NEWS LETTER
on Superconducting Electronics

S-PULSE
Shrink-Path of Ultra-Low Power Superconducting Electronics
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N° 5 June-July 2010
S-Pulse is a project of the European FLUXONICS Society (www.fluxonics.org), funded under the 7th Framework Programme of the European Commission.

THE 2010 EUROPEAN ROADMAP ON SUPERCONDUCTIVE ELECTRONICS – STATUS AND PERSPECTIVES

by Hannes TOEPFER

Institut für Mikroelektronik- und Mechatronik-Systeme gGmbH (IMMS) Ilmenau - Germany

Superconductive electronics is of potential impact in a variety of fields which determine the contemporary way of life as well as its quality:

- Resources and Environment,
- Health Care,
- Security and Mobility,
- Information and Communication Technology,
- Improved Production Processes,
- Standardization and Measurement.

The special advantage consists of the unique combination of very high operation speed with low energy consumption. This is in contrast to other existing information-processing technologies. The demonstrated energy consumption of about 0.1µW per gate at 100GHz can be further reduced by a factor of 100. Solutions will be presented at the upcoming Applied Superconductivity Conference in August 2010.

Within the European project S-PULSE, a Roadmap for Superconductive Electronics in Europe has been established by a consortium of leading scientists in the field from 15 partner sites.

Besides a thorough assessment of the current state-of-the art, it represents an elaborated proposal for immediate action in order to allow the conversion of the potential offered by this technology into benefits for European society and industry.

Superconductive Electronics for Europe – Theses

Superconductivity already plays a very important role in scientific measurement techniques and ultra-sensitive detectors. In the future, a growing number of superconductor applications in science and industry can be expected.

The European expertise in basic science concerning superconductivity and in material science is strong. Also in the area of applying superconductivity in high energy technology, health care, prospecting, standardization and measurement, Europe is still competitive. But with the current level of support, Europe is in danger to loose ground in the areas of health care and prospecting relative to the competitors in the USA and Japan.

In the important area of information and communication technology, Europe has already lost ground and urgently needs to close the gap to the USA and Japan. These countries have continuously maintained research programs for exploiting the unique features of Superconductive Electronics.

In Europe, the FLUXONICS platform – implemented by means of the European Community - aims at bringing together actors from industry, small and medium-size enterprise, and research organizations such as universities in the field of superconductive electronics

The main challenges for turning the potential offered by superconductive electronics into positive effects for European society and industry can be addressed by focusing efforts on four proposed research fields.

Strengths, Weaknesses, Opportunities and Threats (SWOT) Analysis

STRENGTHS

- well-structured research community, covering all necessary branches
- organization by a society (FLUXONICS),
- availability of a certified fabrication site for integrated circuits as well as of a dedicated design center for integrated circuits and sensors

WEAKNESSES

- sporadic research support,
- fragmented, often uncoordinated research activities,
- scarce recognition of the potential of superconductive electronics for European society

OPPORTUNITIES

- development of superconductive electronics enables new innovations in the fields of
  > Health Care,
  > Security and Mobility,
  > Information and Communication Technology,
  > Improved Production Processes,
  > Standardization and Measurement.

THREADS

- national groups are in danger of running below critical mass
- continuation of fragmented research actions prevents a breakthrough of this technology
- danger of losing ground in comparison with USA and Japan

www.FLUXONICS.org

Superconductive Electronics for Europe-Priorities

For putting Superconductive Electronics into action with beneficial effects in major domains of European society, research and development efforts are necessary, also to maintain the European position in this field.. As a result of the technology assessment in the roadmap, a prioritization has been carried out, leading to a recommendation of four major research activities.

Superconductive Electronics for Europe-Recommendations

With the appropriate support, the European position can be transformed into leadership in a number of important fields. It would be an effective contribution to strengthening the future position of the European industry. Four main research projects have been identified, according to the expected impact on the European competitiveness in Superconductive Electronics so that real-world applications in this technology with significant social and industrial impact become viable:

I. ULTRA-SENSITIVE SENSING AND IMAGING

Superconducting radiation and photon detectors cover a very wide spectral range from millimeter to nanometer wavelengths or in the energy scale between meV and keV with applications in infrared and THz imaging technology.They are also emerging as detector-of-choice in high-throughput mass identification with of macromolecules. A large effort has to be put on maturing single detectors to devices which combine a large number of superconducting detectors and their readout whilst enhancing the manufacturing technology.

II. QUANTUM MEASUREMENT INSTRUMENTATION

Superconducting devices are playing an important role for fundamental metrology and high-precision measurements by means of quantum standards, which enable the reference of physical units to fundamental constants. Important goals consist of the development of electrical current standards in the sub-nanoampere range as well as of a quantum multimeter being a user-friendly multimeter for measuring voltages, resistances, and currents directly referenced to quantum standards.

III. ADVANCED ANALOG-TO-DIGITAL CONVERTERS

One of the important stakes of future generations of communication networks relies on the possibility to introduce flexibility through configuration by software. The main objective is to propose systems to operators and users for which parameters like frequency bands, modulation formats, and number of channels per carrier can be modified after the system is built and during its entire life. This technique requires ultrafast analog-to-digital converters.

To achieve the goals required by software-defined radio, it is necessary to develop extremely sensitive analog-to-digital converters having the high desired dynamic range using Superconductive Electronics technology.

