Progress in Superconductivity Vol.14 No.2 pp.106-109 31 December 2012

Introduction to IEC Standardization for Superconducting Sensors and Detectors

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(Received 21 December 2012 ; accepted 26 December 2012)

Abstract

Superconducting sensors and detectors have been applied to many fields or beginning to enter the maturing stage. The applications spread over a wide range of fields such as radio telescope, medical examination, quantum information, contamination inspection, materials analysis, etc. For users of the superconducting devices as well as developers, we have to avoid confusion of naming, graphical circuit symbols, and measurement methods for device performance. We are trying to formulate international standards under the International Electrotechnical Commission - Technical Committee 90 (IEC-TC90), which is responsible for superconductivity. The sensors and detectors to be considered are divided into two groups: coherent sensors (SQUID, SIS mixers, etc.) and direct detectors (TES, STJ, MKID, SSPD, etc.).

Keywords : IEC-TC90, standardization, superconducting sensors, superconducting detectors, coherent sensing, direct detection

I. Introduction

Superconducting sensors and detectors (SCSDs) provide unconventional performance for sensing magnetic fields and electromagnetic waves, or for detecting photons, electrons, ions, and neutral molecules. The applications include radio telescope, medical examination, quantum information, contamination inspection, materials analysis, etc. In spite of the wide spread of SCSDs over many fields, the SCSD standardization has not been formulated. We believe that the International Electrotechnical Commission - Technical Committee 90 (IEC-TC90 Superconductivity) is one of the best platforms for the SCSD standardization [1].

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The start of our standardization effort goes back to 2005. At first, the standardization of the superconducting electronics field was considered in International Superconductivity Technology Center (ISTEC), which acts as the secretariat office of IEC-TC90. Y. Tanaka was trying to find out standardization items in the superconducting electronics field.

Since then, we have considered many possibilities of standardization for Josephson junctions as fundamental elements of superconducting electronics, superconducting digital circuits, cryogenics, superconducting sensors such as Superconducting Quantum Interference Devices (SQUIDs) and Superconductor-Insulator-Superconductor (SIS) mixers, and superconducting detectors such as Transition Edge Sensors (TESs), Microwave Kinetic Inductance Detectors (MKIDs), Metallic Magnetic Calorimeter (MMCs), Superconducting Tunnel

Junctions (STJs), etc. After the worldwide survey of the demands for standardization and a long discussion [2], the SCSDs remained as candidates. Recent increase of the number of SCSD papers in academic meetings supports that our effort under the IEC-TC90 may be meaningful and it is now the adequate timing.

Since the SCSD standardization seems to contribute benefit of both users and developers, we proposed establishing new 4th ad hoc (ad hoc 4) group on the occasion of the IEC general meeting at Seattle in 2010. The proposal was approved with four votes in favor and one abstention. After the approval, the members of the ad hoc 4 group were nominated from the IEC-TC90 member countries. Eleven experts from China, Germany, Japan, Korea, and USA were constituted the members of the ad hoc 4 group. Current issues include device classification, naming of the sensors and detectors, graphical circuit symbols, and measurement methods for the SCSD performance.

II. Classification of sensors and detectors

The SCSDs can be classified into two groups: coherent sensing and direct detection as listed in Table 1. Typical objects to be measured range from stable magnetic fields to particles. The boundary between coherent sensing and direct detection of quanta is in a THz region. Major coherent sensors include SIS mixers and SQUIDs as shown in Table 2. SIS mixers have a high sensitivity to electromagnetic waves with frequencies of less $2\Delta/h$, and used in radio telescopes etc. SQUIDs operate as magnetic sensors with a high sensitivity considerably better than a magnetic flux quantum of 2.07×10^{-15} Wb, and also as current-to-voltage amplifiers for detector readout.

Table 1. Coherent sensing and direct detection. The boundary between the coherent sensing and the direct detection is in a THz region.

Type	Long electromag. wave (DC – radio – far-infrared)	Short electromag. wave (infrared, visible, γ-rays)	Particles (electron, atoms, molecules)
Coherent sensors	✔		
Direct detectors		✔	✔

Table 2. Classification of superconducting coherent sensors.

Type	Object	Sensing scheme	Operation Temp.
SIS mixer	Electromag. wave	Heterodyne detection	4 K
SQUID	Magnetic flux	Quantum interference	4 – 77 K

Typical direct detectors are listed in Table 3. They are used to detect infrared photons, X-rays, γ-ray, α-particles, electrons, ions, and molecules. The spectral resolution and time response range over several orders. The ideal superconducting detector may have, for example, 1 eV energy resolution and 1 ns time response at once. However, Table 3 shows that it is very difficult. We have to choose a correct detector that fits to the intended application [3, 4].

Table 3. Classification of superconducting direct detectors.

