Structure evolution along the yrast-line in ^{101}Pd *

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Abstract High-spin states in ^{101}Pd have been investigated experimentally via the ^{76}Ge(^{28}Si, 3nγ)^{101}Pd reaction. The previously known bands based on the $d_{5/2}$ and $h_{11/2}$ neutron orbitals have been extended to higher-spin states, and two new structures have been observed. Spin and parity were assigned to the levels on the basis of the experimental results of the angular distribution of γ rays deexciting the oriented states. For the ground-state band, the E-GOS (E-Gamma Over Spin) curve strongly suggests a structure transition from vibration to rotation while increasing spin.

Key words high-spin state, E-GOS curve, structure evolution

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1 Introduction

In the $A\approx100$ mass region, collective quasi-rotational structures associated with the $d_{5/2}$, $g_{7/2}$ and $h_{11/2}$ neutron orbitals were observed to high spins and interpreted within the framework of a cranked shell model [1–4]. Many experiments have been undertaken to study typical characteristics, like collective excitations, band crossings and triaxial deformations in this mass region. Recently, Regan et al. [5] analyzed the positive parity yrast cascade in ^{102}Ru, and suggested a structure evolution from vibration to rotation while increasing spin. Furthermore, phase evolution in the even-even nuclei, such as in Mo, Ru, Pd and Cd isotopes with mass number around 110, has also been pointed out in their research. For an odd-A nuclide, its high-spin states may be formed by coupling weakly the valence nucleon to the respective core excitations. Therefore, the odd-A nuclei in this mass region would be expected to exhibit phase evolution as their neighboring even-even nuclei. In this paper, we aim to investigate the phase evolution in ^{101}Pd. Prior to this work, detailed knowledge of low-spin states in ^{101}Pd was provided from the decay of ^{101}Ag [6, 7]. High-spin states of ^{101}Pd were observed and compared with the results of a rotational model calculation [8].

2 Experiment and results

2.1 Measurement

The excited states in ^{101}Pd were populated via the ^{76}Ge(^{28}Si, 3nγ) reaction. The ^{28}Si beam was provided by the tandem accelerator at the Japan Atomic Energy Agency (JAEA). The target is an isotopically enriched ^{76}Ge metallic foil of 2.0 mg/cm^2 thickness with an 8.0 mg/cm^2 Pb backing. The GEMINI [9] γ-ray detector array was used. At the time of this experiment, the array consisted of 14 hyperpure germanium detectors with bismuth germanite anti-Compton shields. To obtain the ADO (Angular Distribution of γ rays deexciting the Oriented states) ratios, the detectors were divided into 3 groups positioned at 32° (148°), 58° (122°) and 90° with respect to the beam direction. The detectors were calibrated with ^{60}Co, ^{133}Ba and ^{152}Eu standard sources, and the typical resolution was about 2.0−2.4 keV at FWHM for the 1332.5 keV line. To identify the in-beam rays belonging to ^{101}Pd, X-γ-t and γ-γ-t coincidence mea-

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surements were performed at beam energies of 95 and 85 MeV, at which energies the relative yields of ^{101}Pd were large. Here, t refers to the relative time difference between any two coincident γ rays. A total of 2.3×10^8 coincidence events were accumulated. After accurate gain matching, these coincidence events were sorted into a symmetric matrix and two ADO matrixes for off-line analysis. The ADO ratios for the known γ rays observed in this experiment were about 1.3 for stretched quadrupole transitions and 0.7 for stretched pure dipole transitions. Therefore, we assigned the stretched quadrupole character and stretched dipole character to the γ rays of ^{101}Pd with anisotropy around 1.3 and 0.7, respectively.

2.2 Level scheme

Based on a detailed analysis of the coincidence data, a level scheme of ^{101}Pd, considerably extending the previous one, has been established and shown in Fig. 1. Assignments of the observed new γ rays to ^{101}Pd were based on the coincidences with the known γ rays [8, 10]. The ordering of transitions in the level scheme was determined according to the γ-ray relative intensities, γ-γ coincidence relationships and γ-ray energy sums. The transition energies in the level scheme are within an uncertainty of 0.5 keV. The spins and parities for the known low-lying states were adopted from the previous work [8, 10], and these values were used as the reference for the spin and parity assignments for the new states. Results of the γ-transition energies, the relative transition intensities and the assignments of spins and parities (I^π) are presented in Table 1. Some brief explanations of the level scheme are given as follows.