IV. SUPERCONDUCTIVE ELECTRONICS TECHNOLOGY

The Superconductive Electronics technology must be focused to reach very-large-scale integration level as fast as possible. Only this level of integration allows getting access to real-world applications being of significance for the society and the industry as well. An adequate design infrastructure is seen as the enabler for intentionally introducing functionality into technological structures. In order to get best functionality and compatibility to the international mainstream, the software tools to be developed for superconductive electronics should be linked as best as possible to the circuit design software used in semiconductor technology.

HIGH-T_C SQUID-BASED MEG: A NEW TECHNOLOGY PULL FOR MICRO-CRYOCOOLERS

by Justin F. Schneiderman[†,1,2]
Gerard Amorós Figueres[1]
Fredrik Öisjöen[1]
Alexey Kalabukhov[1]
Dag Winkler[1]

1 Chalmers University of Technology, Department of Microtechnology and Nanoscience – MC2

2 MedTech West, Sahlgrenska Academy and Gothenburg University, Institute of Neuroscience and Physiology

[†] Corresponding author, justin.schneiderman@neuro.gu.se

[††] For more information, see www.medtechwest.se

>> An ongoing effort at the Chalmers University of Technology Department of Microtechnology and Nanoscience – MC2 includes development of a MagnetoEncephaloGraphy (MEG) system that would give new information to doctors and researchers studying brain activity. We aim to achieve this challenging goal by overcoming the most significant limitation of state-of-the-art MEG systems: source-sensor spacing. A critical piece of this endeavor thus revolves around development of an array of micro-cryocoolers catered to MEG measurements with high-T_C SQUID sensors.

A newly developed medical technology platform, MedTech West[††], is working to bring together the relevant academic, industrial, and medical partners (including, for example, Chalmers and the Sahlgrenska University Hospital) necessary for advancing academic research, integrating new technology into a better medical device, and exploiting it in a clinical setting. The project includes development of several state-of-the-art advancements:

- adaptation of a new generation of high-T_C SQUID sensors catered to MEG
- measuring the brain's magnetic signals with far smaller source-sensor spacing
- design of a flexible cooling system that can accommodate varying head shapes and sizes
- adaptation of a new generation of source-localization algorithms catered to our system
- performing MEG studies with improved patient mobility and comfort

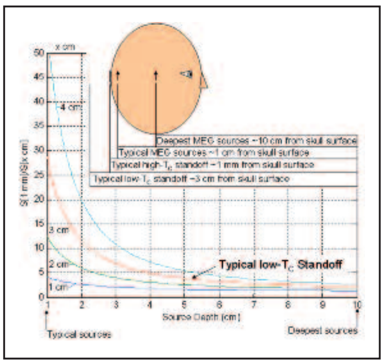
We have advanced materials and fabrication techniques for next-generation high-T_C SQUIDs whose sensitivity are set to approach that of their low-T_C counterparts. With adaptation of mature algorithms for brain activity localization combined with these sensors, we aim for a prototype high-T_C MEG system that will be validated through clinical studies. By bringing magnetic sensors closer to the brain than they have ever been (without invasive breaching of the skull) more fundamental questions about the physics of neural activation, signal propagation, and brain connectivity can be studied with improved accuracy and resolution, providing doctors and researchers with new information about brain activity. Furthermore, our system will provide brain mapping capability catered to any head size/shape and able to more safely and accurately guide surgeries, locate epilepsy centers, study brain plasticity/development, assess brain damage and recovery after trauma/stroke, evaluate therapeutic interventions, etc. Because the new system will no longer require expensive dewars and liquid helium for cooling the sensors, the up-front and running cost for MEG systems will be reduced and thus allow for more universal access in more hospital and clinical settings.

The demands placed on a micro-cryocooler array capable of enabling this technological challenge are strict. The array must:

- maintain a tunable temperature stability at the sensor of +/- 0.05 K in the range of 75-85 K for optimizing individual SQUID performance
- provide a warm-cold standoff distance lower than 1 mm with minimal sensor/cooler vibration
- enable flexible and near complete sensor coverage over the surface of an arbitrary human head, i.e. edge-to-edge sensor spacing lower than 5 mm for 20 x 20 mm sensor chips over e.g. a child and adult head
- contain minimal metallic, magnetic, and electrically conducting materials in order to avoid distorting the very weak magnetic fields (~fT) emanating from the brain

While these requirements are strict, the clinical and commercial applications for which a high-T_C SQUID-based MEG system are catered are very strong motivators for our efforts. Our hope is that the resulting combination of sensor technology, source-localization algorithms, and micro-cryocoolers will enable clinical research and validation through the MedTech West biomedical engineering development platform at the Sahlgrenska University Hospital.

PhD student Fredrik Öisjöen prepares himself for proof-of-principle MEG recordings of his alpha-wave signals with one of our high-T_C SQUID magnetometers housed in an epoxy reinforced glass-fiber cryostat from ILK Dresden. The measurements were performed inside a magnetically shielded room, courtesy Imego AB.



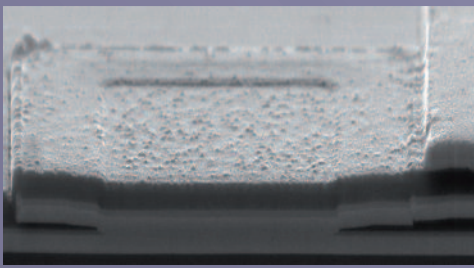
Calculated ratio of signal strength available to magnetometers placed within 1 mm of the room-temperature environment/subject's head, S[1 mm], relative to an identical magnetometer placed some distance from the head, S[x cm], as a function of MEG source depth. Typical sources are magnetic dipoles roughly 1 cm from the surface of the head. Curves are for different sensor standoff distances (x cm). Typical standoff for low-T_C SQUIDs is 3 cm (red). When recording the activity of these sources, high-T_C SQUIDs gain in signal strength by more than a factor of 25. Even with the best low-T_C SQUID standoff of 1 cm, high-T_C SQUIDs gain a factor of 4 in signal strength over their low-T_C counterparts. The high-T_C advantage is still more than a factor of 2 even for the deepest MEG sources.

