# Population and properties of superdeformed bands in $A \sim 150$ region

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**Abstract.** The production of superdeformed nuclei, treated as cluster configurations in the $A \sim 150$ region is described in the framework of statistical approach and the dinuclear system concept. The competition of particle emission from the dinuclear system and quasifission is taken into account. The calculated nuclear characteristics of the superdeformed band in $^{152}$Dy are close to the experimental values.

Among nuclei in which the effect of superdeformation (SD) occurs, the region $A \sim 150$ is of theoretical and experimental interest for certain reasons. The known SD states of several isotopes of Dy, Gd and Tb [1] are produced in different evaporation channels of fusion evaporation reactions. In this region of the nuclear chart it is possible to observe the rotational $\gamma$-transitions from very high ($\sim 60\hbar$) to lower ($\sim 20\hbar$) spins and, in some cases, to determine the energy of the lowest state in the SD band. Such experimental basis allows one to describe theoretically not only the structure of SD states, but also the mechanism of their population.

According to the cluster interpretation, the SD state can be treated as a cold rotating dinuclear system (DNS). The relative distance between the centers of two touching clusters corresponds to the minimum of the pocket of the nucleus-nucleus interaction potential. The large overlap of the DNS nuclei is hindered by a repulsive nucleus-nucleus interaction potential at smaller relative distances. The validity of the cluster interpretation of strongly deformed states was investigated in ref. [2]

The scheme of formation of the SD state in fusion-evaporation reaction is shown in figure 1. The potential energy $U$ of the DNS is calculated as a sum of the mass excesses of the fragments at their ground states and the nucleus-nucleus potential [3]. Due to the shell and even-odd effects, it has its minima at different DNS configurations. After the colliding nuclei pass over the Coulomb barrier and come to the touching configuration, the initial excited DNS is formed. This DNS can evolve by diffusion in the relative distance $R$ between the centers of nuclei and in the charge $\eta_Z = (Z_1 - Z_2)/(Z_1 + Z_2)$ and mass $\eta$ asymmetry coordinates ($Z_1$ and $Z_2$ are the charge numbers of the DNS nuclei). It can also be de-excited by particle emission during this evolution. The residue daughter DNS configuration can be cold enough to be trapped in some potential minimum in both the $R$ and the $\eta_Z$ coordinates and live a rather long time to be interpreted as a SD state. Such a system may emit $\gamma-$quanta between collective rotational states.

One can identify a DNS configuration, which corresponds to the experimentally observed
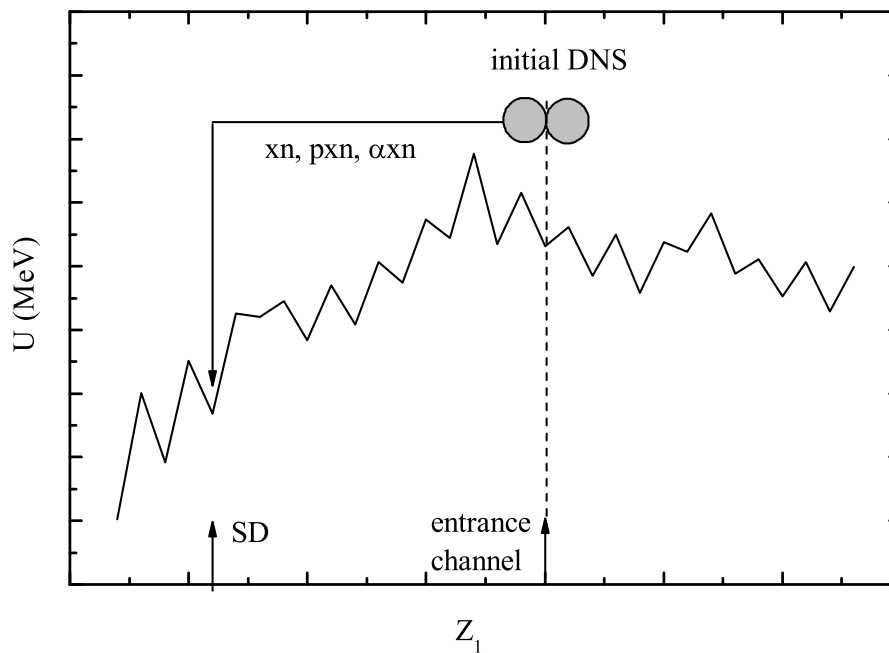
**Figure 1.** The scheme of formation of the SD state in fusion-evaporation reaction. $Z_1$ is the charge number of the lighter DNS nucleus.

SD state by comparing the calculated nuclear characteristics for different DNS configurations with the measured ones for the SD state. For example, the SD states of $^{152}$Dy with measured moment of inertia $\Im_{SD}^{exp}$=85±3 $\hbar^2$/MeV, quadrupole moment $Q_2^{exp}$=18±3×$10^2$(e fm$^2$) and energy of the lowest state in SD band $E_{SD}^{exp}(24^+)$=10.64 MeV can be treated as the DNS configuration $^{12}$C+$^{140}$Nd, for which our calculations give the values $\Im_{SD}^{th}$=76 $\hbar^2$/MeV, $Q_2^{th} = 11 \times 10^2$(e fm$^2$) and $E_{SD}^{th}(24^+)$=9.94 MeV.

