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Positron Lifetime as a Function of Grain Size

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Abstract. Published data on positron annihilation lifetime in copper as a function of grain size have been analyzed to show that there is a linear relationship between the internal grain boundary surface area, per unit volume, S_V, and the positron lifetime, τ. The analysis indicates that grain boundaries are important in the trapping of positrons. It is suggested that the slope of the resulting straight line, $dS_V/d\tau$, can be used to determine the annihilation rate of the grain boundaries.

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A number of positron annihilation experiments have been performed on metals both in the annealed and the cold worked state. Usually, polycrystalline specimens have been used in these experiments. When using such specimens, one has to deal with substantial grain boundaries that are internal to the specimens. A grain boundary is a region of disorder that may have a substantial dislocation density; the kinds of dislocation depend on whether the boundary is tilted (edge), twisted (screw), or mixed (both). This applies to low and medium angle boundaries; for higher-angle boundaries, other models have been proposed. Regardless of the type of model, a grain boundary is a region of high chemical potential, as shown by metallographic etching.

Lynn et al. [1] measured the positron lifetime in specimens of polycrystalline copper that had three mean grain sizes in the well-annealed state and after deformation. The well-annealed specimens showed evidence of having different lifetimes depending on grain size. Because the authors did not describe their method for measuring grain size, it is assumed that they used the accepted grain boundary intercept method. The mean grain diameter, which is usually obtained and used to define grain size, can be calculated by using the following relationship [2]

$$d = L_T/P$$

in which d is the mean diameter (grain size), L_T the total length of the test line, and P the number of grain boundary intersections the test line makes.

One can also write [2]

$$S_V = 2P/L_T \tag{2}$$

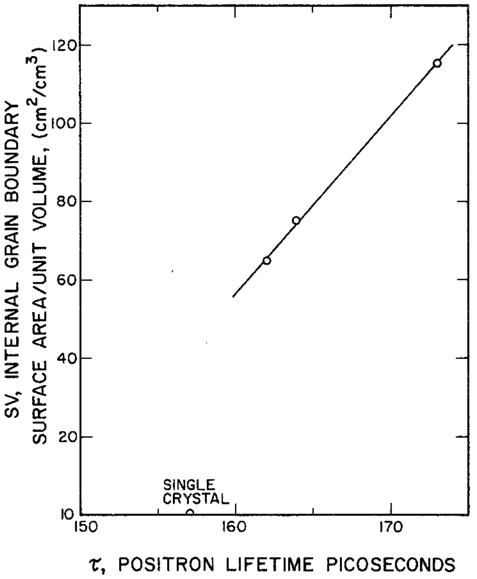

Fig. 1. Plot of grain boundary surface area/unit volume vs positron lifetime. After Lynn et al. [1]

in which S_V is the grain boundary surface area per unit volume. By combining (1) and (2), we obtain

$$S_V = 2/d\,. \tag{3}$$

By taking the data for the average size d, and calculating S_V, one obtains a curve (Fig. 1) when τ, (the positron lifetime) is plotted vs S_V. The positron lifetime for a single crystal can be plotted if S_V is assumed to be zero. The resulting curve has a straight line relationship, which indicates that grain boundaries are indeed regions of disorder where positrons can be trapped and given longer lifetimes. The slope of this curve, $ds_V/d\tau$, should allow one to calculate an annihilation rate for the grain boundary areas per unit volume. For a given specimen, if one knows the volume that is exposed to the positron source, he can calculate the annihilation rate per unit area of the grain boundary.

Because Lynn et al. [1] did not indicate the method they used to obtain the grain size, there may be a systematic error in the analysis presented here. The size of the error would depend upon the method these authors used to determine grain size. In effect, the error results in a constant factor, which would be multiplied by S_V. The result would then change the slope of the straight line curve shown in Fig. 1 and after the value of $ds_V/d\tau$.

References

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2. E.E. Underwood: *Metals Handbook*, Vol. 8., 8th ed. (Am. Soc. for Metals Park, Ohio (1973) 37