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Search for chiral bands in $A\sim110$ neutron-rich nuclei*

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Abstract High spin states in $A\sim110$ neutron-rich ^{106}Mo, ^{110}Ru and ^{112}Ru nuclei have been reinvestigated by measuring the prompt γ-rays from the spontaneous fission of ^{252}Cf. Two similar sets of bands are observed to high spins in each of three nuclei. Through analyzing of characters of the band structures, the chiral doublet bands are suggested in ^{106}Mo, ^{110}Ru and ^{112}Ru.

Key words nuclear structure, high spin states, triaxiality, chiral doublet bands

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1 Introduction

In research on nuclear structure, to investigate the chiral doublet bands is a very interesting topic in recent years. According to the theoretical model[1], when a nucleus has a triaxial shape with significant deformation, and a pair of unpaired nucleon angular momenta are along both the shortest principal axis (particle) and longest principal axis (hole), and the collective rotational angular momentum of the core is along the axis of intermediate length, the chiral symmetry breaking may occur, and the chiral doublet bands may be observed. In experimental studies, the chiral doublet bands have been reported in several nuclei in $A\sim130$ and $A\sim100$ neutron-deficient nuclei, such as, in ^{134}Pr[2], ^{136}Nd[3], ^{104}Rh[4] and ^{106}Ag[5].

In the previous works, it indicated that some $A\sim110$ neutron-rich Mo, Ru isotopes show triaxial shapes. To search for the chiral doublet band structures in this region is very important. In the recent years, great progress in research on the high spin states in neutron-rich nuclei around $A\sim110$ and 140 regions has been made[6]. In the previous reports, we have published some high spin states in ^{106}Mo[7], ^{110}Ru[8] and ^{112}Ru[9]. Here we report on the new chiral doublet band structures in ^{106}Mo, ^{110}Ru and ^{112}Ru by our recent research. The primarily result of chiral doublet bands for ^{106}Mo was briefly reported in a conference paper[10].

2 Experiment and results

The high spin states in ^{106}Mo, ^{110}Ru and ^{112}Ru were studied by measuring the prompt γ-rays in the spontaneous fission of ^{252}Cf. The experiment was carried out at the Lawrence Berkeley National Laboratory. The Gammasphere detector array which, for this experiment, consisted of 102 Compton-suppressed Ge detectors, was employed to detect the γ-rays. A total of 5.7×10^{11} triple- and higher-fold γ-coincidence events were collected. The coincidence data were analyzed using the RADWARE software package[11].

The partial level schemes of ^{106}Mo, ^{110}Ru and ^{112}Ru obtained by our present work are shown in Figs. 1—3, in which only the two sets of bands with

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bands (1) and (2) labeled on top of the schemes are shown in each nucleus. Some levels of the ground bands and one phonon γ-bands in ^{106}Mo, ^{110}Ru and ^{112}Ru, as well as the two phonon γ-band in ^{106}Mo are also shown in the figures in order to see the de-excitation transitions from the bands (1) and (2). The details of the ground bands and the γ-bands can been found in Refs. [7—9]. Partial levels and structures of the bands in ^{106}Mo, ^{110}Ru and ^{112}Ru showed in Figs. 1—3 have been observed in Refs. [7—9], but here we update and expand them. Furthermore, we recently have made γ-$\gamma(\theta)$ angular correlation measurements described in Ref. [12] to determine the spins and parities of some levels in ^{106}Mo, ^{110}Ru and ^{112}Ru which are not done in our previous works[7—9].

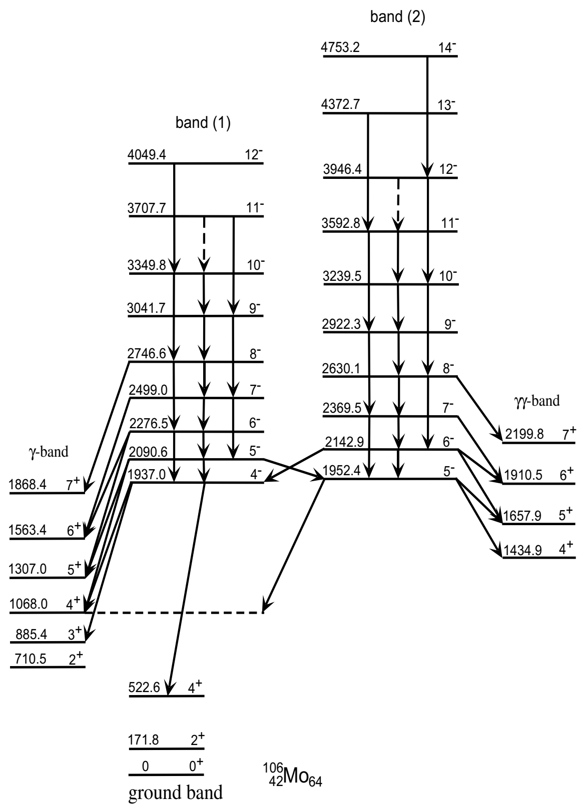

Fig. 1. Partial level scheme of ^{106}Mo.

