【Grant-in-Aid for Scientific Research (S)】

Broad Section C

Title of Project : Establishment of evaluation methods for the physical properties of ferroelectrics using coherent state of the elementary excitation and the device applications

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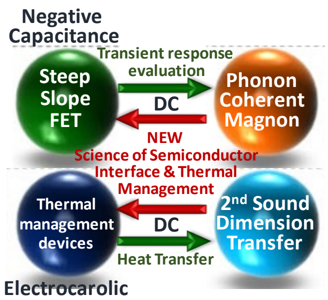
Keyword : Ferroelectrics, Elementary excitation, Steep slope transistors, Solid-state thermal diode

【Purpose and Background of the Research】

Ferroelectrics are used in various forms all around us, including in ultra-small capacitors that use large dielectric constants and actuators that use piezoelectricity. The need for sensors and memory devices has increased in the IoT society, and the use of energy harvesters has been also considered. These devices have been developed with the phenomenological theory of ferroelectric phase transition as support. However, it became clear that the electrical polarization of ferroelectrics originated from the geometrical phase of the wave function, and theoretical understanding of this has progressed dramatically in the last 25 years. New physical properties have been found experimentally in response to the progress of theory, and device applications are expected. This project elucidate the high-speed operation mechanism of two such innovative devices: a steep slope field-effect transistor (FET) that operates with ultra-low power and a thermal management device that cools electronic equipment with high efficiency. In addition, the principles of device design will be established using evaluation methods built on the coherence states of elementary excitation.

【Research Methods】

The final goals of this project are to elucidate an operation model of these new devices using the coherent states of elementary excitation in ferroelectrics and to construct the guiding principles that will enable device design. This project will be configured as shown below. We focus on a steep slope FET that uses negative capacitance and on a thermal management device that exploits electrocaloric effects. The phonon, magnon, and thermal solitons (waves) are used as the elementary excitations across the five-year research period. In the steep slope FET, we evaluate phonon modulation and differences in potential change at the semiconductor surface during ferroelectric polarization switching with a time constant of nsec order by using the coherence states of elementary excitation. Regarding the thermal management device, data on heat transport, absorption, and generation caused by the electrocaloric effect inside the ferroelectrics are collected through real-time measurement and simulation of polarization entropy using elementary excitation, and guiding principles for the design of a solid state heat pump is established.



【Expected Research Achievements and Scientific Significance】

Because various effects are superimposed on the electrically measured device properties, it becomes difficult to clarify the physical picture of the operation mechanism. The use of elementary excitation is an effective method of model verification because the physical phenomenon of coherence in elementary excitation is unique to a device, and the method can be applied to measuring the dynamic behavior of device operation in a specific time domain. In addition, a theory of the quantum mechanical phase interface of ferroelectrics can be constructed based on these results. This research develops not only methods for evaluating device performance but also the science of elucidating the physical picture of operation mechanisms that is important for designing optimized devices. It is now possible to provide physical models of various devices, and the potential ripple effect on society is significant.

【Publications Relevant to the Project】

- Time-resolved simulation of the negative capacitance stage emerging at the ferroelectric/semiconductor hetero-junction, AIP Advance, 9 (2019) 025037
- Ferroelectric Thin Films-Basic Properties and Device Physics for Memory Applications, Topics in Applied Physics vol.98, (2005) Springer
- Second Sound in $SrTiO_3$, Phys. Rev. Lett., 99 (2007) 265502
- Light Scattering in a Phonon Gas, Phys. Rev. B, 80 (2009) 165104
- Writing and reading of an arbitrary optical polarization state in an antiferromagnet, Nature Photonics, 9(2015) 25
・Directional control of spin wave emission by spatially shaped light, Nature Photonics, 6 (2012) 662

【Term of Project】 FY2019-2023

【Budget Allocation】 156,200 Thousand Yen

【Homepage Address and Other Contact Information】

http://www.pe.osakafu-u.ac.jp/device7/