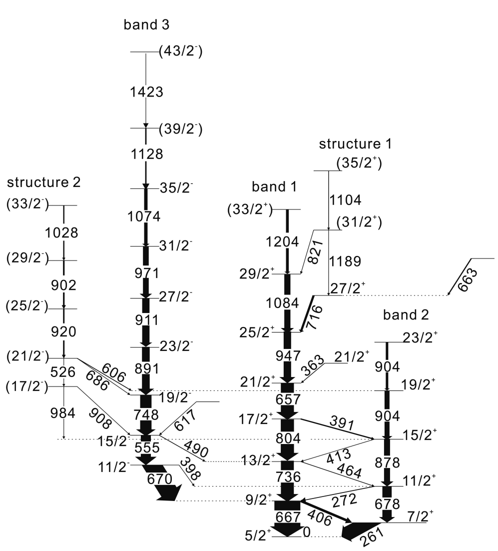

Fig. 1. Partial level scheme of ^{101}Pd established by the present work.

Table 1. γ-ray energies, relative intensities, spin and parity assignments, and ADO ratios in ^{101}Pd.

E_γ/keV[a)]	I_γ[b)]	assignment	R_{ADO}
		band 1 and structure 1	
260.8	109.40	$7/2^+ \to 5/2^+$	0.60(6)
272.0	5.80	$11/2^+ \to 9/2^+$	
362.7	4.88	$21/2^+ \to 21/2^+$	
391.0	9.10	$17/2^+ \to 15/2^+$	0.67(33)
405.9	18.90	$9/2^+ \to 7/2^+$	0.69(10)
413.0		$15/2^+ \to 13/2^+$	
464.1	4.65	$13/2^+ \to 11/2^+$	
656.8	100.00	$21/2^+ \to 17/2^+$	1.36(15)
663.1	8.50		
666.8	198.80	$9/2^+ \to 5/2^+$	1.49(16)
715.5	16.54	$27/2^+ \to 25/2^+$	0.86(28)
735.9	98.84	$13/2^+ \to 9/2^+$	1.18(12)
803.8	100.92	$17/2^+ \to 13/2^+$	1.27(14)
821.6	4.25	$31/2^+ \to 29/2^+$	
947.3	57.15	$25/2^+ \to 21/2^+$	1.24(33)
1084.0	23.32	$29/2^+ \to 25/2^+$	1.39(49)
1104.4	5.37	$(35/2^+) \to 31/2^+$	
1189.1	3.56	$(31/2^+) \to 27/2^+$	
1204.2	20.93	$(33/2^+) \to 29/2^+$	
		band 2	
677.7	71.03	$11/2^+ \to 7/2^+$	1.15(19)
877.5	45.82	$15/2^+ \to 11/2^+$	1.39(17)
903.9	38.44	$19/2^+ \to 15/2^+$	1.57(39)
903.9	18.63	$23/2^+ \to 19/2^+$	1.57(39)
		band 3	
398.3	4.02	$11/2^- \to 11/2^+$	
489.1	5.89	$15/2^- \to 13/2^+$	
554.9	77.61	$15/2^- \to 11/2^-$	1.15(8)
617.3	3.16		
669.9	136.60	$11/2^- \to 9/2^+$	0.98(8)
747.8	87.54	$19/2^- \to 15/2^-$	1.23(12)
891.0	59.21	$23/2^- \to 19/2^-$	1.13(15)
910.5	56.56	$27/2^- \to 23/2^-$	1.30(16)
971.1	44.38	$31/2^- \to 27/2^-$	1.25(18)
1073.7	25.72	$35/2^- \to 31/2^-$	1.20(29)
1128.6	10.42	$(39/2^-) \to 35/2^-$	
1423.0		$(43/2^-) \to (39/2^-)$	
		structure 2	
526.0	2.44	$(21/2^-) \to (17/2^-)$	
606.0	5.40	$(21/2^-) \to 19/2^+$	
686.0	3.99	$(21/2^-) \to 19/2^-$	
902.3	12.05	$(29/2^-) \to (25/2^-)$	
908.0	2.21	$(17/2^-) \to 15/2^-$	
920.1	10.83	$(25/2^-) \to (21/2^-)$	1.14(43)
984.0	0.64	$(17/2^-) \to 15/2^+$	
1028.4	8.87	$(33/2^-) \to (29/2^-)$	

a) Uncertainties between 0.1 and 0.5 keV.
b) Uncertainties between 5% and 30%. Corrected for the efficiency of Ge detectors.

