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（博士課程）
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論 文 要 旨

THESIS SUMMARY

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学生氏名： Student's Name	深代　隆央		

申請学位（専攻分野）： Academic Degree Requested	博士 Doctor of　（　理学　）
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要旨（英文 800 語程度）
Thesis Summary (approx.800 English Words)

Recently, open quantum systems have been extensively investigated with the experimental developments such as cold atomic systems and we observed their interesting phenomena caused by boundary couplings. Though analytical understandings of open quantum systems are generally difficult due to boundary couplings, exact solutions of open quantum systems in the steady state have been obtained for one-dimensional case in the formulation of quantum master equation. However, still many problems remain to be studied such as fluctuation properties and finite temperature effects in the steady state. In the transient regime, the understandings have been limited with numerical calculation and there are few exact results because we need the full spectrum of the time-evolutional operator including effects of boundary couplings.

In this thesis, to analytically understand effects of boundary couplings on open quantum systems, we rigorously investigate the one-dimensional open tight-binding model with N sites coupled to two reservoirs on its edges with the nonequilibrium Green function method. We achieved two facts. First we obtain exact expressions of the mean physical quantities in the steady state and in the transient regime. For the steady state and the symmetric bias voltage case, we analytically obtain an exact expression of the electron density. From the expression, we show that a special state called superradiance state, which has been known in previous studies with the formulation of non-hermitian matrix, does not affect the qualitative behavior of the electron density in absolute zero temperature case. It is interesting because the superradiance state actually exists but it does not affect the qualitative behavior of the electron density in the settings. In addition, we prove that the phase transition which has been observed for the isolated tight-binding model also exists in our open case. This result is important because it is known that the boundary couplings can affect the exponent of the phase transition in isolated case but it does not hold in our open tight-binding model. For the asymmetric bias voltage case, where the steady current exists, we derive a rigorous expression of the steady current and the electron density on the edges with finite temperature effects using the knowledge of orthogonal polynomials. Our approach is different from the matrix product state used in the previous studies with the quantum master equation, where the authors derived the exact expression of the current in the absolute zero temperature or high temperature limit. From the expression, we show that the steady current vanishes in the thermodynamic limit $N \to \infty$. This result is different from that of the zero temperature case where the current does not depend on the total number of the sites N and therefore transport is ballistic. In addition, from the exact expression we show that the superradiance transition vanishes for the finite temperature case. Therefore, we find that the superradiance transition is purely a result of quantum effects caused by the boundaries. In the transient regime, we derive an expression of the time-dependent electron density at absolute zero temperature in the thermodynamic limit. We analytically show that several interesting behaviors exist in transient regime. We prove that a two-step decay appears in the relaxation process purely caused by open boundaries. In addition, we see that the dependence of speed of convergence on boundary couplings qualitatively changes at a certain value of the boundary parameters where the superradiance states appear. We analytically prove that the behavior is caused by an exponential term which only appears when there are superradiance states.

Second, we study the fluctuation properties of the open tight-binding model in the steady state and in the transient regime. In the steady state, we investigate the cumulant generating function of the integrated current in the steady state, which contains the information of all the cumulants of the physical quantity. As a result, we prove that the superradiance transition can appear in all the cumulants. This is because the boundary couplings only exist on the edges. In the transient regime, we study the current correlation function between the two reservoirs at the same time. By rigorously investigate a formal expression of the current correlation function derived in a previous study with the nonequilibrium Green function method, we find that the current correlation function expresses phase information. We numerically find that the dependence of the correlation on the boundary parameters changes when the superradiance states appear. The correlation becomes weaker by increasing the boundary parameters when there are the superradiance states. We also study the effects of finite temperature. We find that the current correlation becomes weaker by increasing temperature. This can be because the quantum transport approaches to classical transport as we increase temperature and therefore the phase information vanishes in the current correlation.

備考 ： 論文要旨は、和文 2000 字と英文 300 語を 1 部ずつ提出するか、もしくは英文 800 語を 1 部提出してください。
Note : Thesis Summary should be submitted in either a copy of 2000 Japanese Characters and 300 Words (English) or 1copy of 800 Words (English).

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