

Design of broadband high-efficiency superconducting-nanowire single photon detectors

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Abstract: In this paper several designs to maximize the absorption efficiency of superconducting-nanowire single-photon detectors are investigated. Using a simple optical cavity consisting of a gold mirror and a SiO₂ layer, the absorption efficiency can be boosted to over 97%; this result is confirmed experimentally by the realization of an NbTiN-based detector having an overall system detection efficiency of 85% at 1.31 μ m. Calculations show that by sandwiching the nanowire between two dielectric Bragg reflectors, unity absorption (>99.9%) could be reached at the peak wavelength for optimized structures. To achieve broadband high efficiency, a different approach is considered: a waveguide-coupled detector. The calculations performed in this work show that, by correctly dimensioning the waveguide and the nanowire, polarization-insensitive detectors absorbing more than 95% of the injected photons over a wavelength range of several hundred nm can be designed. We propose a detector design making use of GaN/AlN waveguides, since these materials allow lattice-matched epitaxial deposition of Nb(Ti)N films and are transparent on a very wide wavelength range.

1. Introduction

Highly efficient detection of single photons is of capital importance not only for advanced quantum optics experiments but, increasingly, for many emerging industrial applications [1,2]. Single-photon detectors (SPDs) are used today in many fields, such as quantum key distribution [3,4], time-of-flight depth ranging applications such as the Lidar [5,6], space-to-ground optical communication [7], singlet oxygen detection for medical applications [8], and integrated circuit testing [9,10].

In recent years, superconducting-nanowire single-photon detectors (SNSPDs) have undergone rapid development, and they now outperform single-photon avalanche diodes (SPADs) [11,12], especially in the infrared spectral range. Very high efficiencies, up to 98% [13–15] have been demonstrated with SNSPDs at telecom wavelength, which, combined with the very high detector speeds, make SNSPDs the ideal candidate for many of the aforementioned applications [16].

The overall system detection efficiency (η_{sys}) of a SNSPD can be seen as the product of three contributions: the coupling efficiency (η_{coup}), the absorption efficiency (η_{abs}) and the internal efficiency (η_{int}) [1]: $\eta_{\text{sys}} = \eta_{\text{coup}} \times \eta_{\text{abs}} \times \eta_{\text{int}}$.

The coupling efficiency η_{coup} is the probability that a photon travelling in the optical fiber carrying the signal is coupled to the detector. The absorption efficiency η_{abs} provides a measure of the probability, for a photon impinging on the detector, to be actually absorbed by it rather than transmitted or reflected. Finally, the internal efficiency η_{int} is the probability of registering a voltage pulse at the nanowire leads when a photon is absorbed. This latter parameter depends on the choice and quality of the superconducting material (reported values reach > 90% for Nb(Ti)N [17], and close to 100% for WSi [13]), and its optimization will not be discussed in this paper.

The coupling efficiency, η_{coup} , is usually boosted by folding the detecting nanowire in a tightly packed meandering structure, covering a circular area several microns in diameter. It is then possible to efficiently couple the light output from a fiber to the center of the nanowire meander with a self-aligning method, achieving coupling efficiencies close to unity, [18].

Achieving high absorption efficiency is often difficult in SNSPDs. Since the light is usually coupled vertically to the thin (4–8 nm) nanowire, only a small fraction of it is absorbed. Several techniques have been developed to enhance η_{abs} . In