Superconducting Technology Highlight

SUPERCONDUCTIVE ELECTRONICS MADE BY FLUXONICS FOUNDRY

by Juergen Kunert

IPHT Jena, Germany



Superconductor technology enables the realization of equipment that was unachievable with conventional technology and bears great anticipation as a technology that will sustain society in the 21st century. Superconductive electronics is an emerging key technology, which can support a wide variety of fields, such as electronics (SE), transportation, medicine, energy and environmental improvement. Today's Superconductive Electronics allows the production of tens of thousands of Josephson junctions on a single chip. It is based on Niobium thin film technology with 2 nm thin Aluminium oxide tunnel barriers.

FLUXONICS Foundry has been established in Europe in 1997. Since that time, it supports European research and development in SE by processing customer requests for circuit fabrication. The FLUXONICS network was founded in 2001 to enable European research accomplishments by networking with Universities, research institutes and industries to promote further research and development in SE to lead to early applications of superconductor devices.

The SE provides an ultra-low power consumption of only 1aJ (10,000 times less than a modern transistor) per logic operation and is therefore a promising future alternative to today's CMOS electronics. It is capable to operate at clock frequencies above 100 GHz. The further growing packaging density in conventional integrated CMOS circuits is already limited by their power density generating a massive thermal heating. SE provides for several special applications an interesting perspective to ensure further progress beyond today's scaling limits.

Many experiments in basic physics utilize in-house design and fabrication of superconductive circuits. This electronics is very often a foundation oriented research branch in several laboratories and not yet industrially applied. However the installation of FLUXONICS Foundry provides a high-level and open-access technological basis for the production of integrated superconductive electronics. To make Europe competitive, the long-term stability for the support of the foundry service for the production of integrated superconductive electronics is essential.

Responsible for the high-level circuit design, cell library maintenance and design support within FLUXONICS Foundry is Ilmenau University of Technology, Germany. The Institute of Photonic Technologies (IPHT) Jena, Germany fabricates the Superconductive Electronics circuits based on the well established and DIN EN ISO 9001 certified 4 inch wafer processes (Fig. 1). IPHT Jena is the leading European institution for extremely sensitive complex instruments based on Superconductive Electronics; such as airborne geomagnetic field scanners and passive terahertz video cameras for security inspection. Several European research projects and development activities have been supported by FLUXONICS Foundry. New magnetic field Sensors (Fig. 2) and ultra-low-power digital circuits (Fig. 3 and Fig. 4) have been designed and fabricated by FLUXONICS Foundry.

DESIGN RULES FOR SUPERCONDUCTIVE ELECTRONICS CIRCUITS AND FURTHER INFORMATION FOR CUSTOMER REQUESTS ARE AVAILABLE ON THE FLUXONICS FOUNDRY WEBSITE WWW.FLUXONICS-FOUNDRY.DE.

CONTACT:
Juergen Kunert
IPHT Jena, Germany
juergen.kunert@ipht-jena.de
www.ipht-jena.de

Thomas Ortlepp
Ilmenau University of Technology, Germany
thomas.ortlepp@tu-ilmenau.de
www.tu-ilmenau.de/it-tet

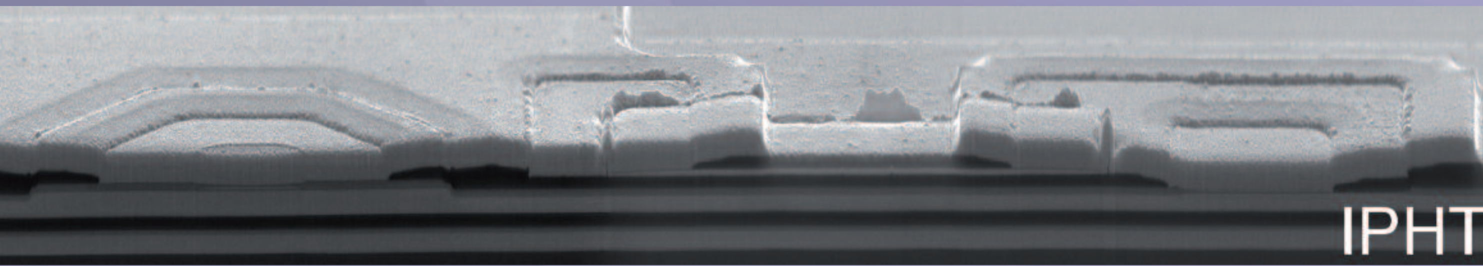


Fig.1. REM cross section view of the active circuit elements of a Superconductive Electronics circuit made by FLUXONICS Foundry.

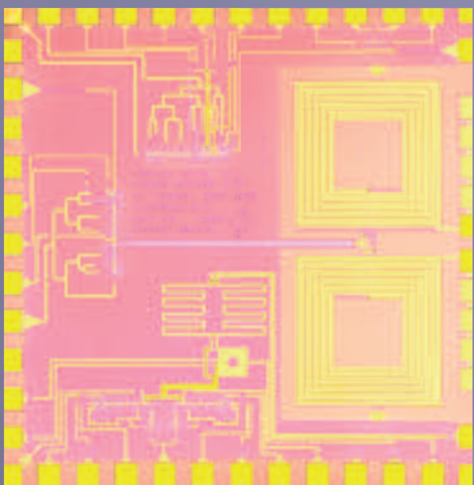


Fig.2. Micrograph of a digital magnetic field sensor. The device was made by FLUXONICS Foundry. It was designed by Ilmenau University of Technology and fabricated by IPHT Jena.

