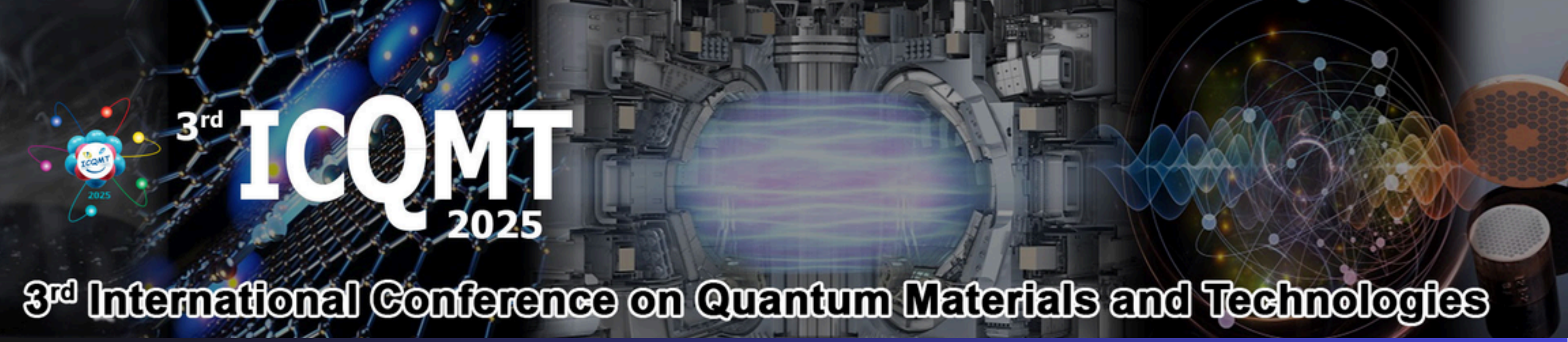

Superconducting Electronics and Spintronics for Energy-Efficient Classical and Quantum Computing

Distinguished Professor
OLEG MUKHANOV

Dr. Oleg Mukhanov is Chief Technology Officer and co-founder of SEEQC, Inc., a quantum computing spinout of Hypres. Prior to that he was CTO and President, Quantum Information Processing at Hypres. He received the Ph.D. in physics (1987) from Moscow State University and the M.S. in electrical engineering (1983) from Moscow Engineering Physics Institute (with honors). Dr. Mukhanov has more than 30 years of experience in superconducting electronics. From 1991 to 2019, he was with Hypres, Inc. – an IBM spinoff focused on the development of high-performance superconducting electronics. He joined Hypres to initiate the development of Rapid Single Flux Quantum (RSFQ) superconductor circuit technology, which he co-invented in 1985. Over the years at Hypres, Dr. Mukhanov went from circuit designer to chief technical officer, initiated and led many projects on high-performance digital and mixed signal RSFQ circuits including data processors and memory, radio frequency signal reception, signal and time digital processing, cryogenic interfaces for a variety of applications including terrestrial and satellite wireless communications, radar, instrumentation, and high-end computing. This resulted in the first commercial use of superconducting digital electronics – RSFQ-based Digital-RF receivers.

Date and Time:
From 26 April to 3 May 2025, exact day&time will be announced later.

Lecture Room:
TBD

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Biography-continued

Dr. Mukhanov designed and demonstrated a number of the world's fastest digital circuits. He co-invented Digital-RF architecture and led the development of the world's first cryocooled Digital-RF receiver system. He also co-invented and led the development of new generation of energy-efficient single flux quantum technology and superconducting ferromagnetic and superconducting spintronic random-access memories for energy efficient computing systems. Dr. Mukhanov authored and co-authored over 200 scientific papers, book chapters and over 50 issued patents. He is a member of advisory committees of international conferences and institutions on superconducting electronics, was chair and member of organizing and program committees of many national and international superconductor electronics conferences. In 2005-2007, Dr. Mukhanov was a president of the US Committee on Superconducting Electronics. He was a long-standing editor of IEEE Transactions of Applied Superconductivity (2002-2019) and received an IEEE outstanding service recognition as an editor of special issues of this journal. From 2020, he is an editor of IEEE Transactions on Quantum Engineering. Dr. Mukhanov is a Fellow of IEEE and member of American Physical Society. He is the recipient of The IEEE Award for Continuing and Significant Contributions in the Field of Small Scale Applied Superconductivity (2015).

Abstract

According to the International Energy Agency (IEA), electricity consumption from data centers, artificial intelligence and the cryptocurrency sector could double by 2026 and exceed 1,000 TWh. Reducing the power dissipation at the highest processing speed is the central objective for any information processing circuit technology. Superconducting Single Flux Quantum (SFQ) digital electronics based on Josephson junction circuits with its unparallel clock speed at tens to even hundreds of GHz at very low-power dissipation has been long considered as the most promising technology for variety of high-end applications including high-performance computing and quantum computing. However, the low integration density and the lack of high capacity, high operational margin superconducting memory technology compatible with digital superconducting circuits has been a major limiting factor in utilizing superconducting electronics for many decades.
Superconductor/ferromagnet heterostructures including Josephson junctions with ferromagnetic materials are capable of addressing these challenges and even potentially enable new applications in neuromorphic, reservoir, and quantum computing. These devices were used to build static phase shifters and switchable junctions in superconducting digital circuits to increase their operational tolerances, reduce total bias current, and enable new functionalities. Another promising area is superconducting diodes. This can be used in dc-biased SFQ circuits to avoid the rise of total bias current with the number of cells limiting the circuit scalability. This is also important for SFQ circuits used for qubit control and readout while minimizing thermal load and electromagnetic noise. The recently developed superconducting diodes demonstrated high efficiency and tunability.
The most significant impact is expected in using superconductor/ferromagnet elements for memory applications. If a junction contains multiple ferromagnetic layers whose relative magnetization directions can be controlled by application of a relatively small magnetic field (e.g., using current lines) or by spin torque, then this device can serve as a memory element. Multiple memory cell designs were proposed and implemented. The key is to design a memory element which can be integrated to form a high density, highly energy efficient, fully addressable memory array compatible with SFQ digital technology. In particular, a hybrid vertically integrated superconducting-ferromagnetic device can act as an addressable memory cell, in which the ferromagnetic junction stores the information, while superconducting Josephson junction acts as a readout device. Electric current applied along the superconducting electrode can change the magnetization of the ferromagnetic layer in such a way that, for one current direction, a magnetic flux penetrates the junction perpendicular to the layers, whereas for the opposite direction, the perpendicular magnetic flux can be removed.
For quantum computing, superconductor/ferromagnet elements have been proposed as circuit elements qubit designs. The characteristic hysteretic behavior of the ferromagnetic barrier provides an alternative and intrinsically digital tuning of the qubit frequency by means of magnetic field pulses. The recent results demonstrated that the ferromagnetic layer does not affect the quality of the junction in qubits.
Integrated superconducting electronics and spintronic elements can open new functionalities, performance capabilities, and practical working characteristics not attained with other technologies.

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