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Simple Model for Selective Helium Pumping of Nickel

— Temperature Dependence of Helium Retention —

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Abstract

A simple model for He selective pumping of Ni, which may be applied for ash removal in a fusion reactor, is proposed to explain the temperature dependence of He retention. The He retention is determined by the balance of trapped He ions in the surface, the diffusion from the surface to bulk and the loss from the bulk due to the Ni self diffusion. In this model, explained is the appearance of maximum He retention in the domain of the irradiation temperature.

1. Introduction

Helium pumping is a major concern to obtain a long pulse DT burning in a fusion reactor. Although the helium ash may be able to be considerably removed by the divertor, the size of a fusion reactor can become smaller or the burning time period can be lengthened, if the pumping efficiency is more improved.

It is known that certain metals such as Ni, V and Cr can selectively trap the helium ions in the metal. Thus, the pumping becomes more effective if such metal is placed on the divertor region. For nickle metal, the retention of He after the exposure to mixed He/H plasmas has been measured[1)-6)]. The maximum retention was observed in the range from 400-500℃[6)]. In our experiment, the He retention had a maximum around 500-600℃[7)]. So the pumping efficiency is improved when the nickel attached on the divertor is kept in such temperature.

While the fluence or the energy dependence has been discussed so far, no detailed temperature dependence has been examined yet. In this note, we consider why the maximum of the He retention in the temperature domain appears, based on a simple model.

2. Model for Helium Retention

Considered is the He ion bombardment with the flux, ϕ_{He}, to the nickle plate with the temperature, T, as shown in Fig 1. Implanted range of He ion is denoted as δ, and the thickness of nickle bulk x. The surface He density and the bulk He density per unit area are expressed as $N_s=n_s\delta$ and $N_b=n_bx$, respectively. Here, n_s and n_b are the densities

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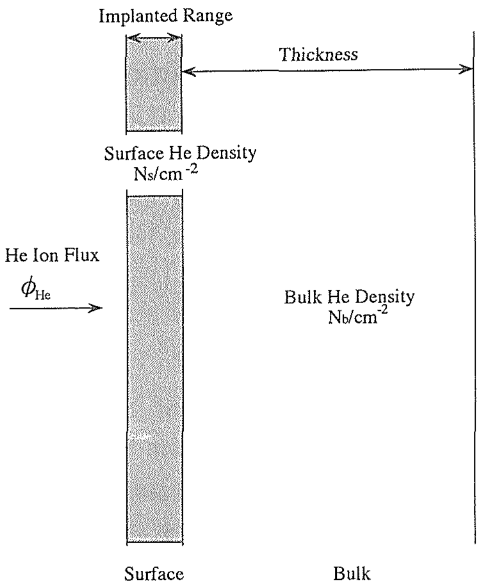

Fig. 1 Geometry considered for modeling.

per unit volumn. The total He density thus becomes

$$N_T = (N_s + N_b)/cm^{-2} \quad (1)$$

Since $\phi_{He} = n_{He}v_{He}$ is very high, of order of $10^{18}/cm^{-2}s^{-1}$, n_s reaches a saturation level within a very short time. So the value of N_s is regarded as constant for the irradiation time. If the defects are produced by fuel hydrogen ion bombardment, the saturation level may increase. In a case that the energy of He ion is large, the surface He density per unit area, N_s, increases due to the enhancement of δ. On the other hand, N_s decreases with the increase of irradiation temperature, T. This relationship has not been obtained yet, so in this study it may be assumed that

$$N_s = N_{sm}e^{-\alpha(T-RT)}/cm^{-2}, \quad (2)$$

where N_{sm} and α are the maximum at room temperature, RT, and the decay constant, respectively.

The bulk He density per unit area shall be determined by the incoming flux from the surface and the loss flux from the bulk, as shown in Fig. 2. The He flux from the surface may be apporoximated as

$$N_s\frac{D_{He}}{X^2}e^{-E_{He}/kT}/cm^{-2}s^{-1}, \quad (3)$$

where D_{He}/cm^2s^{-1}, E_{He}/eV and $k = 8.65 \times 10^{-5}/eV \cdot K^{-1}$ are the diffusion constant of He, the activation energy and the Boltzmann constant, respectively.

