II. 1. Confirmation of Energy Dependence of the Yield of Parent Type Species in Recoil-Implanted Tris(β-diketonato)chromium(III)

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Introduction

It is well known that an implantation method has been successfully applied to prepare semiconductors. The physical description of implanted atoms such as the range distribution was already reported by many research groups. However, knowledge on chemical aspects of implanted atoms is still poor. The authors' group has applied a recoil implantation technique by using nuclear reactions to synthesize new compounds which could not be easily prepared by normal chemical procedures\textsuperscript{1,2}, and has also investigated the chemical reaction of high energy atoms in a solid phase.

Previously\textsuperscript{3}, an increase of substitution yield of the central metal atom by an implanted atom in tris(acetylacetonato)iron(III) (Fe(acac)\textsubscript{3}) was observed as implantation energy increased, and the yield reached a saturation value at comparatively higher energy region (about 100 keV). This phenomena could not be explained by considering ordinary hot atom reaction. It was also found that the energy region concerned to the yield increase corresponded to that in which a recoil atom mainly lost its kinetic energy by an elastic collision process. Therefore, it is strongly suggested that an atomic collision process affects the final chemical reaction of an implanted atom.

In order to examine this implantation energy dependence on the substitution yield, the results in other catchers, tris(dipivaloylmethanato)iron(III) (Fe(dpm)\textsubscript{3}) and tris-(trifluoroacetylacetonato) iron(III) (Fe(tfa)\textsubscript{3}), are presented in this report.

Experimental

The preparation method of irradiation sample is almost the same as reported before\textsuperscript{3}. A vanadium film as a recoil source was deposited onto aluminum foil, about 10μm thick, by vacuum evaporation. As a catcher material, Fe(dpm)\textsubscript{3} and Fe(tfa)\textsubscript{3}, synthesized by ordinary procedures, were put onto the vanadium film by vacuum sublimation. The thickness of
recoil source was determined by measuring an absorption spectrum as VO$_4^-$ ion by the method reported by Telep et al.$^{4}$

The proton irradiation was performed by using 15 MeV protons accelerated by an AVF cyclotron at Cyclotron and Radioisotope Center, Tohoku University. The $^{51}$V(p,n)$^{51}$Cr reaction was used for recoil implantation. The current was about 1 μA, and the target temperature was kept under -100 °C by blowing He gas chilled by liquid N$_2$ during irradiation$^5$ to prevent annealing effects by increase of target temperature. The sample was kept in Dry Ice until chemical separation.

The chemical separation was done as follows. The catcher was washed off with benzene, and $^{51}$Cr(β-dik)$_3$ produced by substitution of central metal atom was separated from other chemical species by silica gel column chromatography. The recoil source was dissolved in conc. HCl. The $^{51}$Cr radioactivity in each fraction was determined by using a Ge semiconductor detector with 4k PHA. The measuring time was about 1000 - 50 000 seconds.

**Results and Discussion**

In Fig. 1, the substitution yield in each complex is plotted against average kinetic energy when a recoil atom was implanted into a catcher (MIE denotes mean implantation energy). This yield is defined as a percent of the amount of $^{51}$Cr(β-dik)$_3$ normalized to the total amount of $^{51}$Cr in the catcher. The tendency of the yield increase is clearly observed in the energy region of about 30 - 40 keV for the catcher complexes of Fe(dpm)$_3$ and Fe(tfa)$_3$, as in the case of Fe(acac)$_3$ previously reported$^3$. The yields saturate at the energy region of about 100 keV, which could not be easily expected by the knowledge of classic hot atom chemistry that mainly concerned with a retention value given after some nuclear transformation events. The saturation yield shows a different value for a different catcher complex, as was previously recognized. The yields are in good agreement with the reported ones$^6$. The difference of the saturation yields among catchers can be explained by the difference of stabilities of those catcher complexes against energy deposition by a recoil atom.

It is worthwhile noting that each substitution yield increases at almost the same implantation energy region (30 - 40 keV) although a catcher complex consists of different ligands. In the case of Fe(acac)$_3$ complex, it was previously recognized that this energy region corresponded to the same region in which an elastic collision (characterized by nuclear stopping power, $S_n$) dominantly took place rather than an electronic collision (characterized by electronic stopping power, $S_e$) in the stopping processes of $^{51}$Cr in Fe(acac)$_3$.

Similar calculation procedure was carried out to estimate the stopping behavior for the combination of the recoil atom $^{51}$Cr and the catcher complexes of Fe(dpm)$_3$ and Fe(tfa)$_3$. It shows almost the same stopping behavior in both Fe(dpm)$_3$ and Fe(tfa)$_3$ compared with that
in Fe(acac)$_3$, because chemical composition, which is needed for the calculation, is not so
different between them. In fact, carbon, oxygen and hydrogen are the main elements
involved in the catcher complexes, and it does not affect the result of calculation so much.
Thus, almost the same energy region can be given for the catchers in which an elastic
collision occurs predominantly, and the significant increase in the substitution yield is
observed in this energy region for each complex. The concordance of the energy regions for
different catchers leads to the following reasoning. A disturbed area created by an elastic
collision of a recoil atom probably promotes the final substitution reaction of a central metal
atom.

Thus, we have confirmed the energy dependence of implantation reaction yield which
could be connected with nuclear stopping processes. The forthcoming paper$^7$) deals with the
clear contrast of implantation reaction to ordinary hot atom reaction; the specific aspects of
implantation reaction will be further described.

Acknowledgement

The authors thank to the crews of the Cyclotron and Radioisotope Center, Tohoku
University for their operation of the Cyclotron.

References

4) Telep G. and Boltz D. F., Anal. Chem. 23, 6 (1951) 901.
   (in press).
Fig. 1 The MIE dependences of the substitution yields obtained by the implantation of $^{51}$Cr atom into Fe(acac)$_3$, Fe(dpm)$_3$ and Fe(tfa)$_3$. 