Observation on Non-linear Dynamical Fluctuation of Rare Nitrate Crystal in Low Temperature Region

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硝酸希土類結晶は室温領域から200Kの温度領域で非線形非平衡現象を有している。同結晶におけるac伝導率の時系列測定により，バースト現象が観測され，時系列は決定論的な構造を持つ。硝酸希土類結晶群に関する測定により希土類元素効果が観られた。決定論的な構造を有する時系列において量子効果の可能性がある。量子効果が支配する低温度領域において，非線形動力学的なゆらぎの構造を明らかにするために，硝酸希土類結晶のac伝導率時系列を測定した。

A physical process in phenomena observed in the nature is essentially irreversible. The physical macroscopic quantities in equilibrium are characterized equal to an average values of the data set accumulated in the experiment. The value of the physical quantity measured at individual time, always fluctuates[1]. The meta-stabilities were observed by measuring sequentially the ac conductivity at temperatures between 203.15K and room temperature in the rare earth nitrate crystal $R(NO_3)_3 6H_2O$ [2]. The metastable phenomena with a memory effect were found dependent on the measuring processes. In the nonlinear dynamical analyses of the time series data of the ac conductivity, it was found that the nonlinear property is deterministic [3]. The distinct intermittent non-periodic oscillations (bursts) were observed in the time series data for the conductivity [4]. The phenomena in the crystals could be classified to a macroscopic chaos in a dissipative dynamical system. Additionally the effect of the rare earth element on the fluctuation was found in the electric properties of the $R(NO_3)_3 6H_2O$ crystals [5]. The rare earth nitrate crystals have the same crystal habit and triclinic space group $P\overline{1}$ where R is rare earth element. The crystal structure is independent of temperature above 80K [6]. The facts in the crystals show possibility of observation on the phenomena related to quantum chaos [7] through detailed measurement on the fluctuation, having both chaotic character and dependence on quantum condition in a material. To find out the nonlinear dynamical fluctuation attributed to the quantum chaos, we have measured time series of ac conductivity of the rare earth nitrate crystals in the low temperature region where the quantum effect is dominant[1]. In the present report, we give the result for the time series of the ac conductivity along the direction perpendicular to c-axis of the praseodymium nitrate crystal $^{59}\mathrm{Pr}(NO_3)_3 6H_2O$ in the low temperature region above 8K. The dimension of the sample was 0.037 ±0.005cm in thickness and 0.0756±0.005 cm^2 in area. The experimental procedures for the measurements of the time series data on the ac conductivity for the crystal were given in Ref.[3]. Figure shows the time series of fluctuation $\Delta\sigma'$ for real part σ' of complex conductivity σ^* at 2 kHz for electric field E applied to direction perpendicular to c-axis at 8K and 9K in heating cycle. The fluctuation $\Delta\sigma'$ is defined by the relation given as $\Delta\sigma' = \sigma' - \overline{\sigma'}$, where $\overline{\sigma'}$ is the average value derived from the data of the conductivity σ'. The bursts occur randomly as non-periodic unstable oscillations in the time series of $\Delta\sigma'$ at the temperatures. The time series data were analyzed by both the statistical and the nonlinear dynamical procedures. The power spectral density $P(f)$ was derived from the time series data $\Delta\sigma'(t)$ by using the statistical method [3]. The temperature variation of $P(f)$ at 8Hz was found at the temperature region $8K \leq T \leq 200K$. Dependence of correlation dimension v on embedding dimension n was derived from the time series data by using the simple nonlinear dynamical procedures of Grassberger and Procaccia [8]. The values of the correlation integrals $C(r)$ were calculated for the time series data $\{\Delta\sigma'\}$ at temperatures. The correlation integrals behaves as power of r for small $r: C(r) \propto r^{\nu}$, where the exponent ν is a correlation one. The correlation exponent $\nu(T,15)$, at the embedding dimension n =15 was dependent on temperatures for 8K≦T≦200K in both cooling and heating cycle.

By the analogy with the critical phase transition, the phenomenon in the present report is corresponded to a transition one in the macroscopic chaos of the dissipative system as observed in holmium nitrate [9]. It could be expected that, in the measurement for the time series of the ac conductivity for the rare earth nitrate crystals in low temperature region, the phenomena attributed to the quantum chaos, acknowledged as one of nonlinear non-equilibrium quantum phenomena, are observable.

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