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What's New in the World of Superconductivity

초전도 뉴스 −세계의 동향−

超导新闻 −世界的动向-

chāo dǎo xīnwén - shìjiè de dòngxiàng-

Yutaka Yamada, Principal Research Fellow
Superconductivity Research Laboratory, ISTEC

★News sources and related areas in this issue

▸Electronics 엘렉트로닉스 电子应用［diànzǐyè yìngyòng]

D-Wave Systems Selected as 2014's 50 Smartest Companies

D-Wave Systems Inc. (February 18, 2014)

D-Wave Systems, the world's first commercial quantum computing company, has been named as one of "2014's 50 Smartest Companies" by the MIT Technology Review in their annual list of the world's most innovative technology companies, an honor that has been previously shared by companies such as Amazon, Google, IBM, and Microsoft. The companies that are included in this list have all demonstrated original and valuable technology within the last year and are bringing that technology to market while strongly influencing their competitors; these companies are considered to represent the disruptive innovations that are most likely to change our lives. D-Wave Systems' quantum computers are based on the laws of quantum mechanics, and the resulting product is expected to help solve complex computing problems in many different domains including machine learning, complex optimization problems in mission planning, cancer research, and financial modeling.

Source: "D-Wave Systems Named to MIT Technology Review's 2014 List of the 50 Smartest Companies"
D-Wave Systems Inc. press release (February 18, 2014)
URL:http://www.dwavesys.com/press-releases/d-wave-systems-named-mit-technology-reviews-2014-list-50-smartest-companies
http://time.com/4802/quantum-leap/
Contact: Beth Sanzone, dwave@launchsquad.com

Collaboration Research with NSF's CHMPR for Quantum Computing

D-Wave Systems Inc. (February 24, 2014)

D-Wave Systems and the National Science Foundation Center for Multicore Productivity Research (CHMPR) at the University of Maryland, Baltimore County, have announced that D-Wave is joining CHMPR to advance work in combined quantum and classical computing. CHMPR is a research consortium that is addressing the productivity, performance, and scalability challenges that accompany the need for increasing computational standards. DWAVE will contribute to this consortium by providing essential insights into their breakthrough research in the field of quantum computing.

D-Wave Systems was founded in 1999 with the goal of integrating new discoveries in physics and computer science into breakthrough approaches to computation. Their flagship product, the 512-qubit D-Wave Two™ computer, utilizes a novel type of superconducting processor that uses quantum mechanics to massively accelerate computation. Last year, in 2013, a D-Wave Two system was installed at the new Quantum Artificial Intelligence Lab, created jointly by NASA, Google, and the USRA. Lockheed Martin has also purchased an upgrade of their previous 128-qubit D-Wave One™ system to a 512-qubit D-Wave Two computer.

Source: "D-Wave Systems Joins the NSF Center for Multicore Productivity Research (CHMPR)"
D-Wave Systems Inc. press release (February 24, 2014)
URL:http://www.dwavesys.com/press-releases/d-wave-systems-joins-nsf-center-multicore-productivity-research-chmpr
Contact: Beth Sanzone, dwave@launchsquad.com

▸Basics 기초 基础[jīchǔ]

Superconducting Graphene

University of Vienna (February 11, 2014)

Using a powerful photoemission method known as angle-resolved photoemission spectroscopy (ARPES), an international team based at the University of Vienna has reported the superconducting pairing mechanism that underlies calcium-doped graphene. The material graphene, which is composed of a single-atom thick layer of carbon atoms, was first discovered in 2004 and is regarded as one of the most amazing and versatile substances known to exist. The impact of this first, real, two-dimensional material has been so great that its discoverers received a Nobel Prize. Until recently, no experimental reports of superconductivity in graphene had been made, even though graphene's close relatives (such as graphite and fullerenes) can be made superconducting through the intentional introduction of electrons (doping). The researchers found that calcium was the most promising doping candidate for inducing superconductivity in graphene, with superconductivity appearing at a critical temperature of about 1.5 K. While this critical temperature is rather low (fullerenes become superconducting at around 33 K), graphene offers several huge advantages over many other materials because it only consists of carbon atoms arranged in single layers, making chemical functionalization relatively easy. In addition, it can be grown in multiple numbers of atom layers in various stacking orders, and it can be doped in several different ways. This versatility enables a multitude of experimental options, potentially enhancing our understanding of superconductivity in general and carbon materials in particular. The group's work has been published in *Nature Communications*.

