ED4-1-INV

Development of a commercial superconducting quantum annealing processor

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In January 2017, D-Wave announced general commercial availability and the first system order of its D-Wave 2000Q quantum computer. This system implements an algorithm called quantum annealing, and is based upon a superconducting integrated circuit chip with over 128 thousand Josephson junctions. I will review quantum annealing, some of its potential applications, and discuss some of the unique challenges encountered commercializing a technology based on superconducting circuits.

Keywords: Quantum computing, Quantum annealing, Josephson junction, Superconductor electronics

ED4-2-INV

ASAC: Application Specific Annealing Circuit – A New Approach Towards Designing a Quantum Annealing Superconductor Integrated Circuit

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A new approach towards designing a quantum annealing superconductor integrated circuit, called Application Specific Annealing Circuit, or ASAC in short, is proposed in this presentation. Quantum annealing circuits designed so far, i.e. generations of pioneering superconductor chips from D-Wave Systems among others, have a fixed regular structure, consisting of general-purpose qubits and flexible couplers with a wide range of variable coupling strength to connect qubits to each other. This design is very similar to the structure of FPGA (Field Programmable Gate Arrays), which has become very popular in the CMOS logic market these days, and provides similar benefits such as: 1) reconfigurability to suit as wide users' needs as possible by mapping a wide range of problems onto the common regular structure, 2) fault-tolerance by mapping the same problem in several ways to avoid faulty parts of the chip and to enhance the usability of the system, and so on.

Although these benefits are essential for the commercial systems to gain as wide markets as possible, the fact remains that there is a performance gap between FPGA and ASIC, which provides several opportunities for performance improvement to be investigated. This motivates our new approach ASAC, in which qubits, couplers (strength and topology), and so on, are specialized and optimized to solve a specific optimization problem in the most efficient way. In this presentation, we will discuss the technical opportunities of ASAC, and show our current development effort on ASAC for integer factoring as an example.