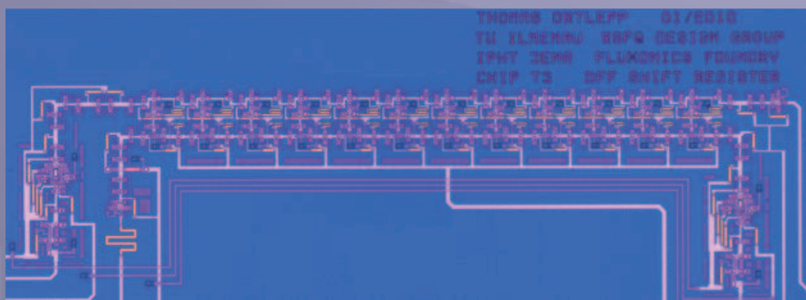


Fig.3. Micrograph of a superconductive 12-bit shift-register for on-chip high-speed cache-memories with 20 GHz clock frequency. This circuit was made by FLUXONICS Foundry.

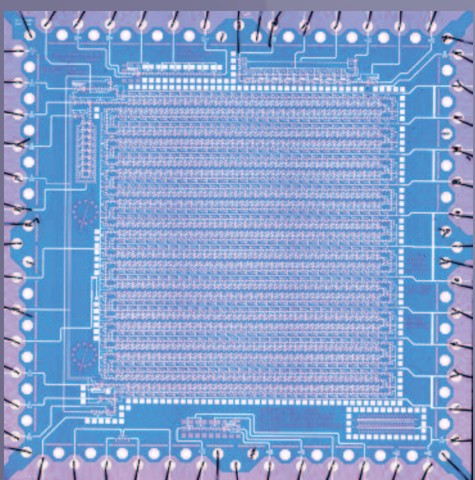


Fig.4. Micrograph of a high-speed 512 bit circular pattern generator for the synthesis of arbitrary waveforms with quantum accuracy. This circuit was made by FLUXONICS Foundry.

By Iwao Kawayama,
Yasushi Doda,
Hironaru Murakami
and Masayoshi Tonouchi

*Institute of Laser Engineering,
Osaka University, 2-6 Yamadaoka,
Suita Osaka 565-0871,
Japan*

OPTICAL INTERFACE FOR SUPERCONDUCTOR ELECTRONICS

Increasing data-traffic on expanding information networks motivates the development of ultrafast electronics for a great number of data processing. Recent technological innovation is enabling THz research to be applied to opto-electronics and some attractive optical devices operative in the THz region are realized. However, large power consumption is inevitable for electronic devices using conventional semiconductor technologies in such a high frequency region. On the other hand superconducting devices with high temperature superconductors (HTSCs) are expected to operate above several hundreds GHz with much lower energy dissipation. Therefore we believe that the HTSC is one of the most suitable materials for developing THz electronics.

Tonouchi et al. discovered that pulsed THz waves were radiated from HTSCs excited with femtosecond (FS) laser pulses and magnetic vortices were generated in superconductive thin films as a result of ultrafast supercurrent modulation [1-4]. Using this phenomenon, we have proposed a new type of superconductive optical switch based on a Josephson vortex flow transistor (JVFT) operative in THz frequency range. This optical switch is expected to be useful for an optical input interface for a single flux quantum (SFQ) logic circuit [5, 6].

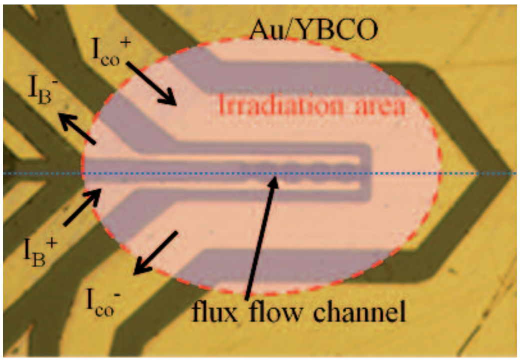


Fig. 1: Micrograph of the active region of a Josephson vortex flow transistor (JVFT).

>> Figure 1 shows a micrograph of the active region of fabricated JVFT. The vortices are generated in the vortex flow channel and the density is controlled by an applied magnetic field via control current Ico, which flows through the control line located near the channel. The YBCO thin film is covered by the Au film except for the flux flow channel which consists of a parallel array of Josephson junctions. The width of Josephson junctions is 3 µm, and each loop area is 10 × 8 µm^2. The mode locked Ti:sapphire laser that provided 100 fs-pulses with 800 nm wavelength at an 82 MHz repetition rate, was used for laser irradiation. The red dashed circle in Fig. 1 shows the laser spot and includes the flux flow channel and the control line, however, only the channel was irradiated with the laser pulses because the Au layer covers the other part of the YBCO thin film.