Source: "How to make the wonder material graphene superconducting"
University of Vienna (February 11, 2014)
URL:
http://medienportal.univie.ac.at/presse/aktuelle-pressemeldungen/detailansicht/artikel/how-to-make-the-wonder-material-graphene-superconducting/
Contact: Alexander Grüneis alexander.grueneis@univie.ac.at

▸Management and Finance 경영정보 经营信息[jīngyíng xìnxī]

China's Supreme People's Court Decides in Favor of AMSC

AMSC (February 19, 2014)

AMSC has announced that China's Supreme People's Court has decided in favor of AMSC with regard to the jurisdiction of AMSC's two software copyright infringement cases against Sinovel Wind Group, Ltd. (Sinovel), and Guotong Electric. The Supreme People's Court has ruled that both cases will be heard as copyright infringement cases separate from the commercial arbitration claims independently in their respective court systems. The cases in questions represent two of the four legal cases that AMSC brought against Sinovel in late 2011 after contractual breaches on Sinovel's part and the discovery of intellectual property theft by Sinovel. In addition, AMSC is also engaged in a commercial arbitration case and a trade secrets case against Sinovel.

Source: "China's Supreme People's Court Decides in Favor of AMSC on Jurisdictional Matters"
AMSC press release (February 19, 2014)
URL: http://ir.amsc.com/releasedetail.cfm?ReleaseID=826639

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Feature Article: Superconducting Microwave/Terahertz Wave Device Technology
- Recent Trends in Superconducting Microwave/Terahertz Wave Device Technology

Shigetoshi Ohshima, Professor
Graduate School of Science and Engineering, Yamagata University

During February every year, Superconductivity Web21 publishes feature articles relating to the "Recent trends in superconducting microwave/terahertz wave device technology". This year, the feature articles are arranged with contributions by Dr. Okubo, AIST, on the "Recent status of superconducting detectors and IEC standardization activities"; Dr. Saito, Yamagata University, on the "Recent trends of high-power superconducting filters"; Dr. Ariyoshi, Nagoya Institute of Technology, on the "Recent trends of MKIDs imaging"; and Dr. Sekiya, Yamanashi University, on the "Recent trends of dual-band superconducting bandpass filters". In this issue, the author was invited to provide summary highlights of the current status of microwave/terahertz wave/X-ray superconducting devices and the development of superconducting probes designed for NMR, currently undertaken by the author and his group.

Superconducting high-frequency devices are typically divided into the following three categories:

1) Devices having low surface resistance
2) Devices exploiting the formation of superconducting quasi-particles
3) Devices exploiting resistance changes due to superconducting transition

A mainstream device exploiting phenomenon 1) is the superconducting filter. It is well known that STI based in USA [1], has already introduced onto the market superconducting filter systems designed for mobile telecommunication base stations, under the trade name of "SuperLink". They clearly publicize that their systems enables the operation of Long Term Evolution (LTE) high-speed mobile phone networks (3.9 G). Also in China, the practical realization of superconducting filter systems is underway. Professor Cao, based at Tsinghua University, stated at EASSE2013 that more than 300 systems were currently in operation [2]. A question was posed by the author via an email sent to Professor Cao regarding the recent trends, who stated, " With the receipt of government approval for R&D funding applicable to 4G-networks superconducting filter systems, R&D activity will soon commence". The development of high-power filters [3),4)] and dual-band bandpass filters [5), 6)] have recently been undertaken extensively by both Japan and China, in addition to the superconducting receiving filters. However, the area where these filters would be applicable is yet to be determined. Despite this, since developmental progress of filters exhibiting superior characteristics is gradually improving, further developments are anticipated in the future. Device development exploiting phenomenon 2) have been actively performed by research focused on MKIDs [7),8)], which offer promising prospects of terahertz wave sensing devices, and undertaken by an array of research institutions based around the world. The possibility of fabricating an imaging system operating with a 4.2K refrigerator increases the likelihood of a system entering the consumer realm. A TES typically exploits phenomenon 3) and is already practically realized as a detector in SEM imaging [9), 10)]. For the three above-mentioned categories please refer to each of the article as follows:

The following two approaches offer the potential to increase NMR sensitivity;

a) Increase the magnetic field strength (increase the measuring frequency)
b) Enhance probe detection sensitivity (increase the detection coil Q-value)

An NMR system exceeding 900 MHz has been already developed and now, the development of an NMR system operating at 1.03 GHz is currently ongoing. However, since approach a) requires the need to steadily strengthen the magnetostatic field, a high magnetic field of 24.2 T is required to realize 1.03 GHz. This approach may already be reaching its limitation any time now. An alternative approach is to enhance the probe detection sensitivity; approach b). The S/N ratio in an NMR employing an ordinary LCR resonator system is given by the equation below [11)]. Here,

$$S/N = KM_0 \left[\frac{\mu_0 2\pi f V_s}{8k_B \delta f}\right]^{0.5} \left[\frac{\eta Q_L}{T_{eff}+T_r}\right]^{0.5}$$

