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Study of high-spin states in the ^{48}Ca region by using secondary fusion reactions

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Abstract. An in-beam gamma-ray spectroscopy study, following a fusion reaction induced by a neutron-rich secondary beam, ^{46}Ar + ^{9}Be, is presented. A low-energy secondary beam of ^{46}Ar at ~ 5 MeV/A was developed in order to induce fusion reactions. Gamma-gamma coincidence and excitation function analysis was performed to study high-spin states in the vicinity of ^{48}Ca, $^{49-52}$Ti .

PACS. 25.60.Pj Fusion reactions – 29.30.Kv X- and γ-ray spectroscopy – 23.20.Lv γ transitions and level energies – 27.40.+z $39 \leq A \leq 58$

1 Introduction

In-beam gamma-ray spectroscopy using fusion-evaporation reactions has been one of the most efficient methods for the study of nuclear structure at high spin since large angular momentum can be brought into the system. However, nuclei produced by fusion-evaporation reactions using stable isotopes are limited in many cases to the proton rich side of the β-stability line. Therefore, in order to study high-spin states of neutron rich nuclei by means of heavy ion induced fusion reactions, it is necessary to use neutron-rich secondary beams. In ^{48}Ca and ^{50}Ti, the presence of deformed shell gaps at $Z = 20$, 22 and $N = 28$ is expected to result in deformed collective states at high spin similar to the observed superdeformed band in ^{40}Ca [1]. In this article experimental results for the high-spin study of $^{49-52}$Ti via a secondary fusion reaction, ^{46}Ar + ^{9}Be, are presented.

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2 Experimental results

High-spin states in $^{49-52}$Ti have been populated following a fusion-evaporation reaction induced by a low-energy ^{46}Ar beam of ~ 5 MeV/A, which was produced at the RIPS Facility [2] in RIKEN via fragmentation reactions. A primary ^{48}Ca beam with an energy of 63 MeV/A, provided by the RIKEN Ring Cyclotron, with a maximum intensity of 100 pnA bombarded a ^{9}Be target of 1.0 mm thickness. An aluminum wedge energy degrader with a mean thickness of 221 mg/cm^2 placed at the momentum-dispersive focal plane (F1) was used to achieve a clear isotope separation and to lower the energy of the fragments to ~ 30 MeV/A. By operating RIPS at the maximum values of momentum acceptance and solid angle, a typical beam intensity of 7.3×10^5 particles per second was obtained at the achromatic focal plane (F2). Particle identification of the secondary beam was performed by the time-of-flight (TOF)-ΔE method. The purity of the ^{46}Ar beam was measured to be 90%.

The energy of the ^{46}Ar beam was further lowered by using an aluminum rotatable degrader of 0.5 mm thickness at F2 and measured to be 4.1 ± 0.9 MeV/A. The ^{46}Ar beam was transported to the final focal plane (F3)

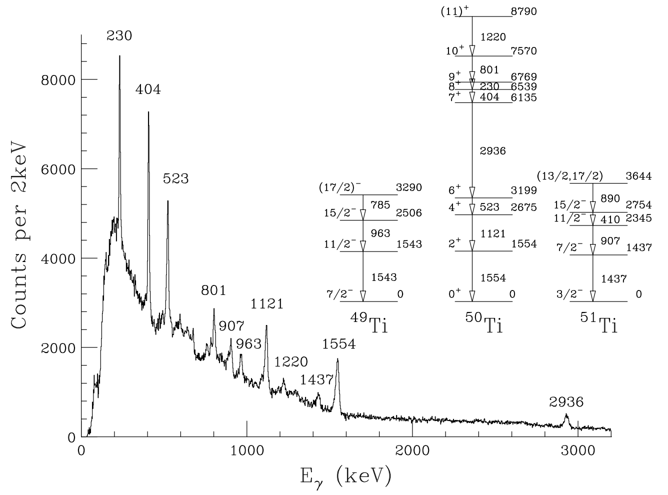

Fig. 1. Gamma-ray spectrum obtained in the reaction, ^{46}Ar + ^{9}Be.