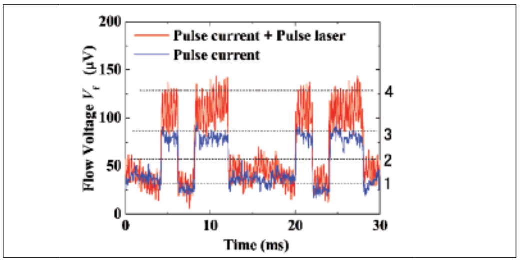


Fig. 2: Output voltage of JVFT without (blue line) and with (red line) laser pulse irradiation. The flow voltage is modulated by a 3.5 mA amplitude square-wave pulse current.

>> In Fig. 2, the blue line shows the output voltage of JVFT when the square pulse current with the amplitude of 3.5 mA flowed on the control line, and the red line shows the modulation of flow voltage under the simultaneous input of pulse current and laser pulse irradiation. This result shows output signals of the JVFT-based optical switch can operate as multilevel switch controlled by both electrical signals and optical signals.

In order to investigate the optical response time of JVFT, we observed output voltages under the irradiation of two laser pulses which time interval was swept by an optical delay system. Using non-linearity of output voltages as a function of the excitation laser power, an autocorrelation of the optical response of JVFT could be observed with this method and the response time of JVFT can be estimated.

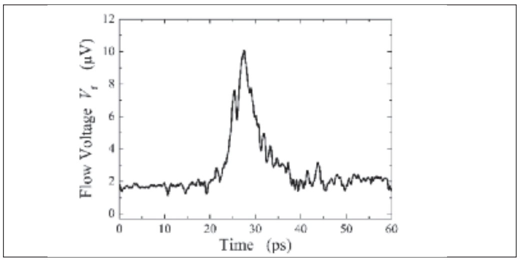


Fig. 3: Optical response of JVFT using the double pulse irradiation method. The photo-response time is around 5 ps.

>> Figure 3 shows the optical response of JVFT using the double pulse irradiation method. The result indicated that the photo-response time is around 5 ps. We expect that the response time should reach sub-pico second range by reducing junction size.

On the other hand, an optical output interface is also necessary for high speed operation of superconductive electronics. However, the development of the SFQ-to-optical output interface is a very challenging issue because SFQ signals are carrying too low energy to convert to detectable optical information. To our knowledge, no efficient practical solutions have been proposed. Recently, we have proposed an ultrafast optical output interface using a magneto-optical effect that converts SFQ signals to optical signals that are detectable as the modulation of the plane of polarized light, and demonstrated the detection of modulated magnetic field corresponding to a single flux quantum using MO detection system[7].

>> **Fig. 4** shows a schematic diagram of the MO detection system. In this system, a linearly polarized green laser with a wavelength of 514 nm was used as an optical light source, and was focused inside the SQUID loop by using an objective lens. The laser beam reflected from the sample surface is led to a high-sensitive differential photodetector, and the output signal from the differential amplifier is directly detected by a digital oscilloscope. The magnetic field inside a SQUID loop, which was controlled by the control current outside the SQUID, was observed by the MO detection system.

>> **Figure 5** shows the modulation of MO signal inside the SQUID loop under the pulsed control currents with the pulse heights of 3mA, 6mA, 9mA corresponding to Φ_0, $2\Phi_0$ and $3\Phi_0$, respectively . Here, the y-axis shows the output voltage signal from the differential amplifier. We can apparently see the modulation of MO signal corresponding to the applied control current at 1 kHz.

In summary, we introduced our recent studies concerning a new type of optical interface for SFQ devices using a JVFT structure and MO detection system, and showed that optical pulse signals could be converted to magnetic flux density flowing in Josephson junction and the modulation of a magnetic field corresponding to Φ_0 in the SQUID loop was detected by the MO detection system. Though these systems used in this study are still far from a practical interface system, the results must be fundamental technologies to develop an ultrafast optical interface for superconducting circuits.

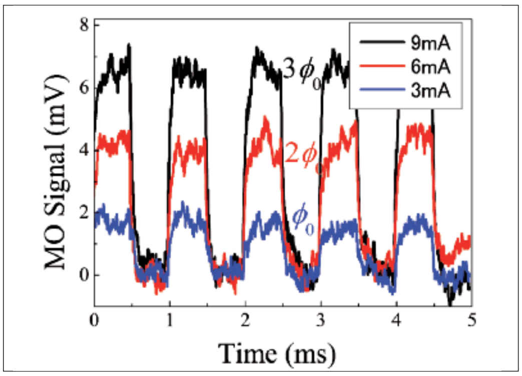


Fig. 5: Modulation of MO signal inside the SQUID loop in presence of pulsed control currents. Pulse heights are 3 mA, 6mA and 9 mA, corresponding to Φ_0, $2\Phi_0$ and $3\Phi_0$, respectively.

[1] M. Tonouchi, M. Tani, Z. Wang, K. Sakai, S. Tomozawa, M. Hangyo, Y. Murakami and S. Nakashima," Ultrashort Electromagnetic Pulse Radiation from YBCO Thin Films Excited by Femtosecond Optical Pulse", Jpn. J. Appl. Phys. 35 (1996) 2624

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[3] M. Tonouchi et al., IEEE Trans. Appl. Supercond. 9 (1999)

[4] T. Fukui, H. Murakami and M. Tonouchi," Observation of optical magnetic flux generation in superconductive YBCO strip-line" IEICE Trans. Electron. E85-C (2002) 818

[5] I. Kawayama, Y. Doda, R. Kinjo, T. Kiwa, H. Murakami and M. Tonouchi, " Study on Sub-THz Signal Input for Superconducting Electronic Devices", IEICE Trans. Electron., Vol. E90-C, March 1, 2007, 588-594.

