbon sheets, thus increasing the width of the surface layer saturated with hydrogen atoms. Thus this pumping scheme is ideal for high temperature divertor operation.

The basic reason why carbon sheets are used instead of the conventional thick carbon tiles is purely technical reason. Baking thick tiles installed on the vessel, up to 700 ~ 1000 C^o is a very difficult task. The sheets can be baked easily by a direct drive of current running through them. In this context, thinner ones are better. But its temperature needs to be below, e.g., 200 C^o for maintaining a good pumping capability during a discharge, requiring a few mm thickness for an expected charge exchange neutral particle heat flux. We are working to demonstrate technical feasibility of the carbon sheet in large toroidal devices, in particular in LHD [10,11]. Since the recycling control is the key for high plasma performance in the present large devices [12] , the proposed carbon sheet pumping could become a powerful experimental tool for this purpose.

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Figure Captions

Fig.1 Saturated depth profiles of deuterium at the graphite surface when 1.5 keV deuterium ions are injected. They are measured by ERD (Electric Recoil Detection) method with 1.5 MeV He^+ ions.

Fig.2 Numerical estimation of the pumping efficiency of the carbon sheet.

(a) DIII-D divertor geometry [9] is used for the estimation.

(b) Pumping efficiency vs. Edge temperature.

For simplicity, both ion and electron temperatures are assumed to be the same (T) and uniform in the entire region including SOL or the divertor channel. The density in the SOL is assumed to be $n_S = 1.25 \times 10^1 (T(eV))^{-1.5}$ cm^{-3} . The density in the core (n_c) is 3.0×10^{13} cm^{-3} and the densities in region A and B are $(n_C + 2\, n_S) / 3$, $(2\, n_C + n_S) / 3$, respectively.

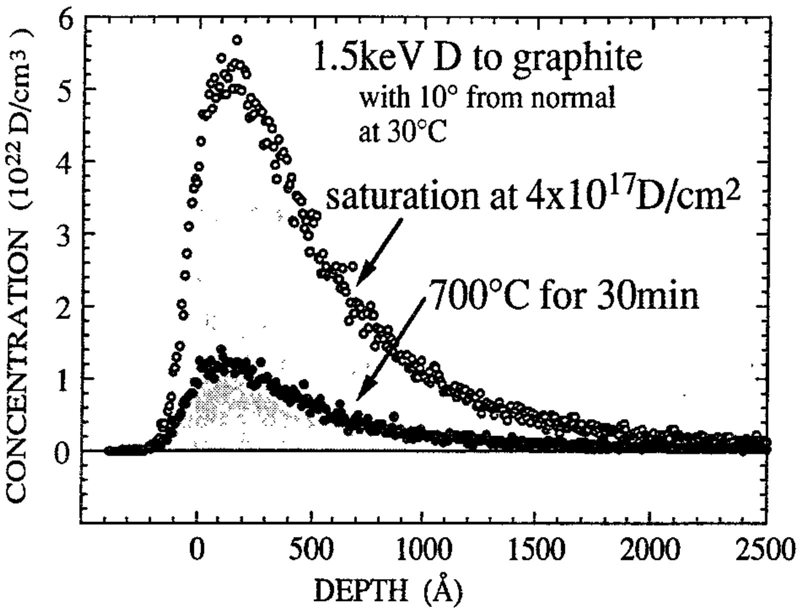
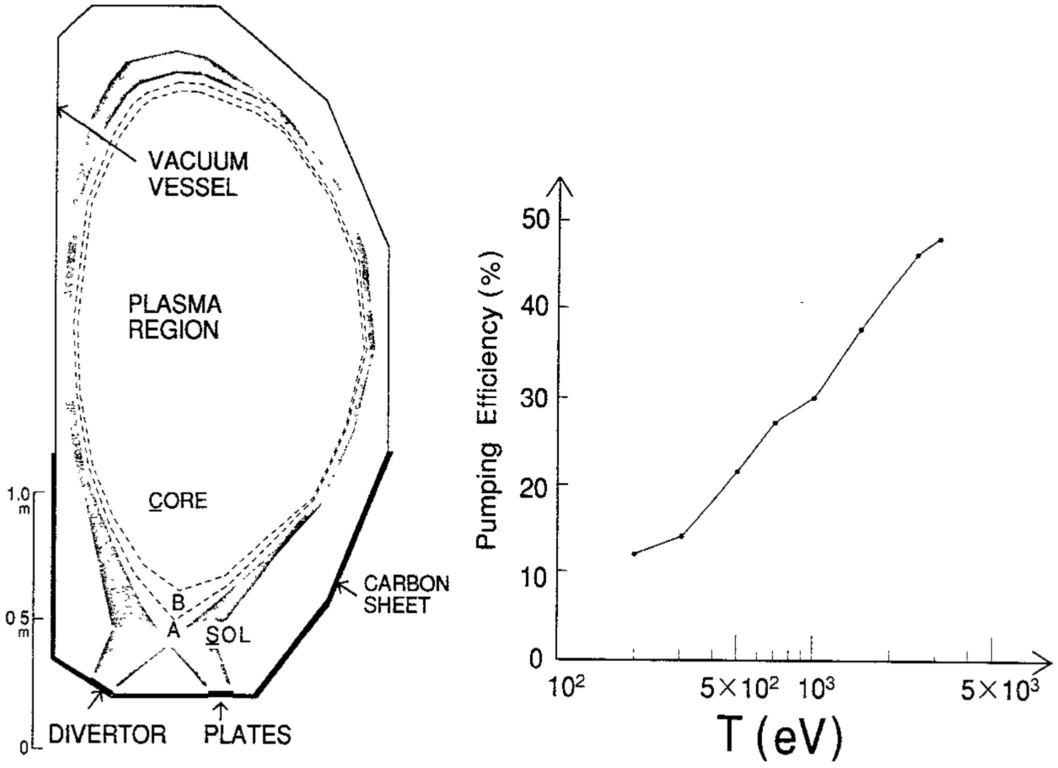

1.5keV D to graphite
with 10° from normal
at 30°C
saturation at 4x10^17D/cm2
700°C for 30min
CONCENTRATION (10^22 D/cm^3)
6
5
4
3
2
1
0
0
500
1000
1500
2000
2500
DEPTH (Å)

Fig. 1


VACUUM VESSEL
PLASMA REGION
CORE
B
A
SOL
CARBON SHEET
DIVERTOR
PLATES
1.0 m
0.5 m
0
Pumping Efficiency (%)
50
40
30
20
10
0
10^2
5×10^2
10^3
5×10^3
T (eV)

(a)

(b)

Fig. 2

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