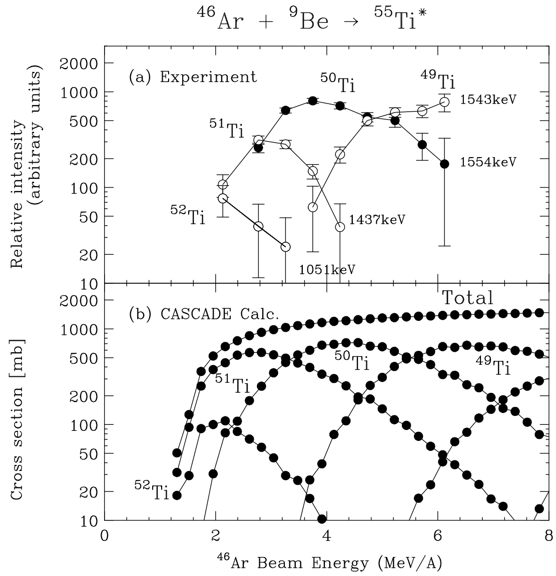

Fig. 2. (a) Normalized gamma-ray yields gated by different energy intervals of ^{46}Ar beam. (b) Cross-section for $^{49-52}$Ti production as a function of incident beam energy in the ^{46}Ar + ^{9}Be reaction calculated by the statistical model code, CASCADE.

and irradiated on the secondary ^{9}Be target of 10 μm thickness in order to induce the secondary fusion reaction. The beam spot size on the secondary target was measured to be 39 mm and 19 mm (FWHM) in the horizontal and vertical directions, respectively. The intensity of the ^{46}Ar beam at F3 was about 3.2×10^5 particles per second.

Gamma rays emitted in the fusion-evaporation reaction were detected using the GRAPE system [3] consisting of 17 Ge detectors in this experiment. Each detector contains two cylindrical-shaped planar Ge crystals and each crystal is electrically segmented in nine pieces. These detectors were placed around the secondary target to cover the angles between 60° and 120° relative to the beam axis. Two PPAC counters [4] placed at the up stream of the target as well as the TOF between the plastic scintillator signal at F2 and the PPACs provided beam profile information containing the position, incident angle, and energy of the beam. These were used for Doppler correction as shown in fig. 1. Gamma rays emitted from excited states in ^{49,50,51}Ti [5,6,7] are clearly observed.

The energy of the ^{46}Ar beam is distributed between 2 and 7 MeV/A due to the energy straggling after passing through the degraders and beam counters. By utilizing this broad energy range of the beam, an excitation function measurement was performed by gating on the different regions of the beam-energy spectrum. Under the assumption that all gamma-ray cascades decay through the first yrast state of each nucleus, the relative gamma-ray intensity of these transitions in the Ti products, normalized by the beam intensity, is plotted as a measure of the excitation function in fig. 2(a). Figure 2(b) shows a calculated cross-section for $^{49-52}$Ti production in the ^{46}Ar + ^{9}Be reaction as a function of the incident beam energy. The statistical model code, CASCADE [8] was used for the calculations. The peak position of the measured excitation function curve for ^{50}Ti is about 0.6 MeV/A lower than the CASCADE prediction. The angular momenta brought into the compound nucleus were estimated, by the Bass model calculations [9], to be $\sim 21\hbar$ and $\sim 25\hbar$ at the ^{46}Ar beam energy of 3.0 MeV/A and 5.0 MeV/A, respectively. By taking this and the observed gamma-ray yield into account, an optimum beam energy to produce high-spin states $\geq 16\hbar$ in ^{50}Ti will be $\sim$ 4.0 MeV/A.

3 Summary

A method to study high-spin states in the ^{48}Ca region by using a fusion-evaporation reaction with a neutron-rich secondary beam was presented for the first time. A low-energy ^{46}Ar beam was developed in order to induce the fusion reactions. Gamma rays following the secondary fusion reaction, ^{46}Ar + ^{9}Be, were successfully observed and high-spin levels up to $11\hbar$ were identified in ^{50}Ti. An excitation function measurement was performed simultaneously utilizing the energy spread of the secondary beam. This method will open new regions for the study of high-spin states in neutron rich isotopes presently not accessible with conventional fusion-evaporation reactions with stable isotopes.

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