2020 Summer Conference of KISAC

Abstracts of
2020 Summer Conference of KISAC

On-line
Aug 18 ~ Aug 19, 2020

Edited by **Woo-Seok Kim**
Changyoung Kim

Organized by
The Korean Superconductivity Society &
The Korea Institute of Applied Superconductivity and Cryogenics

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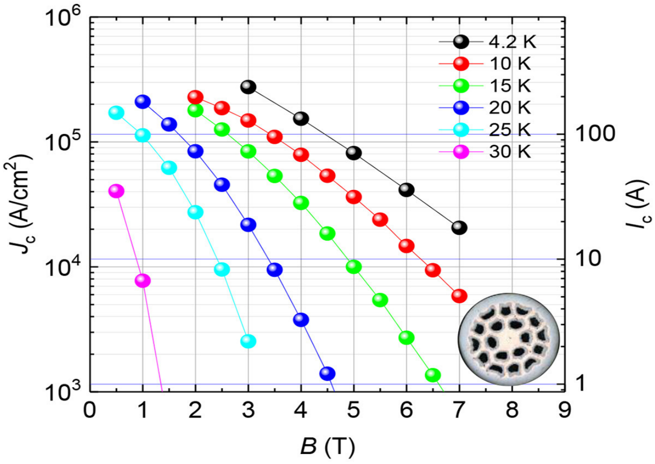
MgB_2 Superconducting wire

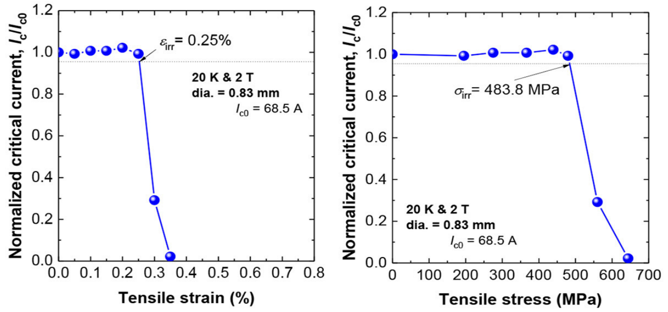
Specification of standard MgB_2 superconducting wire

㈜삼동은 축적된 절연 코일 소재 생산 기술 노하우를 바탕으로 고객의 맞춤요구에 따라 품질, 납기, 가격 등 경쟁력 있는 MgB_2 초전도 선재를 생산합니다.

Electrical Properties (J_c-B-T curve)



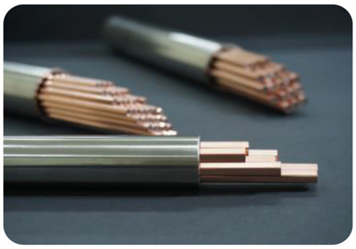
Electromechanical Properties

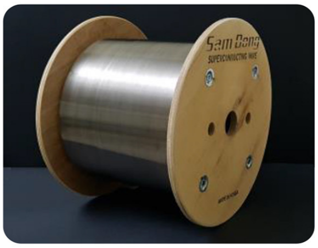


* Courtesy of Andong National University

Specification

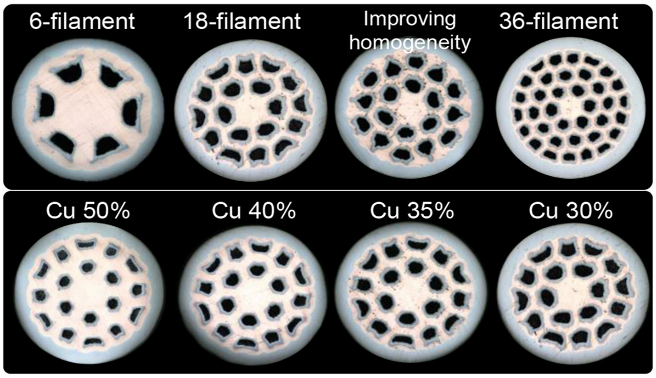
Parameter		Specification
Item		18+'1'Cu multifilament wire for DC application
Length		≥ 1 km
Diameter		0.83 mm$^{\Phi}$
Sheath materials	Outer sheath	Monel (Cu + Ni)
	Inner sheath	Cu
	Barrier	Nb
Cu fraction		About 30 %



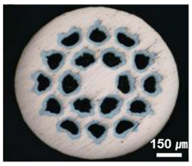


Various design of MgB_2 wire

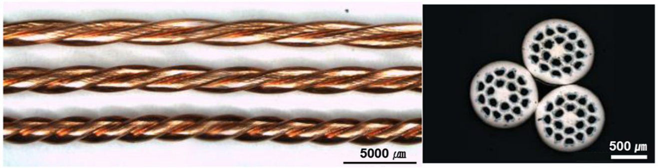
㈜삼동은 맞춤형 주문 생산 방식으로 고객의 수요 및 용도에 따라 다양한 디자인의 MgB_2 초전도 선재를 생산 공급합니다.