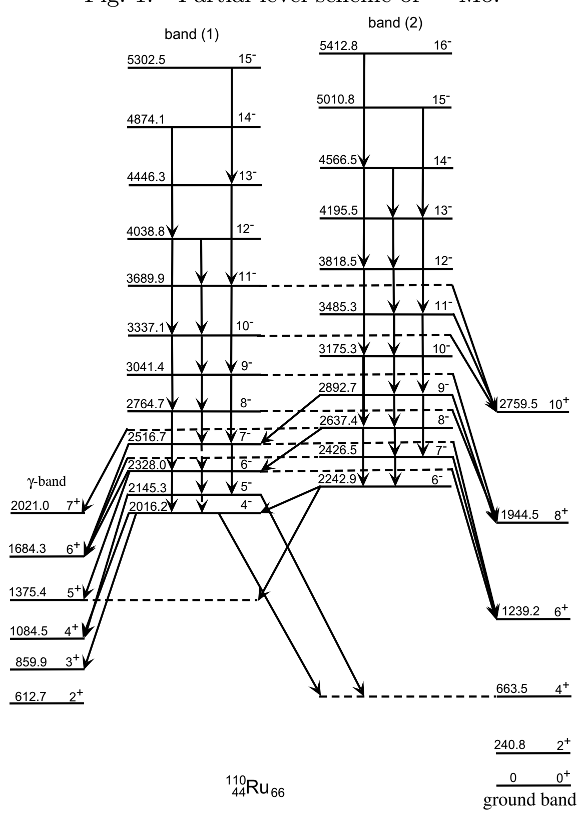

Fig. 2. Partial level scheme of ^{110}Ru.

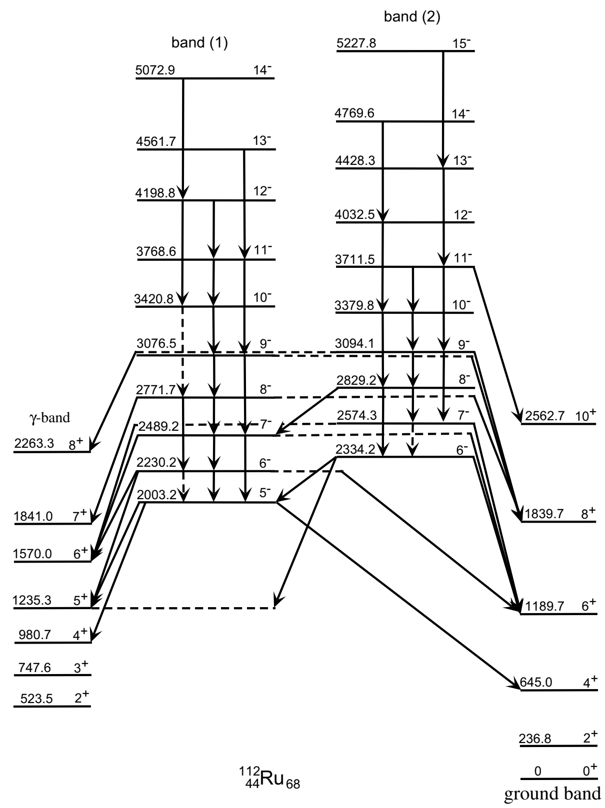

Fig. 3. Partial level scheme of ^{112}Ru.

3 Discussion

From Figs. 1—3, one can see that the two similar sets of bands (1) and (2) are observed to high spins in ^{106}Mo, ^{110}Ru and ^{112}Ru, and they have similar structural characters. We propose that they belong to chiral doublet bands.

In our previous reports, we have indicated that the ^{106}Mo, ^{110}Ru and ^{112}Ru have triaxial shapes which are the basic conditions for the chiral doublet bands. Then the proposed chiral doublet bands in even-even ^{106}Mo, ^{110}Ru and ^{112}Ru with higher excitation energies of the band head levels should originate from two quasi-particle configurations. As the two quasi-proton states lie at higher energy than the two quasi-neutron states, so these doublet bands are interpreted as two quasi-neutron excitations. We propose that these chiral bands in even-even nuclei are with configurations of the $\nu h_{11/2}$ (particle state) and the $\nu d_{5/2}$ (mixed with the $g_{7/2}$) (hole state), that is, $\nu h_{11/2}\otimes[d_{5/2}/g_{7/2}]^{-1}$.

