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Viewpoint

Miniaturizing superconducting nanowire single-photon detection systems

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This is a viewpoint on the letter by N R Gemmell *et al* (2017 *Supercond. Sci. Technol.* **30** 11LT01).

Superconducting nanowire single-photon detectors (SNSPDs or SSPDs)[1] have grown to be one of the most important superconducting quantum detectors since the first demonstration by Goltsman *et al* in 2001 [1]. In comparison with the semiconducting avalanche photodiodes (APDs) and photomultipliers, SNSPDs have many merits in their performance, such as high detection efficiency [2, 3], low dark count rate, small timing jitter, and short recovery time. Therefore, SNSPDs are the key enabling technology for various applications, such as quantum key distribution [4], free space laser communication [5], and light detection and ranging [6, 7]. Owing to the good performance of SNSPDs, a niche market that is mainly boosted by the research and development (R&D) of quantum information has been created and will grow in the coming decades. Six companies, namely ID Quantique (Switzerland), Photonspot (USA), Quantum Opus (USA), Scontel (Russia), Shanghai Photon Technology (China), and Single Quantum (Netherlands), are working on the commercialization of SNSPD technology.

For all the superconducting devices, a harmonic family is required to be formed together with a cryogenic system, which provides a temperature that is low enough for the superconducting devices to operate. SNSPDs, without exception, usually require an operating temperature lower than 0.5 T_c, where T_c is the superconducting transition temperature. For example, SNSPDs made of NbN/WSi usually function at a temperature lower than 4 K/2 K respectively. Lowering the temperature improves the performance. Fortunately, commercial two-stage Gifford–McMahon (GM) cryocoolers (for example, RDK-101D from SHI Cryogenics) can provide a temperature as low as 2.1 K that has been proven to be excellent for SNSPDs made of Nb(Ti)N. The integrated commercial SNSPD systems based on GM cryocoolers have been applied in both lab R&D and field tests. However, this kind of SNSPD system is disadvantageous in comparison with the semiconducting single-photon detectors when the size, weight and power (SWaP), and the extra price of the cooler are considered.

Recently, research targeting the SWaP of SNSPD technology has been undertaken. The key issue is to improve the SWaP of cryocoolers. The National Institute of Standards and Technology first presented a proposal of a 2.2 K hybrid compact cryocooler for SNSPD applications at the Applied Superconductivity Conference 2016 [8]. Such a system uses a three-stage linear compressor pulse tube (PT) cooler and a ^{4}He Joule–Thomson (JT) stage, which is projected to consume less than 250 W. However, a suitable JT compressor, which is one of the key components of the JT cooler, has not been developed. Thus, the JT cooler was

[1] This term is well adopted by the community. In the latest released international standard IEC 61788-22-1, Superconductivity–Part 22-1: Superconducting electronic devices—Generic specification for sensors and detectors, it is formally named as a superconducting nanostrip photon detector (SNSPD).

open loop tested using a gas storage bottle as a supply and vacuum pump on the exit. No results on the SNSPD with this system have been reported. In a recent letter [9], the group from the University of Glasgow headed by Robert Hadfield first demonstrated a miniaturized 4 K platform for SNSPDs. This platform was based on Stirling and ^{4}He JT cycles which reached a base temperature of 4.3 K. Using this platform, the SNSPD showed a system detection efficiency (SDE) of 20% at a wavelength of 1310 nm. Although the performance is smooth, similar to the semiconducting APDs, it can be regarded as an excellent attempt to study SNSPDs with acceptable SWaP.

One important viewpoint which was mentioned but not emphasized by the authors is the potential for space applications. The commercial GM cryocoolers are not compatible with space applications. The cooler reported in [9] was originally designed as a demonstrator for the Planck space mission. A functionally equivalent JT cooler has been operated flawlessly in space for nearly 4.5 years. Since the cost of such a cryocooler is much higher than the widely adopted GM one, the commercial market of such a cost-inefficient SNSPD system is very limited and space applications may be the main target market for it.

Recently, a hybrid miniaturized cryocooler was successfully developed by You *et al* from the Chinese Academy of Sciences [10]. Such a hybrid cryocooler comprises a two-stage high-frequency PT cryocooler and a ^{4}He JT cooler driven by linear compressors, which reaches a minimum temperature of 2.6 K with nearly 320 W total electric power input. Using this cryocooler, the Shanghai Institute of Microsystem and Information Technology successfully demonstrated a NbN SNSPD with a SDE over 50% at 1550 nm wavelength and a timing jitter of 48 ps [10], which was double the efficiency of the semiconducting APDs. For comparison, this NbN SNSPD has a SDE of 90% at 2.1 K when it was cooled using the GM cryocoolers.

The recent studies [8–10] have built the foundation for miniaturizing the SNSPD system, which paves the way for the use of SNSPDs for space applications. However, many further endeavors are necessary, such as cooler optimization on SWaP and temperature, device optimization for specific temperatures, and harsh environmental tests for both SNSPDs and coolers for space applications.

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