$K, M_0, \mu_0, f_0, V_s, k_B, \delta f, \eta, Q_L, T_{eff}, T_r$ are coefficients defined by the degree of B_1 magnetic field homogeneity, spin density, vacuum permeability, resonance frequency, sample volume, Boltzmann's constant, full width half maximum of the NMR signal, detection coil filling factors, detection coil load, equivalent noise temperature determined from the detection coil and the sample, and the receiver thermal noise temperature. Of these coefficients the detection coil Q_L significantly influences the sensitivity. Figure 1 shows the relationship between Q_L of the coil and S/N ratio of the NMR. Here, the resonance frequency is set to 700 MHz and a sufficiently small loss in the sample is measured.

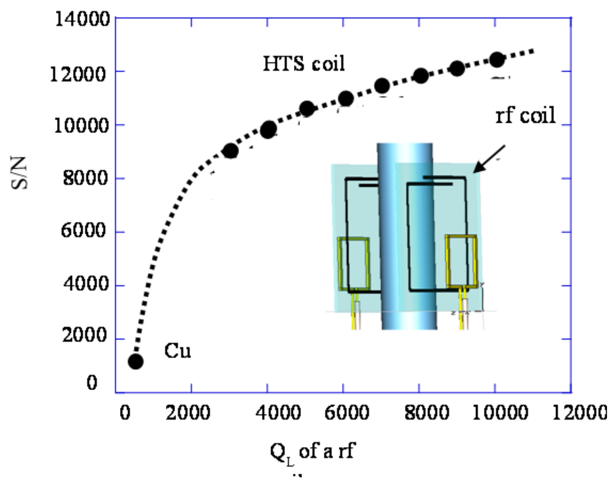

Fig. 1 The relationship between Q_L and the S/N of the NMR detection probe

Figure 1 shows that utilization of a superconducting probe remarkably improves the S/N in NMR. A research group based at the University of Florida has already developed a 1.5-mm 600MHz NMR HTS

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probe [12), 13)]. The author and his group are currently developing a 5-mm 700 MHz NMR HTS probe and are aiming for greater NMR sensitivity, under the JST's S-Innovation program.

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Feature Article: Superconducting Microwave/Terahertz Wave Device Technology
- Recent Trends in MKIDs Imaging

Seiichiro Ariyoshi
Nagoya Institute of Technology
Kensuke Nakajima, Atsushi Saito
Yamagata University
Tohru Taino
Saitama University
Chiko Otani
RIKEN Advanced Science Institute

The Microwave Kinetic Inductance Detector (hitherto MKID) is a relatively new type of superconducting photon detector with a short history, first developed at California Institute of Technology around ten years ago [1]. The MKID operates based on the phenomenon of incident photons with energies greater than the superconducting gap energy breaking Cooper pairs (Figure 1). Specifically, a change in quasi-particle densities caused by Cooper pair-breaking results in changes in the resonance frequency of a microwave circuit (i.e. superconductor-characteristic kinetic inductance component), located downstream of the receiver (Figure 1 shows an example of terahertz antenna). Thus, the MKID measures changes in amplitude and phase that permeate microwave signal lines [2].