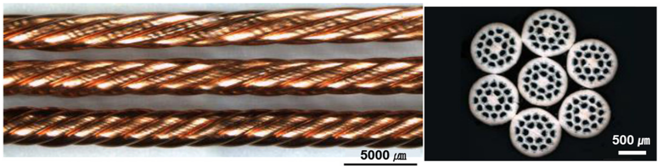


MgB_2 wire with Cu outer sheath



Area fraction (%)	
Cu	65
Nb	20
MgB_2	15





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Sam Dong
WHEREVER THERE IS ENERGY THERE IS SAM DONG

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인 사 말

2020 한국초전도·저온학술연합회 하계학술대회에 참여하시는 한국초전도학회와 한국초전도저온공학회 회원님들을 포함하는 모든 분들께 먼저 감사를 드립니다. 올해는 COVID-19 사태로 인하여 지난 2월에 개최 예정이던 동계 연합학술대회가 취소되었고, 본 하계 학술대회도 역사상 처음으로 온라인으로 개최하게 되었습니다.

그동안 본 학술연합회의 모든 행사 및 학술지의 논문 투고는 이론, 물성-실험, 전자 및 소자 응용, 재료, 응용기기, 그리고 저온공학의 6개 분야로 나뉘어 이루어져 왔습니다. 특별히 이번 학술대회에서는 기초과학연구원(IBS)에서 우주입자물리학에 관련되어 활발한 연구를 수행하고 있는 액시온 및 극한상호작용연구단(CAPP)과 지하실험연구단(CUP)에서의 적극적인 참여로, 초전도 센서 및 검출기 관련 분야를 추가하여 총 7개의 분야로 발표 및 논문 투고가 이루어질 예정입니다. 관련하여 초록을 제출해 주시고 발표에 참여해 주신 모든 분들께 진심으로 감사드리며, 참석하신 회원님들께서도 지대한 관심을 기울여 토론에 참여해 주시면 좋겠습니다. 저희 학술대회가 나날이 발전하며 분야가 확장되고 있는 것을 보며 조직위원으로서 큰 보람을 느낍니다.

아시는 바와 같이 본 학술대회에 투고된 논문은 학술연합회 학회지인 Progress in Superconductivity and Cryogenics에 게재되며, 본 학술지는 SCOPUS 등재지이므로 학술대회 발표뿐만 아니라 논문투고에도 많은 관심을 가져 주시길 당부 드립니다. 이번 학술대회에는 플래너리 강연 2편, 초청강연 21편, 일반구두발표 31편을 포함하여 총 116편의 초록이 접수되었습니다. 관심을 가지고 본 학술대회에 초록을 제출해 주시고 그간의 연구 성과 발표 및 공유, 그리고 활발한 토론의 장에 항상 참여해 주시는 회원 여러분께 진심으로 감사드립니다. 특히, 온라인 학회임에도 불구하고 학술대회의 성공적인 개최가 가능하도록 참여해 관련 기업들께 큰 감사를 드립니다.

전통적인 장소인 용평에서 개최되지 못하는 아쉬움도 있으나, 1986년 고온 초전도체가 발견되어 초전도 연구에 새로운 지평이 열렸던 것처럼, 2020년이 최초의 온라인 학회, 그리고 양 학회의 통합으로 초전도 및 저온 분야의 연구가 더욱 발전하는 새로운 역사가 시작되는 해가 되기를 바라고 있습니다. 본 학술대회가 양 학회 회원들의 적극적인 참여와 풍성한 아이디어 제안이 있는 학술교류 장이 되길 바랍니다. 마지막으로 본 학술대회 준비에 많은 노고를 아끼지 않으신 온라인 학술대회 조직위원들 및 관계자 여러분께 심심한 감사의 말씀드립니다.

2020년 8월 18일

초전도공동학술대회 공동학술위원장 **김창영, 김우석**

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PLENARY I

Exploring quantum critical points of competing orders for understanding emergent superconductivity

Kee Hoon Kim* ***(Seoul National University)***

During the last three decades of research on superconductivity after the discovery of high T_c cuprates, researchers seem to at least reach one consensus that the quantum phase transitions of competing orders (including nematic, spin, charge density waves, spin density waves, and pseudogap etc) are somehow linked to various emerging superconductivity in heavy fermions, cuprates, iron pnictides, and organic materials etc. Even in the conventional BCS superconductors such as the near room temperature superconductivity in metal hydrides are speculated to be associated with a quantum phase transition of a neighboring ground state in phase space. Therefore, how those quantum phase transition/quantum critical points can instigate emerging superconductivity remain as one of holygrail conundrums of condensed matter physics. All may have to look at the material specific situations to extract the most general ideas associated with the pairing of the quasi particles into the Cooper pairs. In such a view, I herein summarize our group efforts in exploring several quantum critical points in detail to cook up a scenario how superconductivity arises out of the fluctuations associated with those competing orders. In particular, with the full use of our machinery tools developed in extreme physical conditions such as high pressures, ultralow temperature, and high fields, and using the conventional chemical routes, we here present several interesting cases that (1) the charge-density wave state in metallic dichalcogenide can be another source of fluctuations as a pairing glue. (2) As in cuprates, the iron based superconductivity itself can exhibit very linear transport behavior of resistivity up to high temperatures once it is close to a quantum critical point of a solely spin density wave order, which in turn give rise to spin fluctuations to pair up the electrons. (3) Nematic order of dynamic type can develop a spin fluctuation gap indicating the gap in density of states, which seems to be quite similar to the case of charge density wave states appearing in high T_c cuprates. All these recent obervations may futher shed light into understanding the roles of quantum critical points and quantum phase transitions on forming the Cooper pairs.