We have carried 3D-Tilted Axis Cranking (TAC) calculations. The calculations show that the angular momentum of the $d_{5/2}/g_{7/2}$ neutron hole is strongly aligned with the long axis, and the angular momentum of the $h_{11/2}$ neutron lies in the short- intermediate plane. It prefers the direction of the short axis, but not very strongly. The remaining ("core") angular momentum prefers the intermediate axis. The calculations indicated that the bands (1) and (2) ^{106}Mo belong to a type of new chiral doublet bands, that is, they are zero- and one-phonon chiral vibrational bands respectively. For the ^{110}Ru and ^{112}Ru, they have similar characters.

Table 1. Experimental branching ratios of the E2 to M1(E2) transitions.

spin	^{106}Mo		^{110}Ru		^{112}Ru	
	band(1)	band(2)	band(1)	band(2)	band(1)	band(2)
12	>6.0	>4.8	>4.4	6.4	>4.0	5.1
11	4.7	>3.9	9.2	11.4	7.0	5.6
10	6.8	8.5	5.9	4.9	5.7	7.0
9	8.3	5.8	6.9	7.9	10.4	8.3
8	6.4	2.7	3.3	3.4		4.2
7	3.2	1.3	2.6			

Our calculations were made further test whether our observed $\Delta I=1$ doublet bands in ^{106}Mo, ^{110}Ru and ^{112}Ru could be accidentally degenerate bands from the coupling of an $h_{11/2}$ neutron to other single-neutron orbitals. The calculations show that in all cases, the B(E2)/B(M1) ratios of the two lowest bands differ typically by one order of magnitude. The experimental branching ratios of E2 to M1(E2) transitions within the two sets of doublet bands in ^{106}Mo ^{110}Ru and ^{112}Ru are given in Table 1. It shows that the equal order of magnitude in bands (1) and (2) in these nuclei. The clear disagreement of the calculated B(E2)/B(M1) ratios based on various quasi-particle configurations with the experimental data is strong evidence that these doublet bands do not arise from the couplings of different quasi-particle configurations which are just accidentally degenerate. It indicates that the doublet bands in each nucleus have very similar structures as required for chiral doublets.

Varman et al.[4] pointed out a test for chiral bands in which $S(I)=1/(2J_1)=[E(I)-E(I-1)]/2I$, where J_1 is the kinetic moment of inertia, should be constant and identical with I for two chiral bands. The $S(I)$ values for ^{106}Mo, ^{110}Ru and ^{112}Ru are shown in Fig. 4. They are much more constant and more equal than found for this reported 'best' case of chiral bands in ^{104}Rh[4]. The TAC calculations also predict a constant J_1.

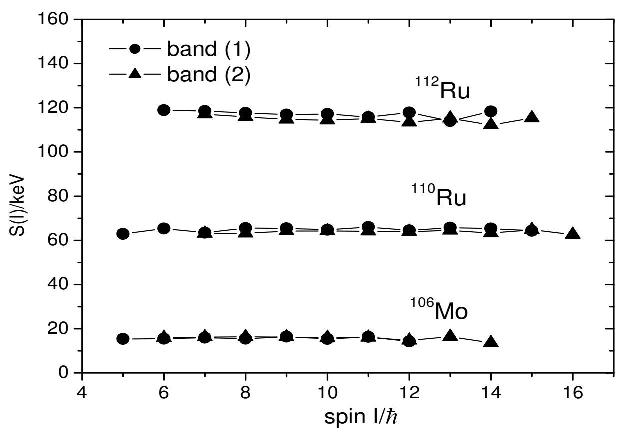

Fig. 4. $S(I)$ for ^{106}Mo, ^{110}Ru and ^{112}Ru. The energy values are separated by 50 keV for display between nuclei.

The research on the energy differences between the levels with the same spin and the variations of excitation energies $E(I)$ vs. spin I for bands (1) and (2) in ^{106}Mo, ^{110}Ru and ^{112}Ru comparing with the chiral doublet bands in ^{104}Rh also were carried out. All the results show the chiral characteristics in these three even-even nuclei.

4 Summary and concluding remarks

High spin band structures in ^{106}Mo, ^{110}Ru and ^{112}Ru have been studied. A pairs of band structures in each nucleus have been observed. These bands are proposed as the chiral vibrational bands.

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