【Grant-in-Aid for Transformative Research Areas（Ｂ）】

Dynamic control of anyons toward novel information technologies

Principal Investigator	The University of Tokyo, The Institute for Solid State Physics, Associate Professor HASHISAKA Masayuki　　Researcher Number : 80550649
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Purpose and Background of the Research

●Outline of the Research

A quantum bit, the physical building block of a quantum computer, loses quantum information when it interacts with its environment, causing errors in computation. The difficulty of error correction has been a bottleneck in developing a quantum computer. Topological quantum computation, fault-tolerant in principle, is widely recognized as a technology to overcome this problem. The starting point for the realization of topological quantum computation is to manipulate the motion of quasiparticles (elementary excitations) referred to as anyons.

Particles in three-dimensional space are categorized as either Bosons or Fermions. On the other hand, quasiparticles (anyons) that defy this conventional wisdom may exist in two-dimensional electron systems. When one anyon round trips around another one, the system's initial and final states are quantum mechanically distinct; this operation is called 'braiding.' A topological quantum computer uses these distinct states as quantum information. This project studies the dynamical control of anyons in the fractional quantum Hall state toward on-demand braiding to pave the way to realize a topological quantum computer.

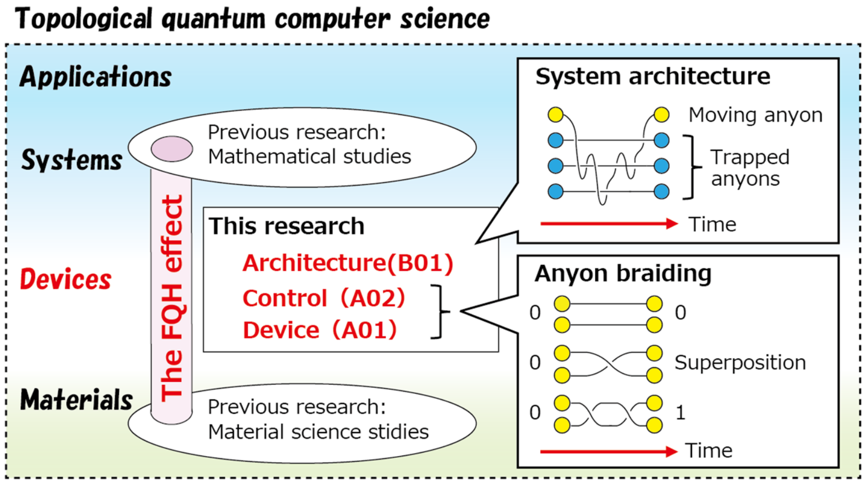

Figure 1. Overview of this project. Some previous works have studied system architectures of topological quantum computation from a mathematical point of view without assuming a concrete material platform. Others have examined the emergence of anyons in topological materials from the material science point of view. Our project aims to bridge these separated research areas through device science for anyons in the fractional quantum Hall state.

●Anyon braiding

When one anyon round trips around another, the states before (|0> state) and after (|1> state) the motion are different quantum mechanically. Because the trajectories of the anyons (blue and green lines in Figure 2) look like entangled strings, we refer to the motion as the braiding.

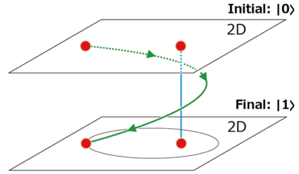

Figure 2. Anyon braiding

●Control of the anyon motion

We need a technique to control the motion of anyons in a two-dimensional space for braiding. Since anyons in a fractional quantum Hall system have an electrical charge, we can expect to manipulate their motion electrically, making them an ideal objective for a braiding technology development. In this project, the experimental teams (Groups A01 and A02) study device structures and high-speed electrical control techniques for manipulating anyon motion. The theoretical team (Group B01) studies the system architecture toward developing a topological quantum computer based on the fractional quantum Hall anyons.

Expected Research Achievements

●Purpose of this project

We promote interdisciplinary research, including mathematics, physics, engineering, and informatics, to achieve technological innovation across the material, device, and system layers of topological quantum computation. Our goal is to create a new research field, which can be called 'topological quantum computer science.'

●Issues to be solved

We consider four steps to establish topological quantum computer science. (1) Demonstration of anyonic quantum statistics, (2) Device fabrication for on-demand braiding operations, (3) Development of a high-speed control technique for the braiding device, (4) Making a proposal of a system architecture for quantum computation based on realistic braiding devices. Recently, the first issue was solved using the fractional quantum Hall aynons. We aim to solve the remaining three issues to reach the goal of our project.

Group A01 studies anyons in fractional quantum Hall systems to develop a prototype device for on-demand braiding operations. It also leads the joint research with the other groups.

Group A02 studies terahertz electronics to achieve high-speed operation of anyon control devices.

Group B01 studies the quantum information theory of fractional quantum Hall anyons to propose a system architecture for information processing based on the anyon braiding.

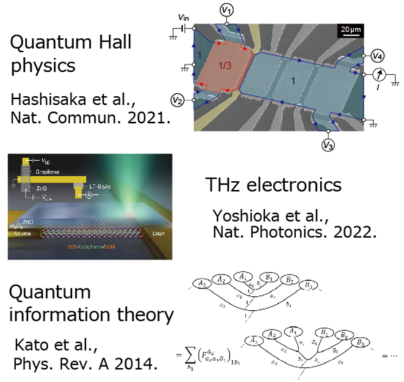

Figure 3. Our strength

Homepage Address, etc.	Project website: https://hashisaka.issp.u-tokyo.ac.jp/anyon.html Researcher's website: https://hashisaka.issp.u-tokyo.ac.jp/Eindex.html