Floating-Electron-Based Quantum Information RIKEN Hakubi Research Team
(2022)

RIKEN Hakubi Team Leader, Erika Kawakami, Ph.D. Degree

(0) Research field

CPR Subcommittee: Physics, Engineering
from Physics, Chemistry, Biology and Engineering

Keywords: microwave, qubit, quantum computer, electrons on helium, Rydberg state

(1) Long-term goal of laboratory and research background

Surface state electrons on liquid helium form an exceptionally clean two-dimensional electron system at the interface between liquid helium and vacuum. Thanks to its cleanness, the quantum states of the electrons on helium are expected to have a long coherence time, which provides a perfect platform to realize qubits with. Thus, we aim to realize a scalable quantum computer using electrons on helium.

We also work on developing new technologies which is required when a large number of qubits are prepared in a cryogenic equipment such as a cryogenic microwave source.

(2) Current research activities (FY2022) and plan

(A) Rydberg-spin qubits of electrons on helium

We propose a new way to realize qubits: a hybrid qubit of the Rydberg state and the spin state of electrons floating on the surface of liquid helium. An artificially introduced interaction between the Rydberg state and the spin state allows us to transfer the qubit state between the Rydberg and spin states. In this way, we can benefit from both the long coherence time of the spin state and the long-range interaction of the Rydberg state in the course of qubit operation.

The interaction between the Rydberg state and the spin state is artificially introduced by a ferromagnet which is placed near the electron. We theoretically showed that the introduced magnetic field gradient mixes the spin state and the orbital state and shortens the spin relaxation time to 50 ms but does not degrade the qubit fidelity. We estimated the single-qubit gate and the two-qubit gate fidelities to be > 99.9999% and ~99%, respectively.

Future plan: We realize the Rydberg-spin qubits experimentally.

(B) Development of a cryogenic microwave source

One of the key features required to realize a fault-tolerant scalable quantum computer is the integration of reliable and energy-efficient electronics for qubit control and readout. Recently, qubit control electronics have been successfully integrated using cryogenic CMOS technology and superconducting Josephson junctions. Here, we focus on the development of readout electronics using tunnel-diode oscillator circuits. Compared to cryogenic CMOS devices and superconducting Josephson junction circuits, the tunnel-diode oscillator (tdo) circuits have lower power dissipation (~1μW). Furthermore,
we propose a new idea to increase the qubit readout fidelity using the synchronization of two oscillator circuits.

Future plan: We will use the homemade tdo circuit to measure the characteristic of an LC resonator at low temperature.

(3) Members

	Name
RIKEN Hakubi Team Leader	Erika Kawakami
Technical Scientist	Ivan Grytsenko
Postdoctoral fellow	Asher Jennings
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Kiattichart Chartkunchand
Takuma Okumura

(4) Representative research achievements

1. E. Kawakami, A. Elarabi, D. Konstantinov, "Relaxation of the Excited Rydberg States of Surface Electrons on Liquid Helium." Physical Review Letters, 126, 106802 (2021).
2. A. Elarabi, E. Kawakami, D. Konstantinov, "Cryogenic amplification of image-charge detection for readout of quantum states of electrons on liquid helium. " Journal of Low Temperature Physics volume 202, 456 (2021).
3. Erika Kawakami, "Dispersive read-out of the Rydberg states of electrons on helium", DAQS2022, Online, February 21-23 (2022).
4. Erika Kawakami, "Towards realizing spin qubits using electrons on helium", QFS2021, Online, August 10-19 (2021).
5. Erika Kawakami, "Radio-Frequency Measurements of the Rydberg States: towards realizing qubits using electrons on helium", Online, Quantum matter at ultra-low temperatures, July 20-21 (2022).

Laboratory Homepage

https://sites.google.com/view/febqi/
https://www.riken.jp/research/labs/rqc/floatelectron_based_qtm_inf_riken_hakubi/