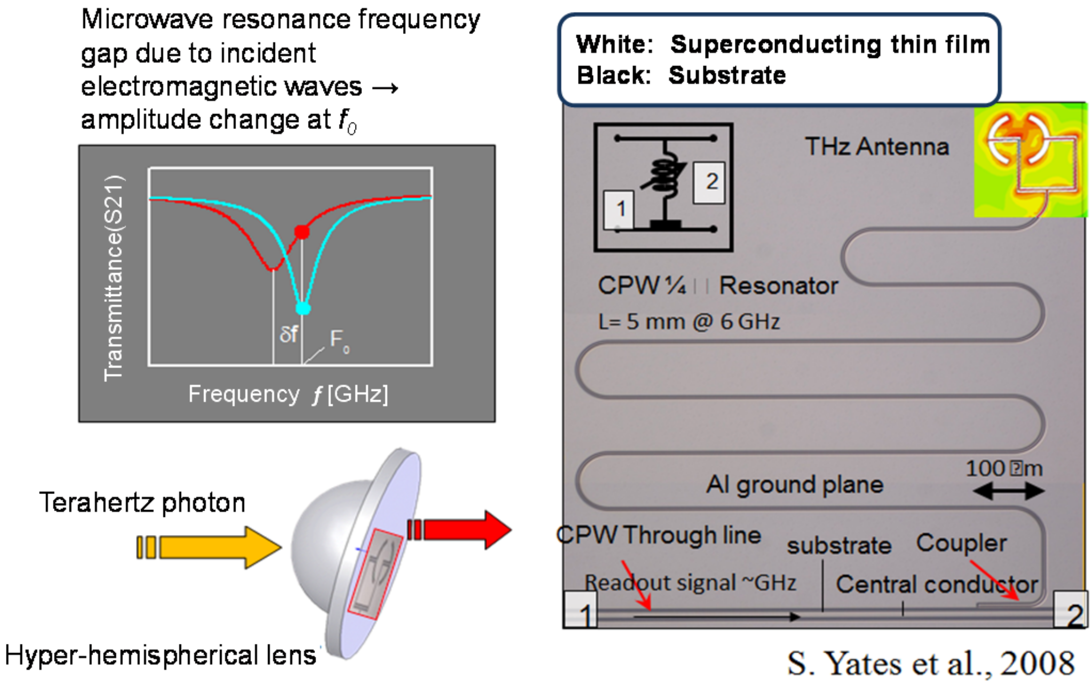

Fig. 1 Detection principle of an MKID

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Recent years have seen worldwide progress in the development of MKIDs operating at 0.1 K [3]. Currently, millimeter-wave astronomical experimental observations have already begun employing 100-pixel class 2D arrays [4]. Also in Japan, a research group based at the High Energy Accelerator Research Organization and National Astronomical Observatory of Japan has advanced the development of MKID arrays applicable to observational studies of Cosmic Microwave Background [5]. However, the mainstream R&D of MKIDs reported until now have been particularly dedicated to "astronomical observation applications", where ultimate sensitivity is a key requirement. These developments have been performed under the assumption that MKIDs are mainly fabricated by aluminum, which exhibits extremely low superconducting transition temperatures (1.2 K), and therefore should be cooled and operated utilizing a 0.1K-class cryocooler such as dilution refrigerator or an adiabatic demagnetization refrigerator. Additionally, for ground-based astronomical observations a narrow-band detector is essential in order to suppress the ambient background noise. Such issues lead to MKID performance characteristics that cannot be easily adopted or widely applicable for broadband measurement instruments.

To address these concerns, the author and his research group has advanced a series of R&D involving design, fabrication and performance evaluation of MKID arrays operating with a ^{4}He refrigerator (minimum reaching temperature ~3 K), along with broadband characteristics targeting future commercialization [6-8]. The developmental aim has been to realize terahertz spectroscopy imaging, supported by the Japan Science and Technology Agency. Figure 2 shows a niobium nitride 2D-MKID array fabricated onto a 10mm-square R-plane sapphire substrate. The agreed targets for the detector performance per pixel for the time being are to achieve more than 1~5 THz frequency band, a response time of less than 100 μsec and around 10^{-14} W/√Hz noise equivalent power. Considering the applicability to 2D-mapping measurements, the detector pixels are arranged greater than a 5x5 pixel array, which includes the center of measurement and the periphery. Moreover, the author and his group aim for the stable operation of the MKID array, constructed with a self-automated ^{4}He refrigerator instead of using conventional complicated cooling system employing coolants (liquid helium), making it user-friendly and negating future cryocooling concerns. The author anticipates that these advances will be applicable to a variety of measurement samples and purposes, which are required by specific industrial needs such as drastic shortening of measurement times, thick sample measurements, enabling the integration of spectral and imaging information.

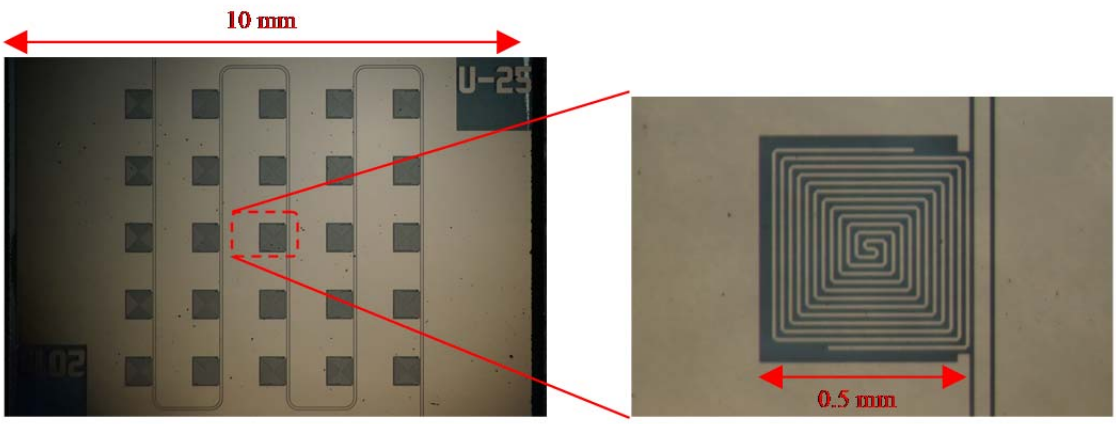

Fig. 2 NbN film MKID-array fabricated on a sapphire substrate (left) and an enlarged photo of one pixel (right)