Type	Spectral resolution (photons)	Time response	Operation Temp.
Calorimeter (TES, MMC)	Extremely high (1.2 eV@ 6 keV) (0.15 eV@ 1 eV)	Slow (1 ms)	< 0.1 K
Junction (STJ)	High (12 eV@ 6 keV) (0.14@ 2.5 eV)	Fast (1 μs)	0.3 K
Strip (SSD)	N/A	Extremely fast (1 ns)	> 4.2 K

A direct detector recently invented to detect photons in a telecommunication wavelength was originally named as Superconducting Single Photon Detector (SSPD) after the name [5], Single Photon Detector, used in the semiconductor field. The detectors are formed by superconducting lines with a thickness of ~10 nm and a width of a few 100 nm. The detection mechanism is a superconducting-normal transition of current-biased lines. The study on nonequilibrium states in current carrying superconductors has a long history [6]. The size of the superconducting lines for photon detectors may be larger than that for quantum suppression of superconductivity [7], and can be treated within a framework of conventional superconductivity in most cases.

The names for this type of photon detector are flooding recently, one of them is appeared as Superconducting Nanowire Single Photon Detector (SNSPD) in a review paper [8]. The same detector structure was effective to detect electrons and ions [9, 10], in which they used the acronyms of Superconducting Nanowire Single Electron Detector (SNSED) and Superconducting StripLine Detector (SSLD). The name, Superconducting Single Photon Detector, may have a problem, since other superconducting detectors also have a capability of single photon detection. The name of SSPD seems not to be unique. Therefore, although more discussion may be needed, in this paper, it is referred to as Superconducting Strip Photon Detector (SSPD) with the same acronym or Superconducting Strip Detector (SSD) in general. The general name takes into account the fact that it can detect electrons or ions.

III. Standardization scheme

We started with naming of SCSDs. Most of them may not need discussion. For SSPD, however, many names have been proposed as described in the above section: Superconducting Nanowire Single Photon Detector (SNSPD), Nanowire Superconducting Single Photon Detector (n-SSPD), Superconducting StripLine Detector (SSLD), Superconducting Nanowire Single Electron Detector (SNSED), depending on the size of thin and long superconducting lines and the objects to be measured.

There is an opinion that "nanowire" is incorrect because the line shape is in the 2-D limit: the lines are extremely thin (~ 10 nm), relatively wide (a few 100 nm), and very long (~500 μm to ~1 m) superconducting lines. In addition, "nanowire" is physically misred as nanoscale quantum effects [7].

The number of acronyms is increasing rapidly, which introduces confusion into users as well as developers. Systematic naming method is preferable. We are now discussing to find out a best solution after the opinion survey on WEB. One of them is naming with the structures and the objects to be measured, for example, Superconducting Strip Photon Detector (SSPD) for photon detection and Superconducting Strip Ion Detector (SSID) for ion detection etc.

After the classification of SCSDs and naming, we plan to formulate graphical symbols. At this moment, there is no international standard even for Josephson junction symbol as well as other superconducting components. Measurement methods of SCDS performance will follow the above efforts.

IV. Summary

According to the discussion in the IEC-TC90 meeting at Xi'an in 2012, new working item proposal from the ad hoc 4 group will be submitted to the IEC office in 2013. We would like to establish new working group for SCSDs after an international vote, and ask scientists and engineers in this field for their cooperation. The SCSD standardization is required for both industries and sciences, and both users and developers.

Acknowledgments

We would like to thank the members of the ad hoc 4 group: B. Mazin, D. Fukuda, J. Kohlmann, L. You, R. Cristiano, S. Tanaka, Y. Chong, Y. Kim, Y. Lee, and Z. Wang. The author is also grateful to the domestic or international members of the IEC-TC90 for fruitful discussion and suggestion. This work was partly supported by the standardization program of Ministry of Economy, Trade and Industry.

References

[1] http://www.iec.ch/dyn/www/f?p=103:7:0::::FSP_ORG_ID:1285.

[2] http://www.istec.or.jp/web21/pdf/12_Winter/E25.pdf.

[3] M. Ohkubo, "Current status of non-equilibrium

superconducting detectors for photons and molecules", AIP Conf. Proc. 1185, 381-388 (2009).

[4] B. Sadoulet, "Recent progress with low temperature particle detectors", AIP Conf. Proc. 1185, 785-796 (2009).

[5] G. N. Gol'tsman *et al*., "Picosecond superconducting single-photon optical detector", Appl. Phys. Lett. 79, 705-707 (2001).

[6] M.Tinkham, "Introduction to Superconductivity 2nd ed.", (McGraw Hill, New York, 1996).

[7] A. Bezryadin, C. N. Lau, and M. Tinkham, "Quantum suppression of superconductivity in ultrathin nanowires", Nature 404, 971-974 (2000).

[8] R. H. Hadfield, "Single-photon detectors for optical quantum information applications", Nat. Photonics. 3, 696-705 (2009).

[9] M. Rosticher *et al*., "A high efficiency superconducting nanowire single electron detector", Appl. Phys. Lett. 97, 183106 (2010).

[10] N. Zen et al., "1 mm ultrafast superconducting stripline molecule detector", Appl. Phys. Lett. 95, 172508-1 – 172508-3 (2009).