[6] Y. Doda, I. Kawayama, H. Murakami, M. Tonouchi, "Optical Responses of Josephson Vortex Flow Transistor under Irradiation of Femtosecond Laser Pulses", Jpn, J. Appl. Phys., Vol. 46, No. 4B, April 24, 2007, pp. 2381–2384

[7] H. Murakami, R. Kitamura, I. Kawayama and M. Tonouchi, Appl. Phys. Lett., Vol. 95, (2009) 192503

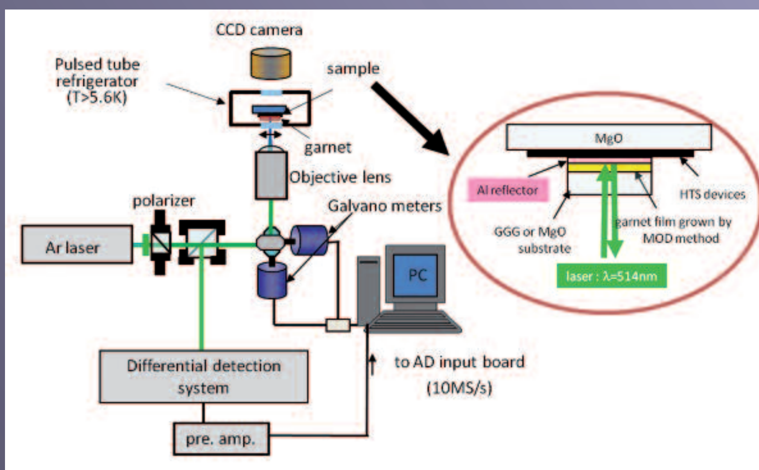


Fig. 4: Schematic diagram of the Magneto-Optical (MO) detection system. A linearly polarized 514 nm-wavelength green laser is used as an optical light source and focused inside the SQUID loop.

2ND KARLSRUHE DETECTOR WORKSHOP 2010

Karlsruhe, Germany - 2-3 March 2010

By Erich Crocoll

Institut für Mikro- und Nanoelektronische Systeme, Karlsruhe, Germany

Following the 1st Karlsruhe Detector Workshop that took place in 2008 at Karlsruhe-Bretten a 2nd workshop was organized at Karlsruhe from March 2 to March 3, 2010. This workshop, supported by the S-Pulse project of the 7th Framework Programme of the European Commission, has gathered 32 participants from 3 countries: France, Russia and Germany.

1. Terahertz Video Camera

The first session was dedicated to the presentation of an overview of the long way from a THz detector to a THz video camera for security, space or medical applications. Especially such issues have been discussed as which type of detectors can be used, which possible methods for scanning objects are and what kind of peripheral devices are needed. Presentations about the fabrication of sensitive detector arrays and SQUID readout circuits followed this talk.

2. Applications

This part dealt with applications of THz detectors: Dr. Alexander Sobolev (invited speaker) presented the development of devices for a superconducting integrated receiver for TELIS for measure species for atmospheric science and for clinical breath analysis for non-invasive medical diagnostics. Further, superconducting devices for sub-mm-wave and THz-applications in material science for nuclear fusion reactors or a Hot-Electron Bolometer for beam diagnostics of the ANKA storage ring had been presented as well as the development of lumped element KIDs and first astronomical results at the IRAM 30 m telescope in October 2009 applying an array of 30 LEKIDs.

3. Detector Arrays, Readout and interfaces

In this session on-chip interfacing issues for the transfer of transient pulses from superconducting nanowire single-photon detectors to SFQ logic have been discussed as well as to use reflection phase gratings as an elegant way of THz beam multiplexing.

For high-speed detector arrays, the energy relaxation processes in YBCO thin films has been studied by frequency and time-domain techniques. A multi-pixel readout for kinetic inductance detector arrays using a FPGA platform was presented and discussed as well as lumped element KIDs for array applications.

4. Technological aspects for the development of detectors

One aspect is the understanding of losses in coplanar wave guide resonators at millikelvin temperatures. To count single photons using an ultrathin NbN meander detector the current induced fluctuations have to be analysed by using physical models and measured data. Other presentation discussed the intrinsic detection efficiency of superconducting nanowire single-photon detectors with different thicknesses, or showed how YBaCuO oxides push advances in bolometric THz detection. NbN nano-layers growth and structuring for terahertz mixers and single photon detector arrays and a new approach to 3D substrate structuring for THz Detectors made from NbN have been presented.

PARTICIPANTS:

5 from France (Unité Mixte de Physique CNRS/THALES (1), UPMC-Paris 6 (2), CEA-INAC (1), IRAM Grenoble (1))

1 from Russia (Kotel'nikov Institute of Radio Engineering and Electronics)

26 from Germany (German Aerospace Center (DLR) (1), University of Ilmenau (2), IPHT Jena (5), Karlsruhe Institute of Technologie (18) (IMS (16), IMF-1 (1), ANKA/LAS (1))

The lessons of the workshop encourage young scientists and students to continue their efforts to enhance the detector devices for applications for radio astronomy, space, civic security applications and some possible new applications, e.g. for detecting synchrotron radiation. A lot of new ideas have been created to be realized in the near future.

S-PULSE WORKSHOP ON (MICRO) COOLING: REQUIREMENTS AND FUTURE ACTIONS

University of Twente, The NetherLands - 22-23 April 2010

By H.J.M. ter Brake

University of Twente, The NetherLands

As pointed out in the 2010 S-PULSE roadmap, most of the developments concerning cryocoolers will be required in the 4K range. At higher temperatures, available coolers meet the requirements of superconducting electronics (SE) fairly well. In addition, most of the SE systems and applications will require 4K operation. Therefore, most of the discussion in the workshop was focused on 4K coolers.