Band 1, based on the $5/2^+$ intrinsic state, has been confirmed. This band has been extended up to an excitation energy of 6100 keV, by adding a new 1204 keV transition. The 1204 keV transition was too weak to deduce its multipolarity reliably. As it continues the quasi-rotational sequence, we have tentatively assigned a stretched E2 character to it. Structure 1, as shown in Fig. 1, was observed first, and it was linked to the $I^\pi=25/2^+$ state in Band 1 via the 716 keV transition. The measured ADO ratio for the 716 keV transition was 0.85(28), and it might be a M1/E2 transition. Therefore, we proposed positive parities for structure 1. In Fig. 2, the coincidence spectrum demonstrates the existence of transitions in band 1 and structure 1. Band 2, which was observed in the previous work [8], has been confirmed in the current study.

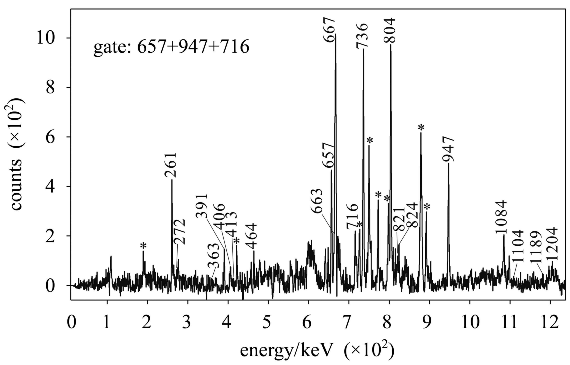

Fig. 2. Sum spectra by gating on the transitions with energies of 657, 947 and 716 keV.

Band 3 is built on the $11/2^-$ intrinsic state. Before this experiment, this band was known up to the $35/2^-$ state. We added two new transitions of 1128 and 1423 keV to this band, and extended it to $43/2^-$ level tentatively. Fig. 3(a) shows a spectrum gated on the 555 keV transition. The 1128 and 1423 keV transitions above $35/2^-$ level can be seen clearly. A new cascade of transitions, labelled as structure 2 in Fig. 1, was observed. The ordering of the transitions was tentatively arranged by the relative intensities. The transitions connecting the new cascade with the known part of the level scheme support the location of this cascade in the level scheme. It should be noticed that this sequence is irregularly spaced. The ADO ratio for the 920 keV transition was 1.14(43), and thus we proposed E2 characters for the transitions in structure 2. The spectrum demonstrating the existence of structure 2 is shown in Fig. 3(b).

Most of the levels and transitions reported in Ref. [8] were confirmed in the present work. However, a nonyrast cascade, consisting of the 588, 677 and 797 keV transitions [8], was not observed in the present experiment.

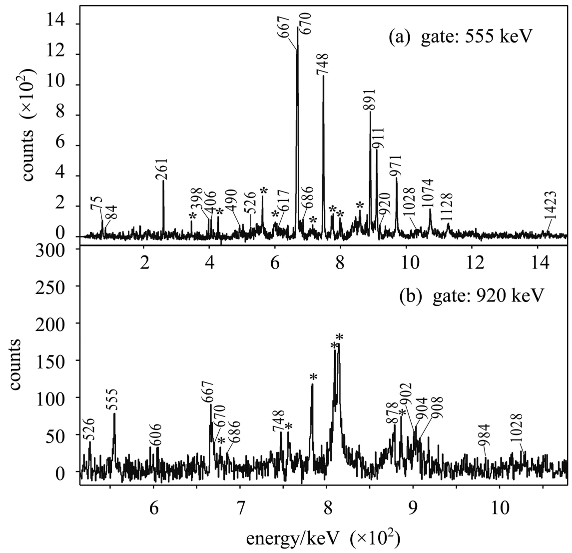

Fig. 3. The γ-ray spectra gated on the 555 keV transition (a) and 920 keV transition (b). The asterisks indicate contaminations.

