High spin states in neutron-rich ^{106}Tc nucleus*

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Abstract The high spin states of the neutron-rich odd-odd ^{106}Tc nucleus have been reinvestigated by observing prompt γ-rays from the spontaneous fission of ^{252}Cf. A previously known collective band is confirmed and expanded, and a new collective band is newly identified. Several levels in previous report in ^{106}Tc are reexamined and they belong to the members of a band in ^{107}Tc. The total Routhian surface (TRS) calculations show that the ^{106}Tc has triaxial shape. The spins and parities as well as the configurations for these bands have been tentatively assigned according to the analysis of the angular momentum alignments.

Key words spontaneous fission, collective band, γ-transition and level energy

PACS 25.85.Ca, 21.10.Re, 23.20.Lv

1 Introduction

Research on the high spin states in neutron-rich nuclei at $A\sim100$ region is an interesting subject for theory and experiment, for examples, the sudden onset of large quadrupole deformation[1, 2], the superdeformed ground state[2, 3], the triaxial deformation in Mo and Ru isotopes[4, 5] etc.. So far, the high spin states in many even-even nuclei and odd-A nuclei in this region have been investigated, but the data for the odd-odd nuclei are still scarce.

For the neutron-rich Tc isotopes, in the previous reports, the high spin states of several odd-A nuclei have been studied carefully and some collective bands have been established, such as in ^{103,105,107,109}Tc[6, 7]. For the odd-odd nuclei, only the higher spin levels of ^{106}Tc and ^{108}Tc were investigated earlier by our collaborators[8]. In the present work, we report on reinvestigation of the new high spin states in ^{106}Tc. Some new transitions are identified and a new collective bands is established. In previous β-decay studies, some low excitation levels of ^{106}Tc have been reported[9].

2 Experiment and result

In the present work, the high spin states of ^{106}Tc have been investigated by measuring the prompt γ-rays emitted from the fragments produced in the spontaneous fission of ^{252}Cf. The experiment was carried out at the Lawrence Berkeley National Laboratory. A ^{252}Cf source of strength ∼60 μCi was sandwiched between two Fe foils of thickness of 10 mg/cm^2. The source then was placed at the center of the Gammasphere detector array which, for this experiment, consisted of 102 Compton-suppressed Ge detectors. A total of 5.7×10^{11} triple- and higher-fold γ-coincidence events were collected. The coincidence data were analyzed with the RADWARE software package[10].

Through γ-γ-γ coincidence analysis, many new levels and transitions in ^{106}Tc are identified. A new level scheme of ^{106}Tc is shown in Fig. 1. The collective bands are labeled on the top of the scheme.

Received 3 September 2008

* Supported by National Natural Science Foundation of China (10575057, 10775078), Major State Basic Research Development Program (2007CB815005), Special Program of Higher Education Science Foundation (20070003149) and U. S. Department of Energy (DE-FG05-88ER40407, DE-AC03-76SF00098)

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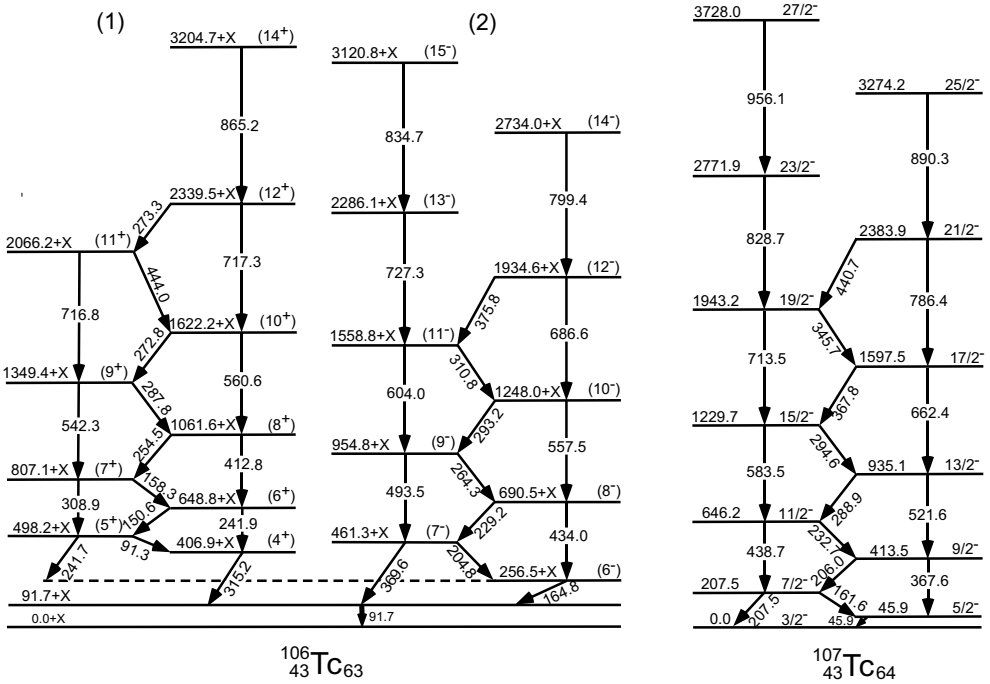

Fig. 1. Level scheme of ^{106}Tc as well as an expanded band in ^{107}Tc obtained in the present work. Energies are in keV.