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Feature Article: Superconducting Microwave/Terahertz Wave Device Technology
- Recent Trends in High-power Superconducting Filters

Atsushi Saito, Associate Professor
Graduate School of Science and Engineering, Yamagata University

A superconducting filter exhibits low-loss properties over the passband region and steep filter skirt characteristics at its cutoff. These characteristics arise because the loss in a superconductor over the microwave region is several orders of magnitude lower than that of ordinary metals [1), 2)]. Researchers have exploited these advantageous characteristics and undertaken research into an array of superconducting filters, already leading to the commercialization of superconducting receiver filters designed for mobile telecommunication base stations based in USA and China [3), 4)]. Additionally, a superconducting hybrid filter designed for weather radar has also been realized for practical use [5)]. The effectiveness afforded by a superconducting transmit bandpass filter aimed at mobile telecommunication base stations is far more anticipated than a receiver system. However, only several such examples have achieved the average 10W power handling capabilities necessary for practical use - these are based at SII in the USA[6)], Toshiba[7)], Yamagata University[8)], University of Yamanashi [9)] etc. There are no reports achieving 100W capability, which is momentarily required. Here, the author introduces research on a microstrip line resonator comprising a thin film and a high-power filter utilizing a single crystal bulk superconductor, which is seen as a recent trend in high-power superconducting filter development.

① 3D-matrix superconducting resonator filter

A resonator employing ordinary thin film microstrip lines concentrates high frequency currents on the surface (terminals along its width direction as well as vertical sides), resulting in its destruction and a strain in superconducting characteristics. Thus, research conducted has involved introducing slits to slice the resonator pattern along its width[10)] and the development of a multilayered thin film resonator sliced along the film-thickness direction[11)]. These methods have already been reported to exhibit enhanced power-handling capabilities. Research underway is progressing towards a 3D-matrix superconducting resonator, sliced along its width and film-thickness directions at the same time. Figure 1 shows a schematic of the 3D-matrix resonator reducing the current concentration in both film thickness and width directions. The experimental results of a 3-pole multilayered filter fabricated comprising of NbN/AlN/NbN, has been confirmed as offering an enhanced 3.1 dB power-handling capability compared to an ordinary resonator (non-sliced) filter.

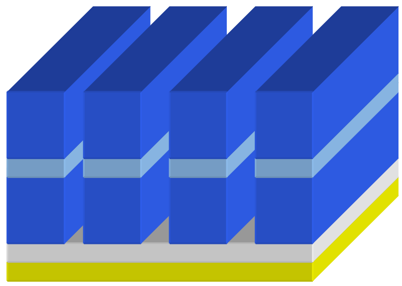

Fig. 1. 3D-matrix schematic diagram of the resonator

② Bulk single crystal superconducting resonator filter

The research employs a single resonator structure (Figure 2), comprised a disc-shaped $GdBa_2Cu_3O_y$ single crystal bulk superconductor fabricated onto a ceramic substrate. The design, prototype fabrication and

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evaluation of a 3-pole filter that is configured to improve frequency characteristics by tuning/trimming the dielectric rod has been undertaken. The target frequency design characteristics are set as having a center frequency of 5±0.1 GHz, a 100±5 MHz bandwidth, and an insertion loss of less than 0.2 dB. The frequency responses of the filter were simulated using a 3D-electromagnetic simulator, MW-Studio. Figure 3 shows an outline picture of the filter package fabricated. Figure 4 shows the typical frequency characteristics of a 3-pole bulk filter. The fabricated filter has favourable characteristics without unnecessary resonance in the vicinity of its operating band. Figure 5 shows the power-handling capability of the filter. The maximum capability is determined to be around 41.7W. This realization of power-handling capability is considered because of a reduction in maximum current density due to the resonator mechanism, attributed to not only materials characteristics but also to superconductor thickness. By further designing and fabricating a multi-pole filter, including analyzing the current density, the author and his group aim for the realization of superconducting filter exceeding 100 W in the future.