PLENARY II

Fusion Magnet: Status and Challenges

Sangjun Oh* ***(National Fusion Research Institute, Daejeon, Korea)***

Ever since the breakeven point has been reach at JET, the Joint European Torus, a path toward ITER, the International Thermonuclear Experimental Reactor, is in some sense straightforward. The fusion power is roughly proportional to the fourth power of the magnetic field intensity. The magnetic energy stored in ITER TF, Toroidal Field magnet is very huge, as high as 51 GJ. These huge high field magnets nowadays, rely on Cable-in-Conduit conductors (CICC's) technology. The obvious merit of the CICC technology is in its cryogenic stability. Copper wires are usually co-wound together with superconducting wires and act as a stabilizer. Also quite a lot of current can flow through the cable and this can be regarded as another merit of cable-in-conduit conductors. It lowers the overall inductance and thereby the voltage which will be generated during quench event can be lowered to a manageable level. Finally, the impact of conduit on the stress relief for individual wire cannot be ignored. The ITER CICC design, we may say, lies at the culmination of 30 years-long endeavor on CICC technology. As the ITER is now in its final phase of construction, many participant countries are actively planning for the next step, so-called DEMO, demonstration reactor. Various types have been discussed but there are one thing in common. The constituent magnet will be more challenging than the ITER magnet. For example, there are legacies of the ITER magnet which need to be overcome. The fabrication and test of the ITER conductor gives us a lot of questions. Most problems occur within the CICC. It was clarified that the significant level of Lorentz force and the expected thermal cycles are both critical harmful to wires, even results in wire core breakage, which consists of thousands of fine filaments. Also, there are challenges of new technology, such as high temperature superconductor cables. Attaining fusion energy for mankind is still a very challenging but a worthwhile task.

* Keywords : Fusion Magnet, Cable-in-Conduit Conductor

SESSION I : TPE I

Theory & Physical Properties & Electronics & Device Applications - I

INVITED

Line-shape analysis of the Raman-spectrum from B_{1g} bond buckling phonon in $Bi_2Sr_2CaCu_2O_{8+x}$

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C. Kim *(Department of Physics and Astronomy, Seoul National University, Seoul, 08826, Korea)*

We performed Raman spectroscopy on two different Pb-free $Bi_2Sr_2CaCu_2O_{8+x}$ (BSCCO) and Pb-doped BSCCO in which superstructure is almost free. Line-shape analysis of the Raman-spectrum was done, focused on B_{1g} bond buckling mode which have drawn a lot of attention, since photoemission studies showed an evidence for strong coupling between the mode and electron. The line-shapes show asymmetry and are well fitted by the Fano line-shape formula. Remarkably, we found that the peak line-widths from B1g bond buckling mode in Pb-free BSCCO show much broader than those in Pb-doped BSCCO. The broad line width can be attributed to the superstructure modulation of BSCCO. Our results imply that B_{1g} bond buckling mode may have close relation to the origin of superconductivity or to boosting the superconducting transition temperature in BSCCO.

Acknowledges support from the National Research Foundation of Korea (NRF) (Grant No. NRF-2017R1D1A1B03036240).

INVITED

Pressure dependent transport properties of La-doped $CeIn_3$

Suyoung Kim *(SungKyunKwan University)*,
Hanoh Lee *(SungKyunKwan University)*,
SoonBeom Seo *(Los Alamos National Laboratory)*,
Sung-Il Kim *(SungKyunKwan University)*,
Dachun Gu *(SungKyunKwan University)*,
Sangyun Lee *(Los Alamos National Laboratory)*,
Soon-Gil Jung *(SungKyunKwan University)*,
Harim Jang *(SungKyunKwan University)*,
Jihyun Kim *(SungKyunKwan University)*,
In-Cheol Kim *(SungKyunKwan University)*,
Chan Koo Park *(SungKyunKwan University)*,
Tuson Park* *(SungKyunKwan University)*

$CeIn_3$ is an ideal candidate for studying the relationship between magnetism and superconductivity near their quantum critical point [1]. We report transport measurements of La-doped $CeIn_3$ under hydrostatic pressure up to 2.5 Gpa, which allows us to manipulate the magnetic as well as Kondo scattering in this compound. Both T_N and T_{coh} are reduced compared to those of the non-doped compound. When the pressure is applied, T_N is suppressed with similar trend to the pure case while the strength of the Kondo effect increases. Consequently, the expected quantum critical point (QCP) appears at around 2.47, 1.8, and 1.2 GPa for 20, 40, and 50 % La-doped cases, respectively. Interestingly, at T_N, the shape of the kink in resistivity varies well below the critical pressure for all three La-diluted cases, suggesting a possible change in the nature of magnetic moment before the system reaches to its quantum critical point. Comparing with the previous studies using NQR and optical conductivity measurements on the pure compound, our resistive transition at high pressure may be associated with itinerant behavior of f-electron in which AFM state still exists, which supports non-local nature of the pressure induced AFM QCP in this compound [2, 3].