3 Discussion

Regan et al. [5] proposed a simple method, known as the E-GOS (E-Gamma Over Spin) curve, for discerning the structure evolution from vibration to rotation in nuclei with increasing spin. In this method, the ratio of $E_\gamma(I\rightarrow I-2)/I$ can provide an effective way of distinguishing between axially symmetric rotational and harmonic vibrational modes [5]. For a vibrator, this ratio gradually diminishes to zero as the spin increases, while for an axially symmetric rotor it approaches a constant, $4[\hbar^2/(2J)]$. Here, J is the static moment of inertia. This prescription has been applied to the yrast cascades in the even-even nuclei and a clear signature for shape phase transition has been found [5]. As discussed in Ref. [5], it was found that there was a transition from vibrational character to rotational character along the yrast-line in ^{102}Pd (see Fig. 3 in Ref. [5]). Fig. 4(a) shows clearly that the E-GOS curve of the yrast-states in ^{100}Pd displays a vibrational character at low spins, whereas at higher spins it has a rotational pattern. The structure phase transition in ^{100}Pd was not discussed previously. In Fig. 4(b), we compared the energy spacings in the yrast cascades in ^{101}Pd and its even-even neighboring nuclei. The striking similarity can be identified. This would suggest that the positive-parity yrast cascade in ^{101}Pd is formed by weakly coupling a $d_{5/2}$ neutron to the core excited states. Therefore, the structure

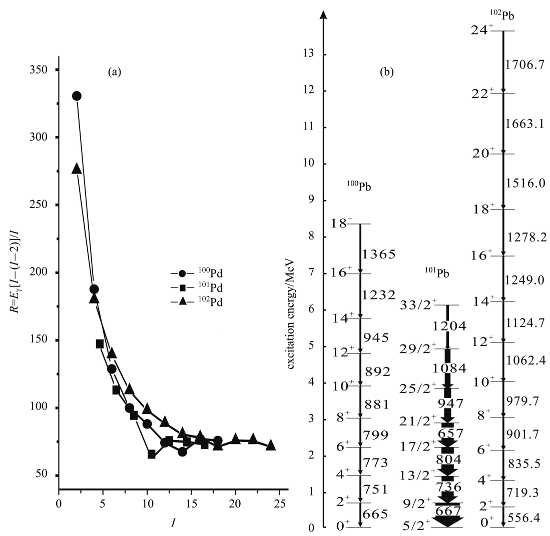

Fig. 4. (a) E-GOS curves for the ground-state bands of $^{100-102}$Pd. Data for ^{100,102}Pd are taken from Refs. [3, 11]. (b) Ground-state bands of $^{100-102}$Pd.

evolution might occur along the yrast line in ^{101}Pd. To reveal the structure evolution in the yrast band of ^{101}Pd, we plotted the $R_{\text{E-GOS}}=E_{\gamma}(I\rightarrow I-2)/I$ versus spin I. As shown in Fig. 4(a), the E-GOS value of ^{101}Pd evolves from an approximate hyperbolic locus expected for vibrational structure to a constant value close to that for an axially symmetric rotor. Namely, the evolution from vibrational to rotational structure as a function of spin is manifest. Furthermore, note that the ratio of excitation energies for the yrast $9/2^+$ and $5/2^+$ states in ^{101}Pd is 2.10. This value can be associated with an approximate harmonic vibrational system [12].

Structure evolution along the yrast-line in ^{101}Pd can be explained microscopically. As proposed in Ref. [8], a band-crossing might occur at a spin of about $21/2\hbar$. We can expect that the wave function of the $21/2^+$ state predominantly consists of maximally aligned quasiparticle orbitals. Since the alignable orbitals reside low in the subshell, they have large components of angular momentum along the rotation axis. These quasiparticles might polarize the core to a small but rigid quadrupole deformation, and thus collective rotational motion would develop.

4 Conclusions

High-spin states of the nominally transitional nucleus ^{101}Pd have been investigated via the ^{76}Ge(^{28}Si, 3nγ) reaction. The previously known bands based on the $5/2^+$ and $11/2^-$ intrinsic states have been extended to $33/2^+$ and $43/2^-$ states, respectively. Two new band structures have been observed. One of them deexcites to the ground-state band while the other decays through some interband transitions to both positive parity and negative parity bands. The characteristic of the E-GOS curve for the yrast-band in ^{101}Pd suggests that this nucleus may undergo an evolution from vibrational to rotational structure with increasing angular momentum.

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