I. 3. An Empirical Rule for Preparation of $^{111}$In PAC Source by Thermal Methods

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Introduction

Preparation of the radioactive source is one of the most important steps for the application of PAC spectroscopy to various topics in various fields. In the application of the spectroscopy for topics in materials science as well as in solid state physics, the present author has developed a melting method that originally has been devised by a Krakow-Göttingen group\(^1\). The technical detail has already been reported in the 1998 issue of the CYRIC report by the present author\(^2\).

This paper reports an empirical rule for the $^{111}$In source preparation for PAC spectroscopy in metallic elements by the melting method as well as diffusion methods, namely, by thermal methods. These thermal methods are superior to the implantation method or the nuclear reaction method, since no accelerator is necessary and also the radioactivity yield has been found quite high.

An Empirical Rule for $^{111}$In PAC Source Preparation

Fig.1 shows the maximum $\alpha$ solid solubility of In in elements as a function of the atomic number for the period 3 (Na-S) to the period 6 (Cs-Bi) as well as for the rare earth group (La-Yb)\(^3\).

Fig.1 immediately reveals that there are two maximum in the solid solubility. Namely the first is centered at the IVB family (Ti,Zr,Hf) and the second is at the VIII family(Ni,Pd,Pt). For those elements with a high solid solubility for In, several experimental trials have shown that $^{111}$In -PAC specimens can be prepared easily by a diffusion method. Namely, with applying $^{111}$In chloride solution on the surface and annealing them at temperatures of 0.5-0.7 Tm (Tm: the melting point) in a vacuum or preferably in hydrogen atmosphere, a very high activity can be introduced in the specimen. As will be shown in several following papers, the diffusion method is also useful to rare earth metals (Gd,Dy,Tb,Er) which also have a high solid solubility for In. So one can conclude that the In solid solubility in the element is a good measure whether $^{111}$In-PAC specimen can be prepared by a diffusion method. The only exception experienced by the present author is
V, where $^{111}$In was found not to diffuse in despite of the relatively high solid solubility.

For those elements with the null or low solubility (Si, Fe, Co...), the diffusion method does not work with the negligible $^{111}$In activity in the specimens after the treatment. The melting method, however, does work for those elements with a reasonably high activity after the treatment for PAC spectroscopy. Also the method has an advantage to prepare alloy specimens at the same time with the $^{111}$In introduction. So PAC spectroscopy has been performed in several binary alloys (Fe, Ni, Si-alloys) and have already been reported5.

This melting method has been extended to Ni-C alloys, many kind of Ni-substitutional alloys, a Si-Cu alloy with the Cu, Si composition, rare earth elements (Nd, Sm, Gd, Tb, Dy, Ho, Er and Tm) and several of their binary alloys. Part of the results of PAC spectroscopy on these systems will be reported in several papers in this volume.

Though the diffusion method works for the elements with the high In solubility, the melting method has an advantage that the $^{111}$In yield is much higher. This enables us to study many systems with a limited amount of $^{111}$In solution (5mCi/ml specific activity) with the application of the melting method. Namely, only 0.01ml of it is required for Ni or rare earth elements with the high enough $^{111}$In activity for the PAC spectroscopy.

During the alloy studies by the melting method, it was noticed that the $^{111}$In activity yield depends on the combination of the elements. The combination of a high In solubility host (HH) and a high solubility solute (HS) has shown a quite high yield. The combinations of HH and a low solubility solute (LS) or LH-HS combinations have shown a reasonably high yield. The LH-LS combinations have shown a low yield though the activity was found high enough for the PAC spectroscopy.

Some Results on Low Melting Point Elements

The melting method also works for elements with the low melting point. Fig. 2 shows the PAC spectrum for Sn, Mg and Zn after the melting method. For Sn, the diffusion method has also been applied for comparison. Since these elements have crystal structures different from the cubic (Mg, Zn: hexagonal, Sn: tetragonal), an EFG should be present at the substitutional site. Indeed, precession signals have been observed in these elements as in Fig. 2 when the specimens are prepared by the melting method. The diffusion method seems not to work as shown by the Sn result where only a flat spectrum is observed suggesting $^{111}$In atoms remain on the surface.

As will be shown in the following several reports, the melting method is quite useful to prepare the PAC source with a reasonable cost, labor and short preparation time. With the application of electron beam or high power laser, the method will be extended to elements with the high melting points as W or Ta.
References


Fig. 1. $\alpha$ maximum solid solubility of In in elements.
(Compiled from "Binary Alloys Phase Diagram" ed. by Massalski)

Fig. 2. $^{111}$In-PAC spectrum for Sn, Mg and Zn prepared by the melting method. For comparison, the spectrum for Sn prepared by a diffusion method is also shown (top).