[1] Mathur, N.D., et al., Nature, 1998. 394(6688) 39.
[2] Kawasaki, S., et al., Physical Review B, 2008. 77(6) 064508.
[3] Iizuka, T., et al.,. Journal of the Physical Society of Japan, 2012. 81(4) 043703.

INVITED

Mixed states of FeSe superconductors under pressure

Younjung Jo* *(Kyungpook National University)*,
Jihye Kim *(Kyungpook National University)*,
Jong Mok Ok *(Oak Ridge National Laboratory)*,
Joonyoung Choi *(Kyungpook National University)*,
Woun Kang *(Ewha Womans University)*

A hallmark of the iron-based superconductors is the strong coupling between magnetic, structural, and electronic degrees of freedom. However, there have been few studies of the interplay between those degrees of freedom and superconductivity. Here, using magnetoresistance of FeSe single crystals under hydrostatic pressure, we show that how pressure induced phase transitions affect the superconducting properties, especially flux pinning mechanism. The overall aspect of the pair breaking field ($H_{c2,0}$) follows the pressure dependent behavior of critical temperature (T_c). The activation energy U_0 in high magnetic field shows similar pressure dependence with $H_{c2,0}$ in accordance with previously reported pressure dependence of critical current. For low magnetic fields, U_0 (p) shows drastic increase near the pressure where antiferromagnetic ordering arises in vortex state.

INVITED

Scaling relation between spin-fluctuation coupled hole spectral weight and T_c in electron-doped cuprates

Dongjoon Song* ***(IBS-CCES, Seoul National University)***,
Suheon Lee *(Chung-Ang University)*,
Woobin Jung *(IBS-CCES, Seoul National University)*,
Wonjun Lee *(Chung-Ang University)*,
Sungkyun Choi *(Rutgers University)*,
Shigeyuki Ishida *(AIST)*,
Hiroshi Eisaki *(AIST)*,
Seoung-Ryong Park *(Incheon National University)*,
Kwang-Yong Choi *(Chung-Ang University)*,
Changyoung Kim *(IBS-CCES, Seoul National University)*

The grand challenge in high transition temperature (high-T_c) copper oxide (cuprate) superconductors is explaining its fundamental nature in a single framework. In particular, although there have been indications that various broken-symmetry phases impact on superconductivity, a key parameter that directly correlates with T_c over the entire doping range of superconducting state in the phase diagram has not been successfully singled out. Here, by combining angle-resolved photoelectron spectroscopy (ARPES) with muon spin rotation/ relaxation (mSR) technique, we report the electronic and magnetic phase diagram of electron-doped cuprate $Pr_{1-x}LaCe_xCuO_{4-d}$. Most importantly, the ARPES found that the electronic density of states forming small hole (H-)pocket Fermi surface exhibits a dome-shaped doping dependence, which remarkably well scales with the superconducting dome. Subsequent mSR measurement manifested that the ordered anti-ferromagnetic phase evolves from long-range, partially spin frozen and truly spin-fluctuating as Fermi surface topology changes from H-pocketless, with less coherent, and coherent H-pocket, respectively. This synchronized response between Fermi surface topology and magnetic phase suggests that H-pocket and spin-fluctuation provide positive feedback to each other, giving rise to optimal condition for superconductivity in electron-doped cuprates.

INVITED

IN TPE I-5

Unusual metallic behavior in a transition metal dichalcogenide

Seung-Ho Baek* ***(Changwon National University)***

We report the ^{77}Se nuclear magnetic resonance (NMR) study on Pd-doped 2H-$TaSe_2$. The Knight shift and the spin-lattice relaxation rates as a function of temperature reveal that the system is not an ordinary metal, but a strongly correlated one. With Pd 6 %-doping, we find that the correlation effect is notably increased, as superconductivity is significantly enhanced. Our data thus suggest that the electron correlation may be an important ingredient for superconductivity in the transition metal dichalcogenide.

INVITED

IN TPE I-6

Exciton condensation in 1T-$TiSe_2$

Jin Mo Bok* ***(SungKyunKwan University)***

Sixty years ago, Mott predicted an excitonic insulator, where electron-hole pairs may condense into the insulating state. In the early days, the theoretical formalism of exciton condensation received attention because it was similar to superconductivity. Candidate materials have been suggested, but the existence of EI has remained unconfirmed. Many recent works support the EI model of the charge density wave (CDW) state below the critical temperature T_c = 200 K of 1T-$TiSe_2$. However, one important requirement has remained unproven. Here, we provide material-specific calculations involving screened Coulomb interaction between electron and hole by solving the BCS-like exciton gap equation. We present a result of the T_c from the experimental parameter of $TiSe_2$ together with the doping dependence of it. Calculated spectroscopic features will be presented. And the results will be compared with experiments. Also, we expect that our approach can be applied to another candidate, such as Ta_2NiSe_5.