4K COOLER DEVELOPMENT

4K SE will need quite some time to develop into mass products for use outside the specialized labs. Therefore, we distinguish two developments on 4K coolers:

A. LAB USE:

- available in relatively short term (1 to 2 years)
- modular cooler approach (as far as possible combine with available techniques/coolers)
- simple to use
- may use LN2 and pressurized gas bottles
- small numbers
- cooling power 20 – 200 mW
- temperature stability, some 0.1 K
- device dimensions typically 10 mm x 10 mm to 1" by 1"
- magnetic shielding[1] (shield not necessarily at low temperature), diameter 25 mm length 150 mm
- not that relevant but still........ small size, low input, low cost

note 1: digital circuits require field compensation by at least a factor of 100; sensor/detectors may even be more sensitive to magnetic interference

B. Commercial 4K SE product:

- available in long term (> 5 years)
- high efficiency[2] (< 1kW/W)
- highly reliable
- low maintenance (closed-cycle operation)
- large numbers
- cooling power[3] 20 – 500 mW
- low noise
- low cost[4]
- small size (10 – 15 % of total)

note 2: increasing the efficiency at 4K is discussed in a separate section

note 3: in order to reduce the required cooling power attention should be paid to the cryo-package, e.g. leads and RF cables (thermal load versus electrical losses)

note 4: cost is mostly determined by the numbers produced (and sold); a dramatic reduction can be realized by introducing batch production of components

HOW TO GET TO HIGHER COOLER EFFICIENCY AT 4K?

Currently, coolers at around 80K have efficiencies of around 15% of Carnot, whereas 4K coolers hardly achieve 1% of Carnot, 0.5% being more typical for the lower power range (0.1W). This is caused by two effects:

- Firstly, conventional 4K coolers (Gifford-McMahon, Stirling, Pulse tube) all operate on basis of expansion of compressed gas in a regenerative cycle. At given pressure ratios and gas flows, the cooling power scales with the temperature, and thus reduces as temperature goes down. On the other hand, losses (conduction and radiation) increase as the temperature difference between environment and cold tip increases. As a result, the net cooling power reduces as temperature goes down.
- Secondly, in regenerative cycles the performance of the regenerator deteriorates as the temperature approaches the phase transition of helium. Because the specific heat of helium increases, the regenerative heat exchange between regenerator material and helium becomes problematic. Nowadays, special magnetic materials are applied in the regenerator with phase transitions in the relevant temperature range. These phase transitions result in increased specific heat of the regenerator. These magnetic materials need to be applied for reaching 4K.

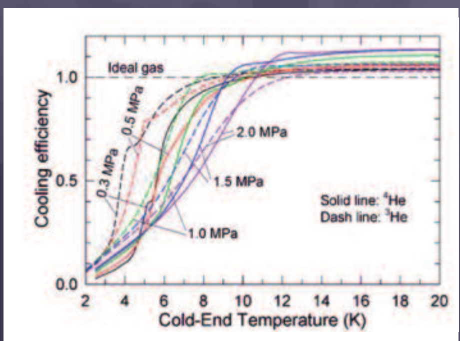
PAST events

NOW, WHAT CAN YOU DO?

Basically, there are two approaches: we can try to reduce the intrinsic losses in the cooler and secondly, we can develop and apply cooling techniques other than gas expansion.

A large part of the intrinsic cooler losses is caused by conduction through the regenerator material. A regenerator needs a good thermal conductance in radial direction but at the same time the conductance in axial direction should be low. This usually is established by stacking wire mesh material or using stacked spheres. However, with recent developments in materials (e.g. incorporating phonon-blocking layers) we could try to improve the regenerators in this respect. It would specifically be of interest to manipulate phonon interaction (i.e. thermal conductance) somehow. Apart from developments in anisotropic thermal conductance, also the heat exchange in a regenerator can be improved by applying nanofibres on the heat-exchanger wall materials, and/or using nanoparticles in the working fluid.

A further significant improvement is expected from using helium-3 instead of helium-4 as the working fluid, specifically at the lowest-temperature stage. Helium-3 has a significantly lower critical temperature than helium-4 (3.35 K compared to 5.2 K, respectively). Therefore, in the temperature range below 10 K, approaching 4 K, helium-3 acts much more like an ideal gas than helium-4. As a result, the losses in the regenerator are less. This was illustrated by De Waele in Eindhoven and later by Thummes in Giessen, who used helium-3 in the second stage of their pulse-tube coolers and thus achieved temperatures of around 2K. Also, at Lockheed Martin (Olsen and Nast) a multi-stage Stirling-type pulse-tube cooler is under development with the coldest stage being operated with helium-3 as the working fluid. After the Twente workshop in March, the benefit of using helium-3 was further discussed at the International Cryocooler Conference in Atlanta in May 2010 by Garaway et al of NIST. They expect that by reducing the regenerator losses, an efficiency of 5% compared to Carnot can be realized. An obvious disadvantage, however, of helium-3 is the significantly higher cost.



Reduction in cooler efficiency due to regenerator losses for helium-3 and helium-4 at different pressures, compared to an ideal gas as the working fluid. Picture taken from I. Garaway et al. "Measured and calculated performance of a high-frequency, 4K stage, He-3 regenerator" presented at ICC 16, Atlanta, May 2010. Courtesy of I. Garaway.