The capture process is described using the quantum diffusion approach, based on the formalism of reduced density matrix [4]. The probability of particle emission from the evolving DNS is calculated using the statistical approach. At each evaporation step the competition between particle emission and the diffusion of DNS to large $R$ (quasifission) is considered for all possible DNS configurations, with their statistical weights given by Bolzmann distribution.

The emission of rotational $\gamma$-quanta from the cold dinuclear configuration corresponding to the SD state competes with tunneling through barriers in $R$ (quasifission) and $\eta_Z$ (fusion). The rates of these processes $\Lambda_{\gamma,R,\eta_Z}$ can be expressed through their times $T_{\gamma,R,\eta_Z}$ as $\Lambda_{\gamma,R,\eta_Z} = \hbar/T_{\gamma,R,\eta_Z}$, and can be calculated, as in Refs. [5, 6].

Measured [1, 7] and calculated intensities of the SD band in $^{152}$Dy are shown in figure 2. The results of our calculation represent the dependence of this value on angular momentum. The strong fall of intensity at $L \geq 50$ can be explained by the significant decrease of quasifission barriers in this region due to the increase of centrifugal forces. At $L \leq 25$ $E2$-transitions are suppressed, as the time of these processes is too large, and the transition to the normally deformed (ND) rotational band (complete fusion, in cluster interpretation) becomes more favorable. Measured [8, 9] and calculated intensities of the SD band normalized to those of the ND band are presented in figure 3 as functions of the bombarding energy. This dependence is similar to the excitation functions for the compound nucleus reactions, but has much broader shape.

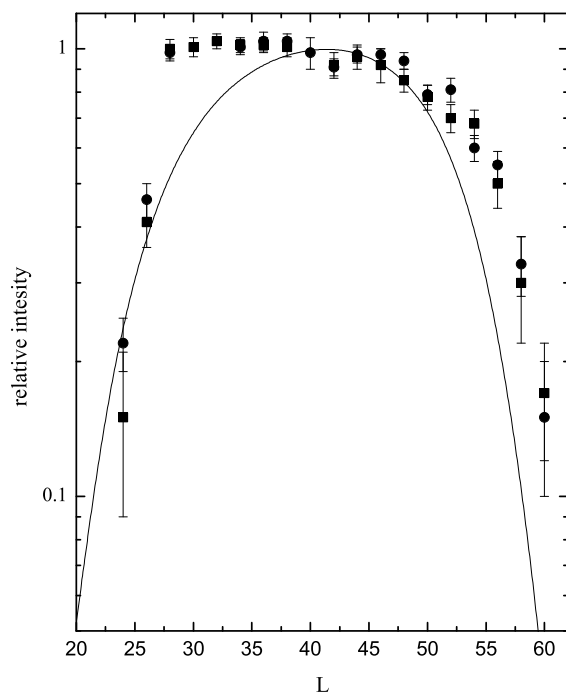The agreement of our results with the experimental data proves the validity of the cluster

**Figure 2.** Measured [1] (circles), [7] (squares) and calculated (line) intensities of the SD band in $^{152}$Dy produced in the reaction $^{108}$Pd($^{48}$Ca,4n).



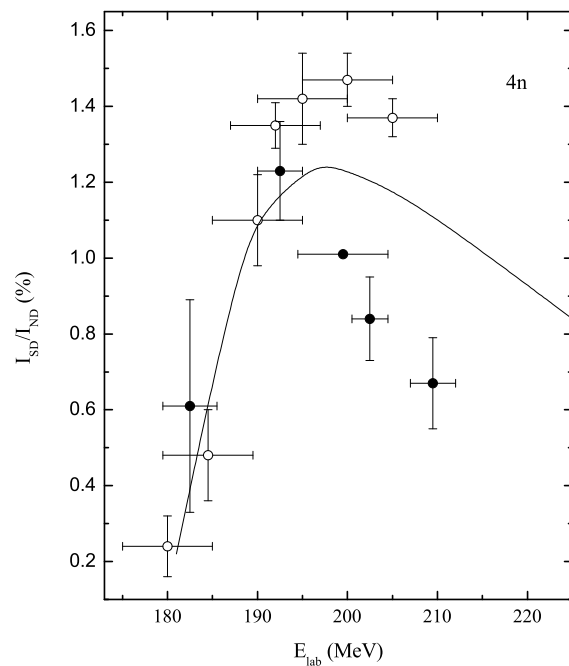**Figure 3.** The ratio of SD and ND band intensities as a function of bombarding energy for the reaction $^{108}$Pd($^{48}$Ca,4n). The results of calculations and the experimental values taken from refs. [8] and [9] are presented by line, full and open circles, respectively.

interpretation of strongly deformed nuclear states and supports the predictions concerning the possible formation of hyperdeformed states in the entrance channel of heavy-ion reactions [5, 6], based on the same theoretical approach.

**References**
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