INVITED

Hidden order transition induced by proximity coupling in a heterostructured iron-based superconductor

Sunghun Kim* ***(KAIST)***

In correlated electron systems, the interplay of interactions can drive various phases with broken symmetry. On the other hand, hidden order transition is one of the mysterious phenomena in solids, of which order parameter and symmetry breaking are yet to be identified though the transition is usually observable in transport and thermodynamic measurement. In heavy fermion superconductor, well-known example exhibiting hidden order phase, it is believed that the implicated itinerant but localized electron and magnetic property would be a key ingredient to stabilize hidden order. In terms of this ingredient, heterostructure of two distinct correlated materials could provide a chance to approach such phase, based on the additional proximity coupling. In the present study, angle-resolved photoemission spectroscopy (ARPES) measurements were performed on an iron-based superconductor Sr_2VO_3FeAs - a heterostructure of iron arsenide (SrFeAs) layer and transition metal oxide ($SrVO_3$) layer, which has moderately high superconducting transition temperature $T_C \sim 35$ K and multiple bands at the Fermi level. ARPES measurements reveal that a fully isotropic and momentum independent gap opens only on the hole Fermi surface across the nonmagnetic transition at $T_{HO} \sim 150$ K, while the other Fermi surfaces remain gapless. This anomalous band gap opening cannot be explained with conventional scenarios of gap opening such as density-wave and orbital selective Mott transition. The dichotomous behavior based on the interlayer hopping and unusual field dependent magnetoresistance below T_{HO}, suggest that hidden order phase can be driven by proximity coupling between itinerant electron of Fe and localized spin of V.

INVITED

IN TPE I-8

Topological superconductivity in centrosymmetric magnetic metals

Bohm Jung Yang* ***(Seoul National University)***

I am going to talk about the topological aspects of the superconductivity that coexists with stable magnetism. In the first part of this talk, we propose a route to achieve odd-parity spin-triplet superconductivity in metallic collinear antiferromagnets with inversion symmetry. Owing to the existence of hidden antiunitary symmetry, which we call the effective time-reversal symmetry (eTRS), the Fermi surfaces of ordinary antiferromagnetic metals are generally spin-degenerate, and spin-singlet pairing is favored. However, by introducing a local inversion symmetry breaking perturbation that also breaks the eTRS, we can lift the degeneracy to obtain spin-polarized Fermi surfaces. In the weak-coupling limit, the spin-polarized Fermi surfaces constrain the electrons to form spin-triplet Cooper pairs with odd-parity. Furthermore, we find that the odd-parity superconducting states host nontrivial band topologies manifested as chiral topological superconductors, second-order topological superconductors, and nodal superconductors. In the second part, I am going to talk about topological superconductivity of spin-polarized fermions in ferromagnets. By developing parity formulas, which can also account for higher order band topology, we show that doped nodal semimetals of spin-polarized fermions can host various types of magnetic higher-order topological superconductivity.

S.L. and B.-J.Y. were supported by the Institute for Basic Science in Korea (Grant No. IBS-R009-D1), Basic Science Research Program through the National Research Foundation of Korea (NRF) (Grant No. 0426-20200003), and the U.S. Army Research Office under Grant Number W911NF-18-1-0137.

INVITED

Topological superconducting phase in high-T_c superconductor MgB_2 with Dirac-nodal-line fermions

Kyung-Hwan Jin* ***(Institute for Basic Science)***

Topological superconductors are an intriguing and elusive quantum phase, characterized by topologically protected gapless surface/edge states residing in a bulk superconducting gap, which hosts Majorana fermions. Unfortunately, all currently known topological superconductors have a very low transition temperature, limiting experimental measurements of Majorana fermions. Here we discover the existence of a topological Dirac-nodal-line state in a well-known conventional high-temperature superconductor, MgB_2. First-principles calculations show that the Dirac-nodal-line structure exhibits a unique one-dimensional dispersive Dirac-nodal line, protected by both spatial-inversion and time-reversal symmetry, which connects the electron and hole Dirac states. Most importantly, we show that the topological superconducting phase can be realized with a conventional s-wave superconducting gap, evidenced by the topological edge mode of the MgB_2 thin films showing chiral edge states. Our discovery may enable the experimental measurement of Majorana fermions at high temperature.

INVITED

Instability of j = 3/2 Bogoliubov Fermi surfaces

Eun Gook Moon* ***(KAIST)***

Exotic quantum phases including topological states and non-Fermi liquids may be realized by quantum states with total angular momentum j = 3/2, as manifested in HgTe and pyrochlore iridates. Recently, an exotic superconducting state with non-zero density of states of zero energy Bogoliubov quasiparticles, Bogoliubov Fermi-surface (BG-FS), was also proposed in a centrosymmetric j = 3/2 system, protected by a Z_2 topological invariant. Here, we consider interaction effects of a centrosymmetric BG-FS and demonstrate its instability by using mean-field and renormalization group analysis. The Bardeen-Cooper-Schrieffer (BCS) type logarithmical enhancement is shown in fluctuation channels associated with inversion symmetry. Thus, we claim that the inversion symmetry instability is an intrinsic characteristic of a BG-FS under generic attractive interactions between Bogoliubov quasiparticles. In drastic contrast to the standard BCS superconductivity, a Fermi-surface may generically survive even with the instability. We propose the experimental setup, a second harmonic generation experiment with a strain gradient, to detect the instability. Possible applications to iron based superconductors and heavy fermion systems including FeSe are also discussed.