It is known that the trapped He be released due to the self diffusion of matrix metal, Ni[8]. Then, the trapped He will be lost within the time period of t, with the probability

$$1 - e^{-\left(\frac{D_{Ni}}{X^2}e^{-E_{Ni}/kT}\right)t}, \quad (4)$$

where D_{Ni} and E_{Ni} are the diffusion constant and the activation energy of Ni self diffusion.

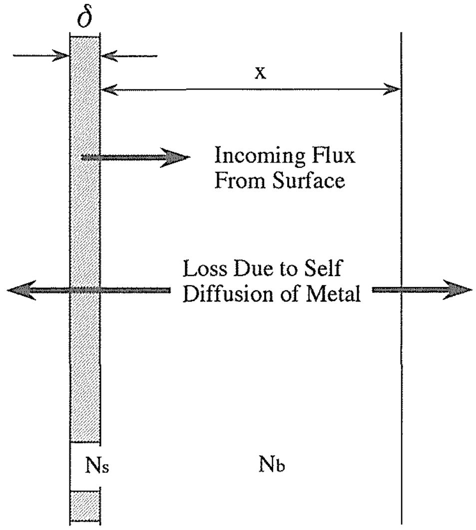

Fig. 2 Particle balance of He retention in nickel.

The probablity for the trapped He to be retained, thus, becomes

$$e^{-\left(\frac{D_{Ni}}{X^2}e^{-E_{Ni}/kT}\right)t}. \qquad (5)$$

The trapped He in the bulk during the time period of t can be written as

$$N_b=\left(N_s\frac{D_{He}t}{X^2}e^{-E_{He}/kT}\right)e^{-\frac{D_{Ni}t}{X^2}e^{-E_{Ni}/kT}}, \qquad (7)$$

Since the time constant of the self diffusion, $\tau_{Ni}=(D_{Ni}/x^2\exp(-E_{Ni}/kT))^{-1}$ is much longer than t, the term of $\exp(-D_{Ni}t/x^2\exp(-E_{Ni}/kT))$ does not rapidly drop with the time.

3. Discussions

The He retention in the surface region, N_s, and the term of self diffusion decrease, with the increase of the irradiation temperature. On the contrary, the diffusion from the surface increases with the irradiation temperature. Thus, the total He density per unit area should have a maximun to the irradiation temperature, as shown in Fig. 3.

The maximum occurs without the term of the self diffusion. But the self diffusion term shifts the maximum to lower temperature region. Since the nickle surface may be contaminated by oxygen and carbon, it is not easy to estimate the value of the He diffusion term. So the peak temperature can not be calculated due to the lack of the database. However, the appearance of the peak observed in the temperature dependence of the He retention can be explained based on the present simple model.

In summary, suggested is the model for He trapping in the metal, in which the He retained in the projected depth, the diffusion from the surface to the bulk and the loss due to the self diffusion of metal atom are taken into account. Explained is the appearance of the peak of He retention in the domain of the irradiation temperature.

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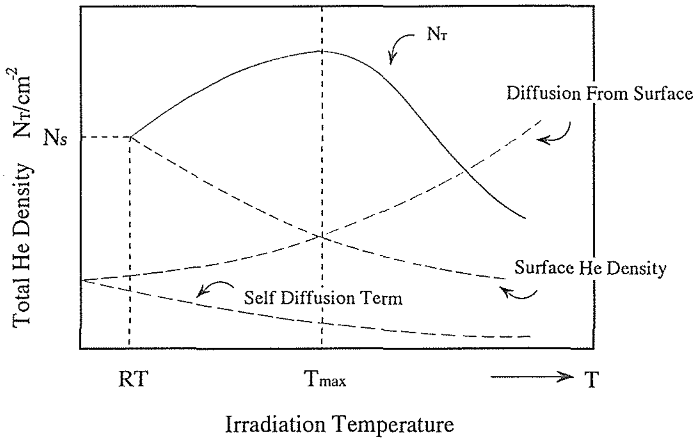

Fig. 3 Temepratature dependence of He retention.

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