Trapping rate of positrons at Frank sessile dislocations and voids in quenched aluminum

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(Received 14 July 1992)

The trapping rate of positrons at Frank sessile dislocations and voids induced in quenched aluminum is considered. The trapping rate per atomic site on the dislocation is $(2\pm1)\times10^{15}$/s at 294 K, which is ~5 times as high as that at a vacancy. The trapping rate of a void increases from 0.1×10^{17}/s to 0.5×10^{17}/s at 300 K and from 0.1×10^{17} to 1.3×10^{17}/s at 77 K as the increase of averaged void diameter from 2 to 14 nm. The trapping mechanism of a void is controlled by positron diffusion at 300 K and the effect of transitions into a void is to increase the trapping rate at 77 K.

Trapping rates and lifetimes of positrons at an *identified defect* reveal the nature of the interaction of positrons with the defect; with the electron state of the defect, the defect type, the size and density of defects in the sample under study, and so on.

Many studies have been reported on the trapping rate and the lifetime at dislocations. The trapping rates and lifetimes obtained are for mixed dislocations containing jogs in unknown concentrations since the dislocations were induced upon plastic deformation[1,2] or particle irradiation.[3] The trapping rates and lifetimes at irradiation-induced bubbles have been studied.[4,5] The irradiation-induced bubble contains He atoms which reduce the lifetimes of trapped positrons.[6] The bubbles are formed with rough surfaces which are probably decorated with impurities. We are interested in the trapping rates and the lifetimes at straight-edge dislocations and at voids surrounded by smooth surfaces.

We have already reported[7] the positron lifetime at a hexagonal loop of pure edge Frank sessile dislocations enclosing a stacking fault on a (111) plane, and that at an octahedral void surrounded by equilateral $\{111\}$ planes in quenched aluminum. The shortest lifetime τ_1 ranges from 0.030 to 0.120 ns which is shorter than the positron lifetime by free annihilation in bulk aluminum, 0.163 ns. The lifetime τ_2 is ~0.240 ns, and the longest lifetime τ_3 varies from 0.580 to 0.520 ns. The lifetimes τ_1, τ_2, and τ_3 are associated with free annihilation, annihilation at a sessile dislocation and annihilation at a void, respectively. In this paper we report the trapping rates at sessile dislocations and at voids, and consider the rate-controlling mechanism of positron trapping at these defects.

Based on the model of positron trapping by defects,[8-10] the trapping rate of positrons by a faulted dislocation loop is calculated using the relation

$$\mu_2=(I_2/\rho_d)\left[\frac{1}{\tau_1}-\frac{1}{\tau_2}\right], \tag{1}$$

where ρ_d is the number concentration of loops expressed as an atomic fraction. The rate increase is almost proportional to the mean loop diameter. The specific trapping rate of the dislocation, the rate per unit dislocation density, is calculated to be $\sim1.2\times10^{-4}$ m^2 s^{-1} and is independent of the mean loop diameter. This value is in good agreement with that reported by Hashimoto, Morita, and Kino,[1] which is $1-2\times10^{-4}$ m^2 s^{-1}.

The positron-trapping rate per *one atomic site* on the dislocation, μ_{2s}, is calculated and plotted in Fig. 1 as a function of the mean loop diameter. This specific trapping rate is $(2\pm1)\times10^{15}$ s^{-1} which is ~5 times as high as that of a vacancy.[11,12] The trapping rate of the dislocation does not depend on the temperature throughout the range 294 to 77 K.

The specific positron-trapping rate of a void is calculated using the relation

$$\mu_3=(I_3/\rho_v)\left[\frac{1}{\tau_1}-\frac{1}{\tau_3}\right], \tag{2}$$

where ρ_v is the atomic concentration of voids. The value of μ_3 increases with increasing void diameter from 2 to 14 nm as shown in Fig. 2.

