High-efficiency, superconducting nanowire single-photon detectors from ultraviolet to infrared

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***Abstract*—Superconducting nanowire single-photon detectors (SNSPDs) have demonstrated outstanding performance metrics over a wide range of wavelengths, from the ultraviolet to the long-wave infrared (LWIR). System detection efficiencies approach 100% at specific wavelengths with very low dark count rates and low timing jitter. Recent experiments such as time-resolved photoluminescence of mid-IR emitting semiconductors and integration of SNSPDs with ion traps will be described.**

Keywords—single-photon detectors, quantum optics, SNSPD

I. Introduction

Advances in superconducting nanowire single-photon detectors (SNSPDs) in the past decade have enabled these detectors to become the first choice for the most demanding applications in quantum optics as well as classical applications that require the best signal-to-noise ratio while detecting single photons. SNSPDs typically consist of a meander of a superconducting metal cooled to below the transition temperature from normal metal to superconducting metal. Most metals can absorb light over a very wide spectral band width, and this enables SNSPDs to be engineered for optimum performance at wavelengths ranging from the ultraviolet to the long-wave infrared. This manuscript summarizes some the most significant results demonstrated in the Applied Physics Division of the US National Institute of Standards and Technology, in conjunction with various collaborators, over the past several years.

II. Introduction to SNSPDs

SNSPDS were first demonstrated in 2001 [1]. These devices were formed from sputtered NbN thin films, and their performance metrics (~ 20% detection efficiency at a wavelength of 810 nm, high count rate, and short reset time) attracted significant attention from the quantum optics community. Despite these promising early results, fabrication challenges limited the performance of these detectors. In 2012, our group demonstrated tungsten silicide (an amorphous superconductor) SNSPDs with high efficiency (~20-40% system detection efficiency) at wavelengths as long as 1850 nm and, more importantly, a wide plateau in the efficiency with increasing bias current, indicating a saturation of the internal efficiency [2]. This led to the first very high system detection efficiency (~93%) SNSPDs at a wavelength around 1550 nm in 2013 [3].

III. Applications

Some of the most significant impact of SNSPDs comes from enabling unprecedented demonstrations in the field of quantum optics. An early example of a quantum optics experiment includes the direct generation of three-photon entangled states via cascaded downconversion [4], where the high-efficiency and low dark rates of the SNSPDs were necessary to obtain these measurements. Another significant milestone in quantum optics was achieved in 2015 in which high-efficiency, low dark count rate SNSPDs were used to perform a loophole-free Bell experiment [5]. In this experiment, the high efficiency of the SNSPDs was essential to enable the closure of the fair sampling loophole. With multiple companies now offering SNSPD systems, with detectors available at many wavelengths from the visible through the infrared, most state-of-the-art quantum optics experiments that require the best performance metrics for single-photon detection utilize SNSPDs.

In addition to enabling many quantum optics experiments, SNSPDs also offer many opportunities for new and improved measurements in classical experiments. Some examples include mid-infrared, laser induced fluorescence from monolayers of CO at cryogenic temperatures [6], time-resolved photoluminescence of long wavelength emission from semiconductors [7,8], space-to-ground optical communications, and LIDAR.

Finally, SNSPDs are one of the leading candidates for integration with various types of quantum computers that rely on single-photon detectors for each qubit. SNSPDs have demonstrated excellent performance around 400 nm when integrated with ion traps [9], and they are also utilized for photonic quantum information processing [10].

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