The energy of the lowest level of ^{106}Tc in Fig. 1 can not been determined by the present work, as we did not find any γ-transition in ^{106}Tc reported in the previous β-decay measurements[9]. This level is most probably with a long lifetime. Thus, the level scheme of ^{106}Tc in Fig. 1 is sits at an unknown energy x keV above the ground state, as indicated in Ref. [8]. Above that, all the level energies are added with the x keV.

From Fig. 1, one can see that two collective bands labeled (1) and (2) in ^{106}Tc have been observed. The level scheme of ^{106}Tc is considerably extended and expanded. In Ref. [8], the band (1) based on 406.9+x keV level has been established up to 2339.4+x keV level. We add two new levels at 2066.2+x and 3204.7+x keV, along with four new transitions, 716.8, 865.2, 444.0 and 273.3 keV to this band. So the band (1) is updated. Band (2) is newly established in the present work. In the earlier report[8], another band structure with five levels at 162.0+x, 368.3+x, 601.5+x, 890.1+x and 1551.8+x, along with five transitions of 206.3, 233.2, 288.6, 521.6 and 661.7 keV as well as a linking 162.0 keV transition was reported in ^{106}Tc. However, in an recent publication[11], these levels and transitions were assigned as the members of the $\pi 5/2^-[303]$ band in ^{107}Tc. But this band was not reported in another ^{107}Tc result[7]. In order to clarify the inconsistency, we have made the data analysis of the relative yield distributions of correlated fission fragment pairs of Tc-Cs isotopes using the method in Ref. [12]. The intensity ratio of the Tc partner's γ-transitions of the 388.9 keV in ^{141}Cs and the 397.2 keV in ^{143}Cs can be calculated in the present work. When we gate on the 91.7 and 315.2 keV γ-transitions in ^{106}Tc, the value of this ratio obtained is 0.43(5). When we gating on the 71.7 and 138.4 keV as well as the 172.3 and 329.0 keV γ-transitions in ^{107}Tc[7], these values obtained is 1.89(3) and 1.95(6), respectively. Then, we gate on 45.9 and 161.6 keV γ-transitions which belong to the members of the argument structure in Refs. [8,11], the value of 2.11(14) is obtained. So, these results indicate that these levels and transitions of ^{106}Tc reported in Ref. [8] should belong to ^{107}Tc, as reported in Ref. [11]. In the present work, this collective band of ^{107}Tc is extended as shown in Fig. 1 also. Four new levels at 2383.9, 2771.9, 3274.2 and 3728.0 keV along with eight new transitions of 294.6, 367.8, 345.7, 440.7, 786.4, 828.7, 890.3 and 956.1 keV are added to this band. An uncertain transition of 288.6 keV[11] is confirmed as 288.9 keV in this work. We also carried out the lifetime analyzing for the band head level at 256.5+x keV of the band (2) in ^{106}Tc using the method in Ref. [13]. From our analyzing, about 10 ns lifetime for this level has been obtained.

3 Discussion

In the previous report[8], the spin and parity (I^π) for any level in ^{106}Tc were not assigned. In order to

discuss the I^π for the observed levels and the configurations for the band structures, we have made the analysis of the angular momentum alignments i_x for observed bands in ^{106}Tc. This method was used and discussed in Refs. [14,15]. By using the experimental data of the neighboring odd-A nuclei ^{105}Tc[7] and ^{105}Mo[16], the average alignment values (i_x) calculated are: 1.0 $\hbar$ for the $5/2^-[303]$ band, 1.3 $\hbar$ for $7/2^+[413]$ band, 0.6 $\hbar$ for $\alpha = +1/2$ component and 1.6 $\hbar$ for $\alpha = -1/2$ component for the $1/2^+[431]/[420]$ band in ^{105}Tc, and 2.3 $\hbar$ for the $5/2^-[532]$ band, 0.7 $\hbar$ for $3/2^+[411]$ band, 1.4 $\hbar$ $5/2^+[413]$ band and 0.8 $\hbar$ for $1/2^+[411]$ band in ^{105}Mo. The average i_x values for ^{106}Tc are: 3.0 $\hbar$ for band (1) and 3.7 $\hbar$ for band (2). So the average i_x values of the bands (1) and (2) in ^{106}Tc are near to sum of the i_x average values of the $1/2^+[431]/[420]$ band ($\alpha = -1/2$) in ^{105}Tc and the $5/2^+[413]$ band in ^{105}Mo, and $7/2^+[413]$ band in ^{105}Tc and the $5/2^-[532]$ band in ^{105}Mo, respectively. Because of the large decouple effect observed between the $\alpha = +1/2$ and $\alpha = -1/2$ components for the $1/2^+[431]/[420]$ band in ^{105}Tc, here we separately give the i_x value in each signature component and will consider the coupling in the odd-odd nuclei independently. That is , we take the $\pi 1/2^+[431]/[420](\alpha$ = -1/2)$\bigotimes\nu 5/2^+[413]$ for the band (1) in ^{106}Tc. From the above analysis, the configurations of the two band heads (1) and (2) in ^{106}Tc were shown to be consistent with a description in terms of the $\pi 1/2^+[431](\alpha$ = -1/2)$\otimes\nu 5/2^+[413]$ and $\pi 7/2^+[413]\otimes\nu 5/2^-[532]$, respectively. The bands (1) and (2) in ^{106}Tc were based on the band-head levels at $I^\pi = 4^+$ with $K^\pi = 3^+$, and at $I^\pi = 6^-$ with $K^\pi = 6^-$, respectively.