SESSION II : SSD I

Superconducting sensors for Axion searches

ORAL

O SSD I-1

Improvement in Axion Dark Matter Search by Superconductor Technology

Woohyun Chung* ***(Center for Axion and Precision Physics research)***

It is extremely challenging to build an axion dark matter search experiment that could explore the wide range of plausible masses with enough sensitivity. However, thanks to recent technological advances in superconducting material research, physicists are now embarking on the most sensitive search yet for axions. For the last six years, IBS/CAPP has established the state-of-the-art axion detector facility in Korea with six dilution refrigerators, of which three axion detectors are running in parallel on the low vibration pads now. New 12 T big bore (32 cm) Nb_3Sn superconducting magnet will be added to the line-up early next year. Utilizing a conventional 8 T superconducting magnet, we have built the complete microwave axion dark matter experiment in 2018 and successfully collected axion dark matter physics data for the first time in Korea. This milestone is the result of less than two years of research and development since the first delivery of our dilution refrigerators. CAPP is now standing at the critical time of moving forward with improvements from R&D's to raise the axion-to-photon conversion power and eventually increase the scanning speed. The critical R&D's include the development of quantum noise limited amplifiers in collaboration with the Nakamura group in the U. of Tokyo and the superconducting YBCO cavity that sustains high Q-factor even at 8 T. We are now preparing an axion data run with quantum amplifiers and a superconducting cavity within this year. I will present the status of CAPP axion search and R&D efforts, including future plans.

ORAL

Josephson Parametric Amplifier for CAPP axion search experiment

Sergey Uchaikin* ***(Center for Axion and Precision Physics research)***

CAPP launched the first axion search experiment in South Korea based on haloscope in the frequency range of 1-7 GHz. In that experiment, it is critical to detect the expected week signal linked with axion to photon conversion with an amplifier which adding as little noise as possible. In the frequency range Josephson Parametric Amplifiers (JPA) have been demonstrated to operate close to the quantum limit and can be implemented in axion search experiments because well matched for frequency bandwidth and operation temperature. In this talk, we will describe our amplifier and technical details of implementation the JPA in our experiment.

NMR signal pick up using SQUIDs in axion mediated spin dependent interaction

Younggeun Kim* ***(KAIST)***

Axion Resonant InterAction DetectioN Experiment (ARIADNE) measures the interaction between two fermions via pseudo scalar boson, the axion. The fermion current makes the effective magnetic field on the spin fermion vertex. This effective magnetic field is not governed by the Maxwell's equation, therefore it is called an effective magnetic field and it is not shielded by the magnetic shield. The polarized 3He is used as the spin-polarized fermion, and the tungsten is used as the source mass. ARIADNE uses the SQUID based magnetometer. However, it has low sensitivity due to the microphonic noise. The planer gradiometer can solve this microphonic noise problem, and we demonstrated the planer gradiometer with two SQUIDs based magnetometer. We showed that the planer gradiometer immunes from the external vibration. We study the effect from the microphonic noise in the vibration criterion-G level condition and compared the vibration noise and the magnetometer intrinsic noise level. The noise estimation showed that the vibration noise is 10~100 times larger than the magnetometer's intrinsic noise. We compared the SNR with the vibration noise and the magnetometer/gradiometer intrinsic noise, and we could show that the gradiometer has 100 times larger SNR than the magnetometer.

ORAL

Noise Calibrations of a Flux-driven Josephson Parametric Amplifier for Axion Searches

Caglar Kutlu* ***(Center for Axion and Precision Physics research)***

The pilot experiment at the Center for Axion and Precision Physics Research (CAPP-PACE) is searching for axions as constituents of the dark matter in the universe using P Sikivie's haloscope method. The method is based on the coherent conversion of axions into microwave photons within a microwave cavity immersed in a strong magnetic field. The signal-to-noise ratio of the experiment is mainly limited by the thermal noise background of two components: the resonator and the readout system. The resonator noise is suppressed via lowering the cavity temperature, while the readout chain noise is dominated by the physics of the first amplifier. The CAPP-PACE experiment is currently being upgraded to employ a flux-driven JPA as a first stage to reach the standard quantum limits on measurement. It is crucial to be able to reliably estimate the background levels in order to reduce systematics on the estimated axion to photon couplings. In this talk, a detailed description of our test bench, the methodology of noise temperature measurements and the results will be given.

ORAL

High-temperature superconducting $YBa_2Cu_3O_{7-x}$ axion cavity in a strong magnetic field

Danho Ahn* *(Center for Axion and Precision Physics research)*

Superconducting cavity have been used in a wide range of particle physics, because superconducting surface shows extremely low surface resistance. In dark matter axion search of IBS/CAPP in Korea, we also have to collect tiny signal with resonant cavity from axion to photon conversion without significant energy loss. However strong magnetic field, in which uniform superconducting phase breaks down, is necessary to increase axion signal. Still, there is no superconducting cavity which maintain its low surface resistance in strong magnetic field. In this talk, we are going to show how this problem can be solved. First, using high-temperature superconductors are promising. $YBa_2Cu_3O_{7-x}$ (YBCO), which material we used, gives high critical field (> 100 T) and intrinsic pinning by its lattice structure, so low surface resistance due to low number density of vortices and vortex pinning at the mixed state can be achieved. Second, using commercially available biaxially-textured YBCO tapes enables to attach high quality YBCO films on the inner surfaces of cavities. We designed polygon-shaped resonant cavity. The prototype cavity have showed a clear superconducting phase transition at 90 K, and a very high quality (Q) factor at 8 T (330,000, 4 K, 6.9 GHz, TM010 mode) which is 6 times higher than the Q factor of same size oxygen-free high thermal conductivity (OFHC) copper cavity. There was no significant degradation of Q factor from 1 T up to 8 T. This is the first indication of possibility of realizing high-temperature superconducting microwave cavity in a strong magnetic field.