Seeger[13] deduced the specific trapping rate by a defect by considering the positron diffusion and transition into the defect. Eldrup and Jensen[5] expressed the specific trapping rate of cavities using Seeger formulation as

$$\mu_3=\left[\frac{1}{Ad_v}+\frac{1}{Bd_v^2}\right]^{-1}, \tag{3}$$

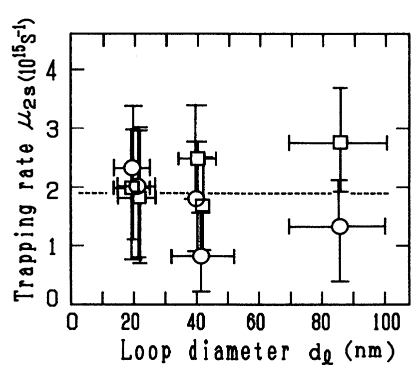

FIG. 1. The specific trapping rate μ_{2s} calculated per *one atomic site* on the Frank sessile dislocation at 300 K (squares) and at 77 K (open circles) as a function of averaged loop diameter.

where d_v is the diameter of the cavity, and A and B are

$$A = 4\pi D(T)/(2\Omega) , \quad (4a)$$

$$B = \kappa_3(T) , \quad (4b)$$

where $D(T)$ is the positron-diffusion coefficient at temperature T, Ω is the atomic volume, and $\kappa_3(T)$ is the rate of transition of positrons from the free state in the bulk to the trapped state in the cavity. The values of A and B are estimated from the size dependence of μ_3 shown in Fig. 2. The results are $A = (5\pm2)\times10^{15}/(\text{nm s})$ and $B = (4\pm3)\times10^{16}/(\text{nm}^2\,\text{s})$ at 294 K and $A = (15\pm3)\times10^{15}/(\text{nm s})$ and $B = (1.0\pm0.7) \times10^{16}/(\text{nm}^2\,\text{s})$ at 77 K. The value of A increases while that of B decreases as the temperature changes from 294 to 77 K. The increase of A and the decrease of B at low temperature are reasonably well understood from the increase of diffusion rate and the decrease of transition rate as the temperature decreases. Trumpy and Bentzon[14] have shown that the transition-limited positron-trapping rate decreases linearly with the temperature decrease. The present result on the temperature dependence of B is qualitatively consistent with their conclusion. At 294 K, the controlling mechanism of the positron trapping is mainly diffusion, since $Ad_v \ll Bd_v^2$ for voids whose diameters are between 2 and 14 nm. At 77 K, Ad_v approaches Bd_v^2 for the diameter $d_v \leq 2$ nm. The transition mechanism increasingly affects the trapping rate at low temperature.

The value of A at 294 K is about one order of magnitude lower than that for the He bubble $[90.7\times10^{15}\times\frac{1}{2}/(\text{nm s})]$ obtained by Jensen *et al.*[4] The discrepancy may arise from a different distribution of dislocations coexisting with voids or bubbles. In the present study, voids are contained within faulted dislocation loops which are spatially isolated. On the other hand, the He bubbles studied by Jensen *et al.*[4] coexist with dislocations which are supposed to be tangled. The diffusion of a positron is considered to be affected by the dislocation.

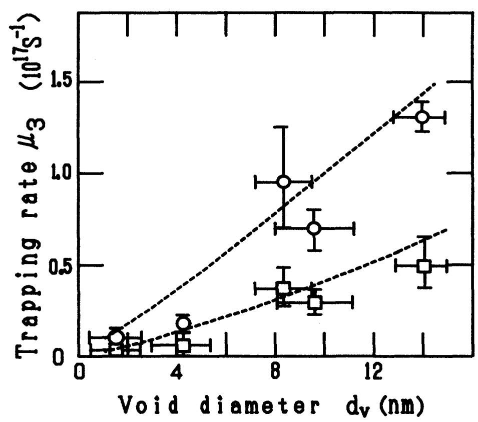

FIG. 2. The trapping rate of a void at 300 K (squares) and at 77 K (open circles) as a function of average void diameter.

In conclusion, we note the following.

(1) The positron lifetime at a sessile dislocation is 0.239 ± 0.010 ns.[7]

(2) The lifetime of positrons trapped in a void varies from 0.520 ± 0.020 to 0.580 ± 0.020 ns as the averaged void diameter decreases from 14 to 2 nm.[7]

(3) The positron-trapping rate of sessile dislocations per one atomic site is 2×10^{15}/s which is $\sim$5 times as high as that of a vacancy.

(4) The trapping by a void is mainly controlled by the diffusion mechanism at 294 K, and that for a small void is increasingly affected by the transition mechanism as the temperature decreases.

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