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Supraleitende Einzelphotonenzaehler: Optimierung der Zeitaufloesung und Anwendungsbeispiele aus der Spektroskopie Brandel, Julia, 2019-08-21 **Photon Counting** Nikolay Britun, Anton Nikiforov, 2018-03-21 Photon counting is a unified name for the techniques using single photon detection for accumulative measurements of the light flux normally occurring under extremely low light conditions Nowadays this approach can be applied to the wide variety of the radiation wavelengths starting from X ray and deep ultraviolet transitions and ending with far infrared part of the spectrum As a special tribute to the photon counting the studies of cosmic microwave background radiation in astronomy the experiments with muon detection and the large scale fundamental experiments on the nature of matter should be noted The book provides readers with an overview on the fundamentals and state of the art applications of photon counting technique in the applied science and everyday life Nanophotonics and Plasmonics Dr. Ching Eng (Jason) Png, Dr. Yuriy Akimov, 2017-08-21 This book provides a first integrated view of nanophotonics and plasmonics covering the use of dielectric semiconductor and metal nanostructures to manipulate light at the nanometer scale The presentation highlights similarities and advantages and shows the common underlying physics targets and methodologies used for different materials optically transparent materials for nanophotonics vs opaque materials for plasmonics Ultimately the goal is to provide a basis for developing a unified platform for both fields In addition to the fundamentals and detailed theoretical background the book showcases the main device applications Ching Eng Jason Png is Director of the Electronics and Photonics Department at the Institute of High Performance Computing Agency for Science Technology and Research Singapore Yuriy A Akimov is a scientist in the Electronics and Photonics Department at the Institute of High Performance Computing Agency for Science Technology and Research Singapore *Design of Broadband High-efficiency Superconducting-nanowire Single Photon Detectors*, 2016
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Handbook of Superconductivity David A. Cardwell, David C. Larbalestier, Aleksander Braginski, 2022-07-05 This is the last of three volumes of the extensively revised and updated second edition of the Handbook of Superconductivity The past twenty years have seen rapid progress in superconducting materials which exhibit one of the most remarkable physical states of matter ever to be discovered Superconductivity brings quantum mechanics to the scale of the everyday world Viable applications of superconductors rely fundamentally on an understanding of these intriguing phenomena and the availability of a range of materials with bespoke properties to meet practical needs While the first volume covers fundamentals and various classes of materials the second addresses processing of these into various shapes and configurations needed for applications and ends with chapters on refrigeration methods necessary to attain the superconducting state and the desired performance This third volume starts with a wide range of methods permitting one to characterize both the materials and

various end products of processing Subsequently diverse classes of both large scale and electronic applications are described Volume 3 ends with a glossary relevant to all three volumes Key Features Covers the depth and breadth of the field Includes contributions from leading academics and industry professionals across the world Provides hands on familiarity with the characterization methods and offers descriptions of representative examples of practical applications A comprehensive reference the handbook is suitable for both graduate students and practitioners in experimental physics materials science and multiple engineering disciplines including electronic and electrical chemical mechanical metallurgy and others

European Particle Accelerator Conference (Epac 94) (In 3 Volumes) Christine Petit-jean-genaz, Vic Suller, 1994-11-26 These proceedings aim to provide a comprehensive overview of research technology and applications in the field of accelerators Contributions from the entire field of accelerators are presented including low and high energy machines and medical and industrial accelerators *Nuclear Science Abstracts*, 1971 NSA is a comprehensive collection of international nuclear science and technology literature for the period 1948 through 1976 pre dating the prestigious INIS database which began in 1970 NSA existed as a printed product Volumes 1 33 initially created by DOE s predecessor the U S Atomic Energy Commission AEC NSA includes citations to scientific and technical reports from the AEC the U S Energy Research and Development Administration and its contractors plus other agencies and international organizations universities and industrial and research organizations References to books conference proceedings papers patents dissertations engineering drawings and journal articles from worldwide sources are also included Abstracts and full text are provided if available Department of Defense Appropriations for 1970 United States. Congress. House. Committee on Appropriations, 1969 Department of Defense Appropriations United States. Congress. House. Committee on Appropriations. Subcommittee on Department of Defense, 1970 **Energy and Water Development Appropriations for 2008: Dept. of Energy FY 2008 budget justifications: science, nuclear waste disposal, defense nuclear waste disposal** United States. Congress. House. Committee on Appropriations. Subcommittee on Energy and Water Development, 2007 Publications of the National Institute of Standards and Technology ... Catalog National Institute of Standards and Technology (U.S.), National Institute of Standards and Technology (U.S.). Information Resources and Services Division, 1994 *Energy and Water, and Related Agencies Appropriations for Fiscal Year 2007* United States. Congress. Senate. Committee on Appropriations. Subcommittee on Energy and Water, and Related Agencies, 2006 **Energy and Water Development Appropriations for 2007** United States. Congress. House. Committee on Appropriations. Subcommittee on Energy and Water Development, 2006 *A Selected Listing of NASA Scientific and Technical Reports for ...* United States. National Aeronautics and Space Administration. Scientific and Technical Information Division, 1966 *A Selected Listing of NASA Scientific and Technical Reports for 1966* United States. National Aeronautics and Space Administration. Scientific and Technical Information Division, 1967 *NASA Scientific and Technical Reports* United States.

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