

Preface

Over the past decade, superconducting devices have risen to prominence in the arena of quantum optics and quantum information processing. Superconducting detectors provide unparalleled performance for the detection of infrared photons. These devices enable fundamental advances in quantum optics, the realization of quantum secure communication networks, and open a direct route to on-chip optical quantum information processing. Superconducting circuits based on Josephson junctions provide a blueprint for scalable quantum information processing as well as opening up a new regime for quantum optics at microwave wavelengths. We have endeavored to provide a timely compilation of contributions from top groups worldwide across this dynamic field. This volume provides both an introduction to this area of growing scientific and technological interest, and a snapshot of the global state-of-the-art. Future advances in this domain are anticipated.

Part I of this volume focuses on the technology and applications of superconducting single-photon detectors for near infrared wavelengths.

Chapter 1 provides an authoritative introduction to superconducting nanowire single photon detectors by leading researchers from the Massachusetts Institute of Technology, the NASA Jet Propulsion Laboratory, and the National Institute of Standards and Technology (NIST), USA. The superconducting nanowire device principle is discussed in detail. Key concepts are introduced such as detection efficiency, dark count rate, and timing jitter. The use of amorphous superconducting materials to achieve high device yield and extended mid-infrared sensitivity is highlighted. Parallel wire architectures are presented and an outlook is given on the scale-up to large area arrays.

Chapter 2 introduces another key superconducting detector technology, the superconducting transition edge sensor. The chapter is contributed by the team at NIST, USA, who has been in the vanguard of developments in this technology. The device operation principle is introduced, including key considerations for maximizing sensitivity for the detection of infrared photons and photon-number resolving capability. A range of important quantum optics experiments exploiting

the unique capabilities of transition edge sensors are reviewed. Finally, the integration of transition edge sensors with optical waveguide circuits is discussed.

Chapter 3 focuses on superconducting nanowire detectors integrated with GaAs photonic circuits. The chapter is contributed by a team of authors from the Technical University of Eindhoven, the Netherlands, Consiglio Nazionale delle Ricerche (CNR) Rome, Italy and the University of Bristol, UK. This approach is compatible with quantum dot single photon emitters, opening the pathway to fully integrated quantum photonic circuits.

Chapter 4 reviews progress on superconducting nanowire detectors on silicon-based photon circuits. This work is contributed by researchers at Yale University, USA, and the University of Muenster, Germany. The marriage of superconducting detectors with mature planar lightwave circuits is a compelling alternative for on-chip quantum information processing. A range of technological applications are discussed, including single photon characterization of on-chip resonators and optical time domain reflectometry for long haul fiber links.

Chapter 5 gives an overview of applications of superconducting nanowire single photon detectors in the realm of quantum communications. The chapter is authored by a team of researchers from the National Institute of Information and Communication Technology (NICT) in Japan. The chapter describes how low noise superconducting nanowire single photon detectors enabled the world's most ambitious quantum cryptography network to be realized in Tokyo, Japan. This chapter also describes developments in heralded single-photon source and quantum interface technology, enabled by high-performance superconducting detectors.

Part II switches the emphasis to quantum optics in the microwave regime using superconducting circuits at millikelvin temperatures.

Chapter 6 gives an authoritative introduction to the emerging field of microwave quantum photonics. It describes the basic building blocks including transmission lines, cavities, artificial atoms (qubits), and measurement setups. This chapter is authored by researchers from the University of Queensland, Australia, and Jiangxi Normal University, China. This chapter highlights the potential of superconducting circuits to access and control quantum phenomena in the realm of microwave photons.

Chapter 7 explores the role of continuous weak measurements as a probe of quantum dynamics in superconducting circuits. In particular, it discusses the possibility to experimentally characterize the systems evolution in terms of quantum trajectories and also how to use the feedback from weak measurements to stabilize Rabi oscillations. This chapter is contributed by experts from Washington University, St. Louis, USA, the University of California, Berkeley, USA, and the Tata Institute of Fundamental Research, Mumbai, India.

Chapter 8 focuses on digital feedback control methods for superconducting qubits. In particular, it describes the use of projective measurements and feedback for fast qubit reset and deterministic entanglement generation. This chapter is contributed by leading researchers at the Delft University of Technology, the Netherlands, and Raytheon BBN Technologies, USA. This high fidelity projective measurement-based technique now allows fast initialization of superconducting

qubits and brings deterministic generation of entangled states by parity measurement within reach.

Chapter 9 highlights the use of surface acoustic waves (SAWs) in connection with superconducting quantum circuits. In particular, it describes the coupling of a superconducting artificial atom to propagating SAWs and also how to form SAW cavities in the relevant parameter regime of high frequency and low temperatures. This chapter is authored by a team from Chalmers University, Sweden, Columbia University, USA, RIKEN, Japan, and the University of Oxford, UK. This new technique enables exploitation of single phonons as carriers of quantum information between superconducting qubits as well as providing a method of storage of quantum information in high quality phononic cavities.

This book arose out of a special symposium on ‘Superconducting Optics’ at the joint Conference on Lasers and Electro-Optics—International Quantum Electronics Conference (CLEO ®/Europe—IQEC conference) which took place in Munich, Germany, in May 2013. One of us (R.H.H.) was a chair of the symposium and the other (G.J.) was an invited speaker. We thank Prof. Dr. Jürgen Eschner of Universität des Saarlandes, Germany, and the CLEO ®/Europe—IQEC programme committee for proposing the special symposium. We undertook the task of editing this book with encouragement from Dr. Claus Ascheron at Springer and Prof. Gerard J. Milburn of the University of Queensland, Australia, Springer Quantum Science and Technology Series Editor. We thank Praveen Kumar and his team at the Springer production office in Chennai, India, for their diligent handling of the proofs. We thank the authors for their high-quality contributions and their dedication in meeting challenging deadlines. We also acknowledge colleagues who proofread parts of the volume, including Dr. Chandra Mouli Natarajan, Dr. Jian Li and Dr. Robert Heath of the University of Glasgow, and Dr. Matti Silveri of Yale University, USA. Finally, we thank our respective families of their patience and forbearance as we guided this volume towards completion.

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