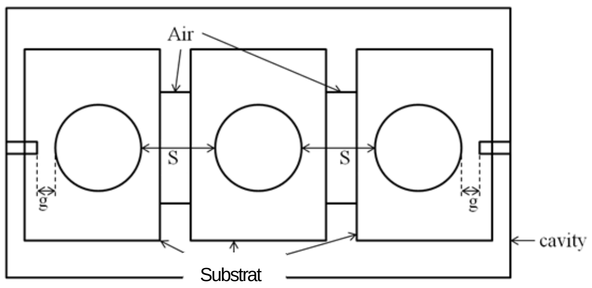

Fig. 2. 3-pole disc-shaped bulk resonator filter prototype

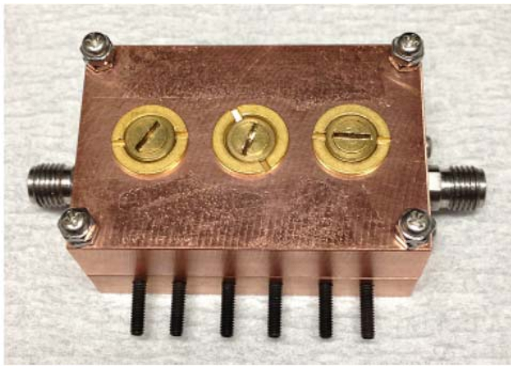

Fig. 3 Outline picture of filter package

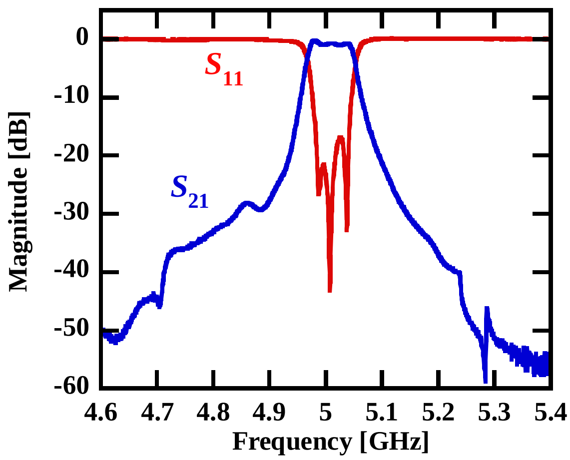

Fig. 4 Frequency characteristics of 3-pole bulk resonator filter

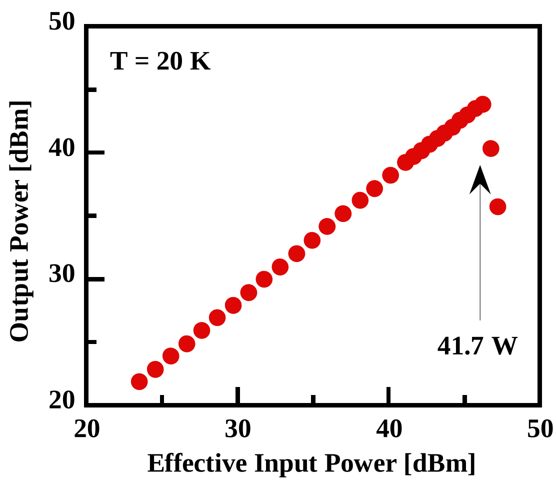

Fig. 5 Power-handling characteristics of 3-pole bulk resonator filter

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Feature Article: Superconducting Microwave/Terahertz Wave Device Technology - Recent Status of Superconducting Detectors and IEC Standardization Activities – Superconducting Sensor and Detector Standardization Proposals (Generic Specification) and International Vote Kick-off!

Masataka Ohkubo, Chief Innovation Coordinator
National Institute of Advanced Industrial Science and Technology

Superconducting detectors or sensors have enabled measurements that proved impossible using other technologies (although “detector” and “sensor” are synonymous, IEC standardization now considers the use of these two terminologies because the way they are used differs). It has been a while now since SQUIDs realized micro magnetic field detection sensitivities unrivaled by any other technologies, leading to their practical deployment in magneto-cardiograph, magneto-encephalograph, contamination test, mineral exploration etc. Now, their application to earthquake prediction is gathering attention. Recently, the development of an optically pumped atomic magnetometer exceeding SQUID sensitivities and progress of a non-superconducting sensor utilizing spintronics has advanced. Despite this, the SQUID still maintains its advantages as a measurement system for practical use. It has been a while now since a Superconductor-Insulator-Superconductor (SIS) mixer was employed as a heterodyne detector in radio astronomy applications. Amongst the opinions from individuals at the IEC propose that the term ‘SIS mixer’ should be more appropriate to a Superconducting Tunnel Junction (STJ) mixer. The above-mentioned superconducting detectors are all that can be categorized under the term coherent detection [1].