As alternatives to gas-expansion coolers, specifically solid-state coolers are of interest. Most of the recent developments are in thermo-electric cooling (TEC). Phonon-blocking layers reduce the conductive heat loss and thus increase the efficiency. Lower temperatures can be realized but still far above the SE operating point. However, TEC can be applied at precooling stages in hybrid cooler chains. Unfortunately, we have no clear idea on what alternative cooling techniques could be developed that may have significantly larger cooling powers at 4K. It is suggested to organize a special workshop on "crazy" cooling ideas with input of solid-state and semiconductor research.

Apart from a higher efficiency, also the size and required power input can be reduced by increasing the operating temperature and by reducing the required cooling power. Concerning the operating temperature, a temperature of 4.2 K requires a system that is one third larger in size and input power than a temperature of 5.6 K. However, SE community prefers to have the operating temperature at 4.5 K or lower. A reduction in required cooling power (by reducing dissipation or heat load through the wiring) directly translates into a reduced input power and size.

Group picture of the second Savoie workshop, May 27-28, 2010, Chambéry, France

By Pascal Febvre

University of Savoie, France

SAVOIE WORKSHOP ON SUPERCONDUCTING ELECTRONICS

27-28 May 2010 - Chambéry, France

Following the first Savoie workshop that took place in Chambéry in April 2009, the second workshop on Superconducting Electronics was localized in Chambéry (headquarters of the University of Savoie) and in Le Bourget du Lac, in the premises of the IMEP-LAHC laboratory. The workshop was an opportunity to show attendants the laboratory facilities in Superconducting Electronics, microwave and optoelectronics. It comprised nine students to achieve one of the goal of S-PULSE, centered on dissemination of Superconducting Electronics.
The workshop was divided in three working sessions: (i) technological characterizations for foundries, (ii) electrical interfaces and, (iii) optoelectronics and superconductivity.

The first session was an opportunity to present to the audience the status in fabrication and design of the European Superconducting Electronics Foundry, known as the FLUXONICS Foundry, located at the Institute of Photonic Technology (IPHT) in Jena in Germany. This was achieved by Dr Juergen Kunert of IPHT and by Professor Hannes Toepfer from the Institut für Mikroelektronik- und Mechatronik-Systeme gGmbH (IMMS) and the University of Technology of Ilmenau in Germany. Their two talks showed several examples of the FLUXONICS Foundry achievements that are at the state-of-the-art at world level and allow European researchers and industrial partners to access ISO-9001-certified Superconducting Electronics chips associated with a thorough expertise in design. Dr Pascal Febvre of the University of Savoie presented the first results of a different technological process developed with and by the National Italian of Metrology (INRIM) located in Torino, that is foreseen as a next technological step to increase integration and speed of future generation of digital circuits. All these activities are developed by institutional members of the FLUXONICS Society which work tightly together to provide a stable and reliable foundry for future European ultra-high-speed applications in fields where standard semiconductor or optical technologies cannot compete for fundamental physical reasons.

The second session focused on the interfaces of Superconducting circuits with the external world: namely a new design of Analog-to-Digital converters to be placed at the input of Superconductive Digital Electronics circuits, studied by THALES Research and Technology in France, on-chip superconducting amplifiers studied at IPHT to amplify output signals, and wireless microwave interfaces developed at the University of Savoie to extract output signals at room temperature.

The third session was focused on the combination of optoelectronics with superconductive devices. Dr Iwao Kawayama from Osaka University presented an overview of the last developments in the field in Japan. In particular, the optical response of Josephson junctions with photomixing experiments has been showed, along with the electrical characteristics of superconducting nanobridges and the detection of single-flux quantum voltages pluses with a magneto-optical setup. At last, Dr Villégier from CEA-INAC in Grenoble, France, has presented the development of superconducting nanowire single photon detectors to be integrated with NbN self-shunted single-flux-quantum technology.

This workshop was supported by the FP7 S-PULSE project and by the Division of International Affairs and the "Bonus Qualité Recherche" programme of the University of Savoie.

The 2010 Savoie workshop gathered 18 participants from 4 countries:

11 FROM FRANCE (University of Savoie (8), CEAGrenoble (1), THALES TRT (1), THALES ALENIA SPACE (1))

3 FROM GERMANY (University of Ilmenau (1) and Institute of Photonic Technology (2));

1 FROM JAPAN (Osaka University)

3 FROM SOUTH AFRICA (University of Stellenbosch and NioCad)

Upcoming events

SEFIRA DAYS
FRÉJUS, FRANCE
MAY 30 - JUNE 1, 2011
FRÉJUS, FRANCE

The seventh edition of the French Superconducting days (SEFIRA days) related to Superconducting Electronics and Physics of Superconductors will be held in the city of Fréjus on the french Riviera from May 30 to June 1, 2010. If you want to attend, present an oral talk or a poster, in english or in french, you can register directly from SEFIRA website www.sefira.org.

SUPERCONDUCTIVITY CENTENNIAL CONFERENCE 2011 (EUCAS2011, ISEC2011, ICMC2011), THE HAGUE, NETHERLANDS, SEPTEMBER 18-23, 2011

For the first century of the discovery of superconductivity, the EUCAS, ISEC and ICMC conferences will be held simultaneously to deal with the development in the field of superconductivity and applications, of superconducting electronics and of cryogenic materials. More **INFORMATION:**
www.eucas2011.org
www.isec2011.org
www.icmc2011.org

Edited by:

Pascal Febvre
University of Savoie
73376 Le Bourget du Lac - France - Phone: +33 479 758 864
Pascal.Febvre@univ-savoie.fr