ORAL

Superconducting systems in CAPP18T experiment

Hojin Yoon* ***(KAIST)***

The presence of dark matter had profound consequences on the evolution of the Universe. The Standard Model does not accommodate a suitable dark matter candidate. Therefore, the existence of dark matter is a crucial phenomenological evidence for physics Beyond the Standard Model. The pressing goal of current and future dark matter experiments is to answer the question of whether dark matter interacts with normal matter other than gravity; i.e. if dark matter is detectable. Among the plethora of dark matter candidate particles, the Weakly Interacting Massive Particles (WIMPs) and the Axions are the most outstanding contender. In this talk, we will present the dark matter axion search projects at the Center for Axions and Precision Physics Research at CAPP/IBS, especially focused on the CAPP18T axion dark matter search experiment which utilizes a 18T High Temperature Superconducting solenoid magnet.

SESSION II : SSD I

Superconducting detectors for neutrino and dark matter studies

ORAL

O SSD I-7

Neutrino studies using superconducting detectors

Yong-Hamb Kim* ***(Center for Underground Physics, Institute for Basic Science)***

Superconducting detectors have become one of the important tools that demonstrated their extremely high energy sensitivity exceeding the limit of semiconductor-based detectors. Those detectors utilizing noble characteristics of superconducting circuits and electronics are used in a number of astroparticle physics projects that require a high energy resolution. In particular, these detectors have been playing major roles in modern neutrino physics research such as search for neutrinoless double beta decay and direct detection of neutrino mass. In the talk, the needs and advantages of superconducting detectors is reviewed with recent progress on the applications to neutrino research.

ORAL

O SSD I-8

Metallic magnetic calorimeters: Introduction and Applications

Jin-A Jeon* ***(Center for Underground Physics, Institute for Basic Science)***

Metallic magnetometers (MMCs), which are very sensitive temperature sensors operating at milli-Kelvin temperatures, measure the increase in temperature due to energy absorption in a detector system. The sensor technology is based on sensitive measurement of magnetization change of a magnetic material with a superconducting circuit. Meander-shaped superconducting loops are typically micro-fabricated as field generation coils to magnetize the sensor material and signal sensing coils to measure the induced current due to a particle absorption. The current change in the superconducting loop is measured by a current sensing dc-SQUID. These MMC-based low temperature detectors are used in a number of applications taking their advantages of high energy and timing resolutions. In this presentation, we will introduce the working principle, present status, and applications of MMCs.

ORAL

On-chip switches for persistent current injection in planar superconducting loops

Sora Kim* ***(Center for Underground Physics, Institute for Basic Science)***

Metallic magnetic calorimeters (MMCs) are a class of sensitive detector technologies to be used in large scale particle astrophysics projects such as AMoRE (Advance Mo-based Rare process Experiment) project. The AMoRE require operating hundreds of MMC devices composed of a superconducting circuit and a magnetic sensor material. Each MMC sensor has a superconducting loop that can host a persistent current as large as 140 mA. In a typical configuration of MMC circuit design, a persistent current is injected in planar superconducting loops by applying a heat pulse near a bypass part of the superconducting loop. Moreover, we also developed MMCs having an on-chip switch by changing the temperature. A part of the superconducting loop is fabricated with another superconducting material with its transition temperature (T_c) lower than that of niobium T_c. An alloy of 38 % Nb and 62 % Ta concentration (NbTa) was adopted as the Tc switch material. The sputtered layers of NbTa showed a clear superconducting transition at 5.29 K. A persistent current can be injected in the loop while reducing the temperature from above to below the T_c. As large as 120 mA were successfully inject with the NbTa on-chip switch. In addition, we fabricated heater a part of the chip. That is the MMC device can be heated to reach the temperature of the device at the Tc of the switch while keeping the system temperature unchanged. Moreover, a periodic supply of small current pulses on the heater can be used as a reference signals. We report on the recent progress on this hybrid configuration with multi-channel application of the on-chip switch.

ORAL

O SSD I-10

Low threshold detectors for low mass dark matter detection

HyeLim Kim* ***(Department of Physics, Kyungpook National University)***

Direct detection of dark matter (DM) is one of the fundamental and immediate goals in particle physics for understanding the Universe. A WIMP (weakly interacting massive particle) is one of the strong DM candidates. Until most up-to-date DM research, the low mass region of the parameter space for the possible interaction between a nucleon of normal matter and a WIMP has not been intensively explored. We studied a low temperature particle detector specialized for a low energy threshold for the low mass WIMP searches. Metallic magnetic calorimeters (MMCs) use superconducting loops of meander shape for detecting the magnetization change of magnetic sensor material caused by a small energy input. Our detector is employed an MMC readout with an optimized two-stage SQUID circuit and a pure CaF2 crystal as a particle absorber. The detector performance will be presented in this study.