Additionally, superconducting detectors operated in direct detection mode emerged around thirty years ago, initially for the science to detect solar neutrinos and dark matter [2]. The development of these types of detectors coincided with a now historical international workshop called, International Workshop on Low Temp Detectors (LTD). The type and performance characteristics of a direct detector are summarized in refs.1 and 2. Direct detection involves measuring cooper pair breakage caused by single-photon absorption leading to an energy dispersive spectroscopy of photon energy. This type includes STJ and Microwave Kinetic Inductance Detector (MKID). In addition to the detection principle, where the destruction of superconductivity is initiated by quantum energy, there are other types of superconducting sensors able to measure temperature increases as well as changes in magnetic susceptibility due to single photon absorption. These types can also be categorized as direct detection and include a Transition Edge Sensor (TES) and Metallic Magnetic Calorimeter (MMC). These detectors are now progressing for practical realization in the analysis equipment field to be utilized for R&D, including elemental analysis such as synchrotron radiation material analysis, mass analysis, SEM and TEM, in addition to astronomical studies such as radio telescope astronomy and cosmic microwave background (CMB) detection. The development of direct detection has progressed with the use of multi-element arrays that have enlarged the detection area as well as provided imaging capabilities. The development of an STJ has involved a parallel read-out with one read-out circuit per element, taking the advantage of high-count rates. A 100-pixel STJ can serve a high photon count-rate of 500k cps and suitable for synchrotron radiation applications [3]. The development of a TES has seen the completion of a 10,000-pixel scale THz imager, by using a time division multiplexer

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(frequency-division and code division multiplexing also includes) [4]. With regards to MKIDs, a 2024-pixel has been currently reported. The necessary wires for this read-out are only four in total – two systems, the microwave input/output pairs. Larger-scale arrays are anticipated in the future [5].

In recent years, a simple-structured Superconducting Strip Detector (SSD) has been developed. The SSD has been fabricated by forming strips less than 1 μm wide in a superconducting thin film with a thickness ranging from several-nm to several 10's nm. This type of detector was initially utilized for single photon detection at telecommunication wavelengths. Currently, high quantum efficiencies and high-count rates are anticipated for quantum information communications. With regards to the term Superconducting Single Photon Detector (SSPD), which has been utilized by adding 'superconducting' to Single Photon Detector, was already used and applicable to semiconductor detectors. However, since any type of superconducting detectors enable single photon detection, opinions from individuals at the IEC and related communities state that the term "SSPD" is not appropriate for certain types of superconducting detectors. Currently, the proposal is for SSD. In case of photon detection, the recommended terminology is a Superconducting Strip Photon Detector (SSPD) and its abbreviation is the same, SSPD, as per its original acronym. SSDs have been realized for the detection of electrons, ions and molecules in addition to single photons at communication wavelengths, and its applicability to analysis equipment is also anticipated [6]. There are many types of superconducting detector already in existence, and the emergence of further new types of detectors is expected in the future. The draft idea is to integrate the terminology according to its classification of structure (or functionality) + what to detect + detector (or sensor, mixer).

The proposal to establish an ad hoc group 4 to explore the standardization of superconducting sensors and detectors has been raised by Japan and approved at the IEC General Meeting held in 2010, Seattle. With participants comprising of 11 experts from around the world, standardization activities have been undertaken over the past three years. The outcomes from these meetings have seen the completion of a New Working Item Proposal (NWIP) with regards to Generic Specification (categorization of detectors, term, circuit symbol etc.) at end of 2013. The NWIP, which includes both coherent and direct detections, has entered international voting with effect from 10th January 2014. The voting period lasts for three months, closing on 11th April, with the anticipation of the approval from P member countries of IEC TC90. With the successful international approval for this NWIP, the establishment of a new WG is planned together with collaborations from IEEE. The standardization of terminology and electric circuit symbols [7] that have been written in draft generic specifications will be progressed in collaborations with other WGs. Detailed specifications regarding the standardization and performance testing methods of each type of detector will follow suit in the future.

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Feature Article: Superconducting Microwave/Terahertz Wave Device Technology
- Recent Trends of Dual-band Superconducting Bandpass Filter

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Recent years has seen an explosive increase in image data communications attributed to the rapid development of smart phones and tablets. The realization of the next generation mobile communications equipped with high-speed/high-capacity communication capabilities equivalent to optical fiber communications is therefore anticipated. Simultaneously, the efficient use of frequency resources is urgently required.

Carrier Aggregation technology as a method to realize high-speed/high-capacity communication has therefore been proposed. An elemental component for the method is the dual-band bandpass filter (DBPF), which is attracting attention as it allows the dual bandpass of two frequency bandwidths. In particular, a DBPF utilizing a high temperature superconductor (HTS) has steep cutoff characteristics at low loss, offering promising technological prospects for future mobile communications. Furthermore, this is the only technology anticipated for the realization of high-speed/high-capacity communications and the effective use of frequency resources simultaneously.