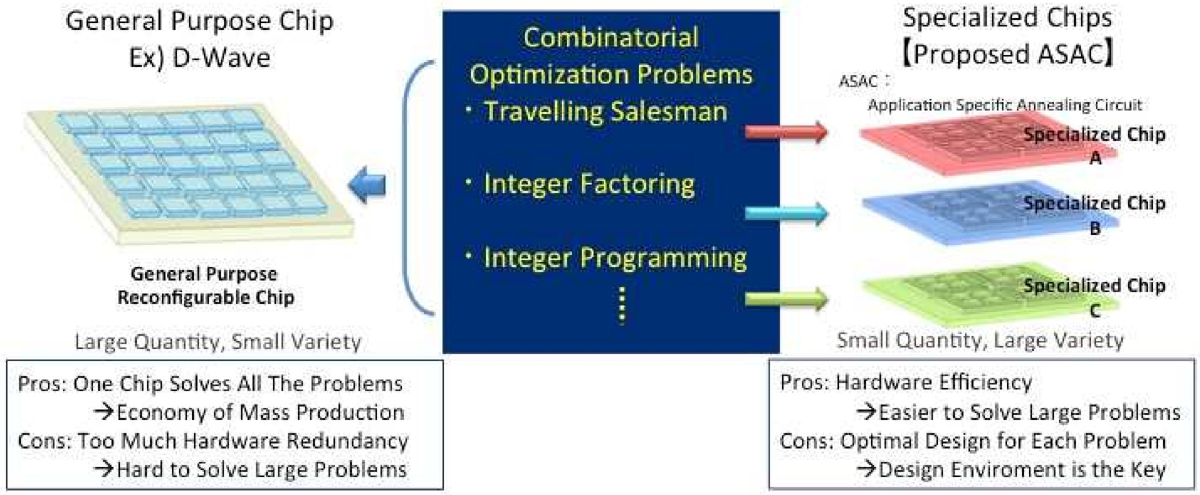

Fig. Concept of ASAC: Application Specific Annealing Circuit

Keywords: Quantum Annealing, Application Specific Annealing Circuit, FPGA, ASIC

ED4-3-INV

Superconducting qubit-oscillator circuit beyond the ultrastrong-coupling regime

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The interaction between an atom and the electromagnetic field inside a cavity has played a crucial role in the historical development of our understanding of light-matter interaction and is a central part of various quantum technologies. The emergence of superconducting qubits has allowed the realization of strong and ultrastrong coupling between artificial atoms and cavities. If the coupling strength g becomes as large as the atomic and cavity frequencies (Δ and ω respectively), the energy eigenstates including the ground state are predicted to be highly entangled. This qualitatively new regime can be called the deep strong-coupling regime.
By inductively coupling a superconducting flux qubit, which has a large magnetic dipole moment due to its macroscopic persistent current states, and an LC oscillator, which has a large zero point fluctuation current, via a Josephson junction coupler with large Josephson inductance as shown in Figure, we have realized deep-strong coupling between the qubit and the oscillator[1]. The spectra obtained in the spectroscopy measurement were well fitted by the Hamiltonian of the quantum Rabi model, which describes a system consisting of a two-level atom and a harmonic oscillator without rotating-wave approximation, and the parameters are obtained to be $g/\omega > 1$ and $g/\Delta >> 1$. We also found that the qubit frequency is suppressed more than 90% from its original value. This can be considered as a huge Lamb shift of the flux qubit due to the deep-strong coupling to the vacuum-fluctuation current of the LC oscillator.

Our results provide a basis for ground-state-based entangled-pair generation and open a new direction of research on strongly correlated light-matter states in circuit quantum electrodynamics.

Reference: [1] F. Yoshihara and T. Fuse et al., Nature Phys. 13, 44 (2017).

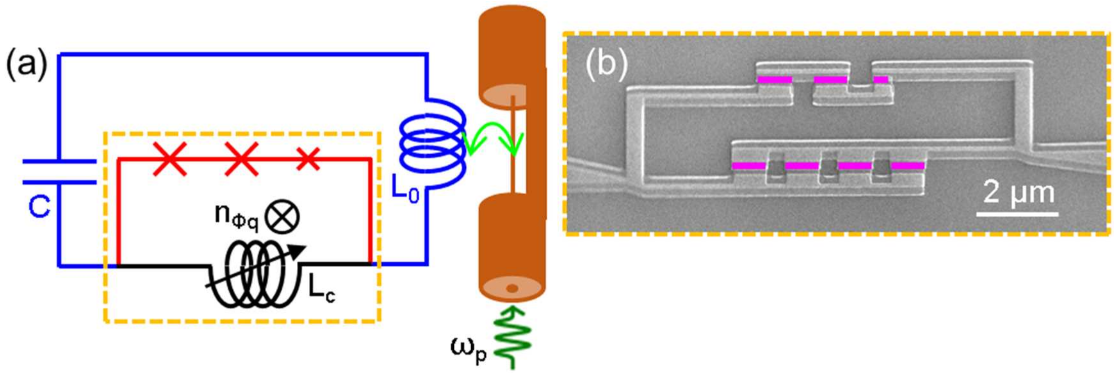

Figure caption: (a) Circuit diagram. A superconducting flux qubit (red and black) and a superconducting LC oscillator (blue and black) are inductively coupled to each other by sharing a tunable inductance (black). (b) Scanning electron microscope image of the qubit including the coupler junctions located at the orange rectangle in (a). Josephson junctions are represented by magenta rectangles. The coupler, consisting of four parallel Josephson junctions, is tunable via the magnetic flux bias through its loop.

