



Title	Study on the Solid-State Electrochemical Thermal Transistors with High Electrical Conductivity Active Layers [an abstract of dissertation and a summary of dissertation review]
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学 位 論 文 内 容 の 要 旨

博士の専攻分野の名称 博士（工学） 氏名 下 志平

学 位 論 文 題 名

Study on the Solid-State Electrochemical Thermal Transistors with High Electrical Conductivity Active Layers

（高電気伝導性活性層を用いた固体電気化学熱トランジスタに関する研究）

The effective reuse of waste heat, stemming from the low conversion efficiency of primary energy sources, is crucial for sustainable development. Waste heat within the low to medium temperature range (100-300 °C) presents a significant challenge as it is insufficient to generate steam for power generation.

To solve this problem, recent attention has been directed towards thermal transistors [1-8] which can electrically switch heat flow on and off. There is potential for thermal transistors to enable thermal displays that visualize heat contrasts using infrared cameras, thus aiding in the effective reuse of waste heat.

Key to this application is the electrical control of thermal conductivity (κ) in the active materials of thermal transistors, necessitating a switch between high κ (on-state) and low κ (off-state). Methods such as electrochemical [2-6] and electrostatic [7, 8] approaches offer pathways to regulate κ in active materials. While electrostatic methods allow for rapid κ control, they are constrained by the need for an extremely thin active material layer at the heterointerface between the gate dielectric and the active material, limiting their suitability for thermal display applications.

Using electrochemical method is ability to modulate κ across entire materials. Previous research has utilized ionic liquids such as organic electrolytes and water for electrochemical modulation of materials [2-4, 6], although integration with integrated circuits remains challenging. In pursuit of thermal displays with significant differences in thermal conductance between on and off-states, all-solid-state electrochemical thermal transistors [5, 9, 10] have been employed.

However, the guiding principle to improve the ON/OFF κ ratio has yet to be clarified because the κ modulation mechanism is unclear. Therefore, in this thesis, I first utilize the $\text{SrCo}_{1-x}\text{Fe}_x\text{O}_y$ solid solution system to clarify the underlying mechanism responsible for the κ of SrCoO_x -based thermal transistors. I find the electron thermal conductivity plays a significant role in certain metallic transition metal oxides.[9] Then, LaNiO_x , as a material that meets these criteria, was identified as a suitable candidate for fabricating thermal transistors with an exceptional κ switching width of $4.3 \text{ W m}^{-1} \text{ K}^{-1}$. The fully oxidized LaNiO_3 (on-state) produced a κ of $6.0 \text{ W m}^{-1} \text{ K}^{-1}$, primarily attributed to a substantial contribution from electron thermal conductivity ($3.1 \text{ W m}^{-1} \text{ K}^{-1}$). [10] This thesis is composed of the

following chapters:

In Chapter 1, a comprehensive background on thermal transistors is introduced

In Chapter 2, experimental methods are introduced.

In Chapter 3, based on our all-solid-state SrCoO_x thermal transistor, I clarified the systematic modulation of κ of $\text{SrCo}_{1-x}\text{Fe}_x\text{O}_y$ ($0 \leq x \leq 1$, $2 \leq y \leq 3$) solid solutions.[9] Hence, I found materials that show a high electrical conductivity (means high electron thermal conductivity) and highly ordered lattices in the ON state, but display electrical insulating properties and disordered lattices in the OFF state should improve the ON/OFF κ ratio.

In Chapter 4, based on my collaborate work on protonation and deprotonation of nickel oxides using ionic liquids, I confirmed the validity of the strategies outlined in Chapter 3 for finding suitable active materials and enhancing thermal transistor performance. Additionally, I have discovered that LaNiO_x is a promising candidate as an active material. I fabricated the all-solid-state thermal transistor using LaNiO_x .[10] This work presents a breakthrough with LaNiO_x -based electrochemical thermal transistors, with an exceptional κ switching width of $4.3 \text{ W m}^{-1} \text{ K}^{-1}$. The LaNiO_x -based electrochemical thermal transistor demonstrated κ cyclability while maintaining the structural integrity of the LaNiO_x crystalline lattice, making it a promising candidate for integration into next-generation devices, particularly thermal displays.

In Chapter 5, the above studies are summarized.

In conclusion, this thesis has discovered a method to achieve high ON/OFF κ ratio and wide κ switching widths by modulating electron thermal conductivity. Based on this discovery, a highly promising LaNiO_x -based thermal transistor has been fabricated. It underscores the significance of κ control for improving energy efficiency and enabling novel applications in thermal management and beyond.

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