In order to have a further understanding of the structural properties of ^{106}Tc, we have carried out the total Routhian surface (TRS) calculations based on the cranked shell model (CSM), employing the non-axial deformed Woods-Saxon potential[17]. The results are presented in Fig. 2. From the figures, the minima can be found at β_2= 0.29, $\gamma = -20.9°$, for $\omega = 0.0$ MeV/$\hbar$, and $\beta_2 = 0.30$, $\gamma = -21.1°$ for $\omega =$ 0.3 MeV/$\hbar$. It indicates that the ^{106}Tc nucleus has triaxial shape with intermediate deformation. On the other hand, the signature splitting and inversion can be found in bands (1) and (2). These may be caused by the triaxial deformation. For the moment of inertia J_1 in ^{106}Tc, the value of rigid body is 49.1 $\hbar^2$/MeV. Through the calculation, the values of J_1 in bands (1) and (2) based on spins assigned by our work are less than the value of rigid body, but larger than that of the bands with corresponding configurations in neighboring odd-A nuclei. This result also indicates that the configurations assigned to the collective bands of ^{106}Tc are reasonable.

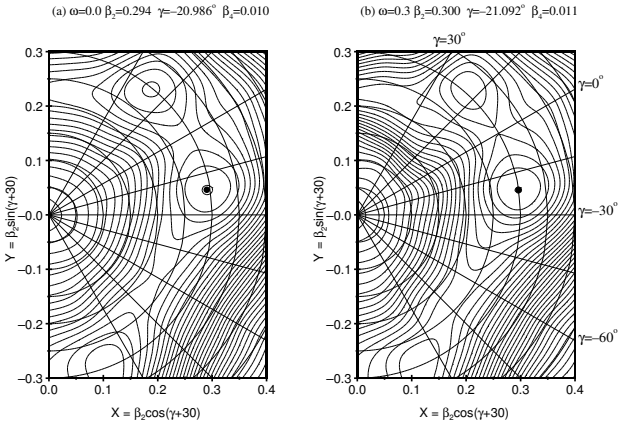

Fig. 2. Polar coordinate plots of the total Routhian surface(TRS) calculated at (a) $\omega =$ 0.0 MeV/$\hbar$ and (b) $\omega = 0.3$ MeV/$\hbar$ for ^{106}Tc.

4 Summary

The high spin states of the neutron-rich odd-odd ^{106}Tc nucleus have been reinvestigated. A new level scheme of ^{106}Tc has been established, and two collective bands are observed. The configurations and structural characteristics for these bands are discussed.

References

1 Cheifetz E et al. Phys. Rev. Lett., 1970, **25**: 38
2 Hamilton J H. Prog. Part. Nucl. Phys., 1985, **15**: 107
3 Hamilton J H et al. Prog. Part. Nucl. Phys., 1995, **35**: 635
4 HUA H et al. Phys. Rev. C, 2004, **69**: 014317
5 ZHU S J et al. Phys. Rev. C, 2001, **65**: 014307
6 Bauchet A et al. Eur. Phys. J. A, 2001, **10**: 145—150
7 LUO Y X et al. Phys. Rev. C, 2004, **70**: 044310
8 Hwang J K et al. Phys. Rev. C, 1998, **57**: 2250
9 de Frenne D, Neglet A. Nucl. Data Sheets, 2008, **109**: 943
10 Radford D C. Nucl. Instrum. Methods Phys. Res. A, 1995, **361**: 297
11 Urban W et al. Phys. Rev. C, 2004, **70**: 057308
12 WANG J G et al. Phys. Rev. C, 2008, **78**: 014313
13 LI M L et al. Chin. Phys. Lett., 2004, **21**: 2147
14 HE Y et al. J. Phys. G, 1992, **18**: 99
15 Hildingson L et al. Z. Phys. A, 1991, **338**: 125
16 DING H B et al. Phys. Rev. C, 2006, **74**: 054301
17 XU F R et al. Phys. Rev. C, 2002, **65**: 021303(R)