Keywords: circuit quantum electrodynamics, superconducting flux qubit, quantum Rabi model

ED4-4-INV

Sensing magnetization oscillation in quantum regime

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Quanta of magnetization oscillation, i.e., magnons, are essential ingredients in spintronics technology. Although their characteristics have been investigated for a long time, the behavior in the quantum regime, where the number of thermal excited magnons is nearly zero, is still unknown. Here we demonstrate ultra-sensitive sensing of magnons using a superconducting qubit. Superconducting "transmon" qubits, which are formed by two electrodes shunted by Josephson junctions, have dipole antennas in their structures and thus they couple to surrounding electromagnetic fields. Owing to their huge dipole moments which are typically 4th-order-magnitude larger than those of atoms, the transmon qubits can detect a change in microwave signal to a single photon level. We exploit such feature for sensing the magnetization oscillation in a magnet. A transmon qubit interacts with an electric microwave field, whereas the magnetization couples to a magnetic microwave field through ferromagnetic resonance. We use a microwave rectangular cavity to induce an effective coupling between them; both the qubit and the magnetization couple with the same microwave field mode but through different components [1]. With an appropriate detuning between the qubit and magnetization oscillation frequencies, the qubit excitation frequency shifts depending on the number of magnons in the magnetization oscillation mode. The qubit resonance peak shift is discretized in the limit where the qubit linewidth is narrower than the shift for a single magnon, so that we can count magnons in the magnetization oscillation mode to a single magnon level. We experimentally show that the coherently excited magnetization oscillation obeys the Poissonian magnon number distribution [2]. Our ultra-sensitive sensing method provides a powerful tool for magnetization oscillation sensing as well as quantum information processing.

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Keywords: Quantum Sensing, Magnon, Superconducting Qubit, Quantum Information Processing

ED4-5-INV

Scanning Nano-SQUID for Nanoscale Thermal Imaging of Dissipation in Quantum System

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Energy dissipation is a fundamental process governing the dynamics of physical systems. In condensed matter physics, in particular, scattering mechanisms, loss of quantum information, or breakdown of topological protection are deeply rooted in the intricate details of how and where the dissipation occurs. More specifically, conversion of electric current into heat involves microscopic processes that operate on nanometer length scales and release minute amounts of power. While central to our understanding of the electrical properties of materials, individual mediators of energy dissipation have so far eluded direct examination.
We recently developed a superconducting quantum interference nano-thermometer device with sub 50 nm diameter that resides at the apex of a sharp pipette and provides scanning cryogenic thermal sensing with four orders of magnitude improved thermal sensitivity of below 1 uK/sqrtHz at 4.2 K [1]. We applied this novel thermal imaging technique to study dissipation processes in hBN encapsulated graphene heterostructures. We reveal local heat released through resonant inelastic electron scattering from individual defects along the edges of graphene that form localized states near the Dirac point. The defects act as switchable phonon emitters providing energy sinks for electrons when brought into resonance with defects' energy levels.

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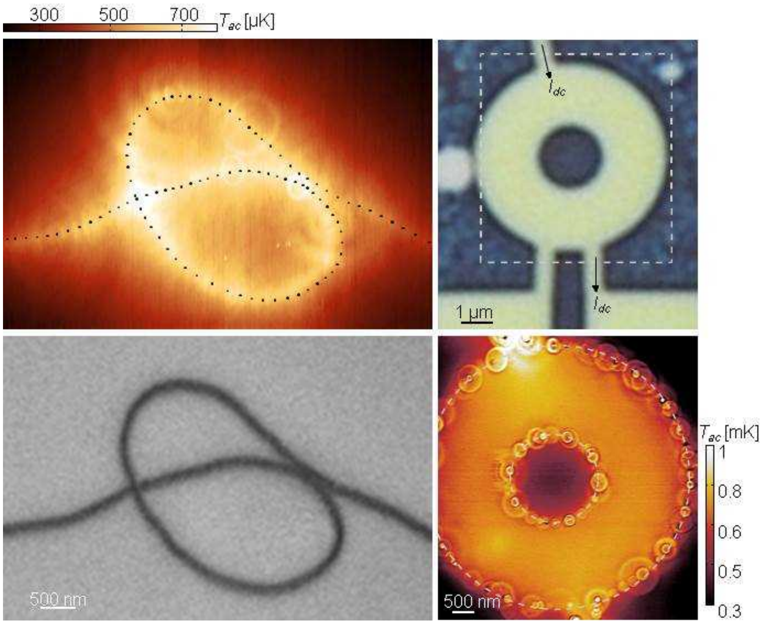

Keywords: Nanoscale thermal microscopy, Scanning nano-SQUID , Graphene