DBPF configurations differ according to, 1) communication by contiguous multiple carriers having the same frequency band and, 2) communication by multiple carriers having different frequency bands[1)]. For type 1), a proposed design method involves a built-in notch within the bandpass filter (BPF) having a wide frequency band in order to realize this type of DBPF configuration [2)]. For type 2), a dual-band resonator has been proposed in order to accomplish this type of DBPF configuration. Proposals to achieve dual-band resonator configurations include a methodology utilizing fundamental and higher resonances as well as a method utilizing even/odd-modes [3), 4)].

DBPF development in Japan has been undertaken by a group based at NTT Docomo, who are currently leading pioneering research into HTS-DBPF since 2008 [4)]. Type 2) DBPFs can realize two frequency bands (band A, band B) each employing a single dual-band resonator, as shown in Figure 1. Applying similar methodology to conventional single-band bandpass filters becomes problematic when trying to individually tune design parameters such as the resonance frequency of the two bands and coupling coefficients between the resonators. Therefore,

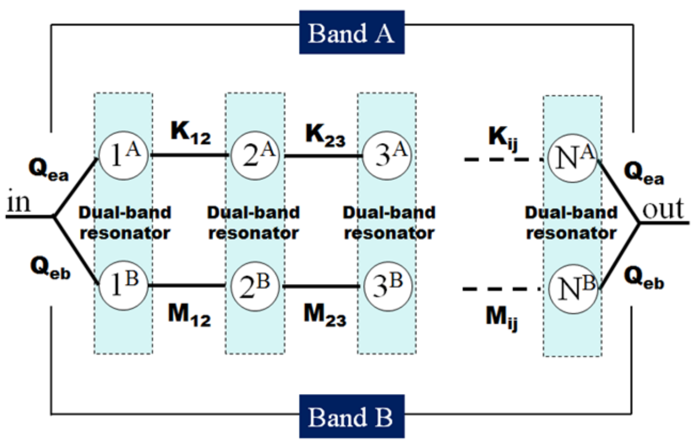

Fig. 1 Coupling configuration of DBPF utilizing dual-band resonator

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multi-band filters designs necessary for the HTS-DBPF to realize steep cutoff characteristics, but are extremely challenging due to increases in the number of design parameters required to be tuned, which increases in proportion to the number of stages.

To address these challenges, University of Yamanashi has developed their own unique resonator configurations and coupling coefficient-tuning methodologies [5] that has led to the development of 3.5/5.0 GHz band 5-pole HTS-DBPF [6]. Figure 2 shows the schematic of the 5-pole HTS-DBPF fabricated. The measurement results shown in Figure 3 demonstrate the realization of dual BPF having favorable frequency characteristics in the 3.5 GHz and 5.0 GHz bands.

Future ongoing research is focused on the unprecedented development of a multi-stage design and a tri-band bandpass filter with more than 8-poles, operating at three frequency bands.

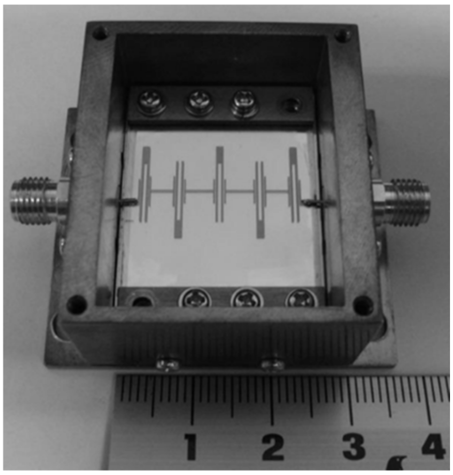

Fig. 2 The DBPF fabricated

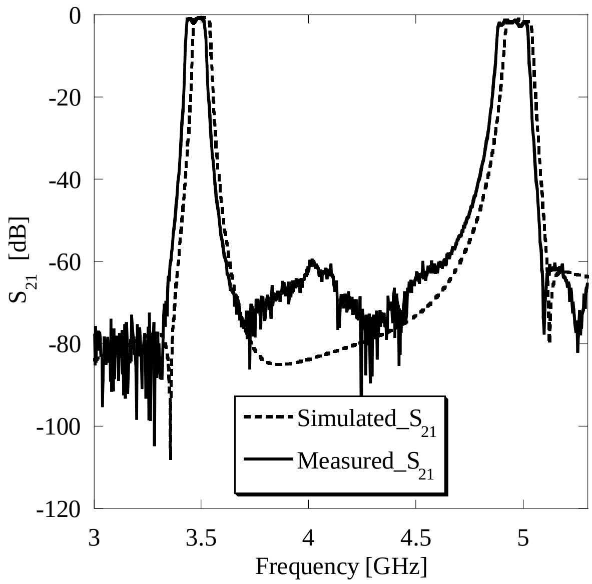

Fig. 3 Simulated and measured frequency characteristics of a 5-pole DBPF

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