ORAL

O SSD I-11

Current status of the AMoRE Project

HanBeom Kim* ***(Department of Physics and Astronomy, Seoul National University)***

Advanced Mo-based Rare process Experiment (AMoRE) is an international collaboration project searching for neutrinoless double beta decay (0νββ) of 100Mo using molybdenum-based crystals in a cryogenic condition. To detect this extremely rare decay event, AMoRE aims at operating the detector in zero-background condition. Thus, we carried out 3 years of pilot phase during which we identified and reduced various background source. The experiments have been performed at milli-Kelvin temperatures in order to minimize the thermal fluctuation. In the next phase of the project with larger size detectors, AMoRE-I, we are going to use 18 molybdate crystals with a total mass of 6 kg for simultaneous detection of heat and light signals based on Metallic Magnetic Calorimeter (MMC) readouts. It is going to be carried out in the dilution refrigerator installed at Yangyang laboratory which is the same one used in the pilot phase.

ORAL

O SSD I-12

Cryostat and refrigeration for large-sized detectors operating at mK temperatures

Chan-Seok Kang* ***(Center for Underground Physics, Institute for Basic Science)***

The AMoRE (Advanced Mo-based Rare process Experiment) is an international research project to search for neutrinoless double beta decay ($0\nu\beta\beta$) of 100 Mo using a large-scale low temperature detector. The AMoRE project measures scintillated phonon and photon signals generated from the molybdate crystals with MMC (Metallic Magnetic Calorimeter) at mK temperature. We will present the design and fabrication status of large scale cryostat for the AMoRE-2, the second phase of AMoRE project. The experimental set up for AMoRE-2 consists of 200 kg of molybdate crystals, copper frame, lead shield, and overall mass is almost 3.6 ton. This heavy set up is supported by specially designed holding system from outside of the cryostat and thermally connected with 1 meter of mixing chamber plate by soft contact. The cryostat is cryogen free system using three PTRs (pulse tube refrigerator) and the PTRs are mechanically decouple with cryostat by soft copper braids to reduce the vibration noise. We will discuss the details of the refrigeration units, the vibration cares and the shield system of the AMoRE-2 cryostat.

SESSION III : LC I

Large Scale Applications & Cryogenics - I

ORAL

O LC I-1

Design of a 10 MVA fully superconducting generator with dual field windings and 3 phase 4 pole armature windings

Myeonghee Lee *(Korea Polytechnic Univercity)*,
Miyeon Yoon *(Korea Polytechnic Univercity)*,
Sangho Park *(Korea Polytechnic Univercity)*,
Woo-Seok Kim *(Korea Polytechnic Univercity)*,
Ji-Kwang Lee *(Woosuk University)*,
Kyeongdal Choi* *(Korea Polytechnic Univercity)*

전기자와 계자가 모두 초전도인 전초전도 동기발전기에서 원주 방향의 자속은 기전력 발생에 기여하지 못하고 오히려 초전도 전기자 권선의 수직 자기장으로 작용하여 임계전류를 떨어뜨리며 손실을 발생시킨다. 본 연구진은 이전의 연구에서 전기자에 유도되는 원주방향의 자속을 줄이기 위해 계자를 나누어 전기자의 내측과 외측에 각각 배치한 이중계자 구조를 제안한 바 있다. 본 논문에서는 분할한 계자간 간격과 전기자 권선의 형상을 변화시켜가며 구한 이중계자 동기기의 교류손실 경향성을 바탕으로 10 MVA 전초전도 동기기를 설계하였다. 초전도 전기자 권선은 고온 초전도 선재로 구리 권선과 다르게 선재를 꺾거나 일정 정도 이상으로 휘게 하는 것이 불가능하기 때문에, 전기자를 실제로 구현 가능하게 하기 위해서 계자 4극 범위 안에서 3상 집중권을 설치한 형태로 설계하였다. 냉매순환 및 리드선 연결 등을 고려하여 계자를 회전시키는 구조로 설계하였다.

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Effect of Key Components on Thermodynamic Performance in 0.5 T/d Hydrogen Liquefaction

Bo Hyun Kim* ***(Hong Ik University)***,
Byung Il Choi *(Korea Institute of Machinery and Materials)*,
Ho-Myung Chang *(Hong Ik University)*

A thermodynamic study is performed to investigate the effect of key components on the power consumption required for 0.5 T/d hydrogen liquefaction system under development. As the liquefaction process is based on two-stage expansion helium Brayton refrigerator with LNG precooling, the key cryogenic components of the system are two turbo-expanders and four counter-flow heat exchangers. The performance index is selected as the adiabatic efficiency for the turbo-expanders and the minimum temperature approach for the heat exchangers. The liquefaction process is rigorously simulated with various values of the performance index. The real thermodynamic properties of helium, LNG, nitrogen and hydrogen are incorporated into a process simulator (Aspen HYSYS) to calculate the specific work required for liquefaction. It is revealed that the cold (second-stage) turbo-expander and the liquefying heat exchanger are most important in reducing the input power for liquefaction.

This work is supported by a grant (20IHTP-B151617-02) of the Korea Agency for Infrastructure Technology Advancement (KAIA) funded by the Ministry of Land, Infrastructure and Transport (MOLIT).

ORAL

Mitigation of Non-uniform Current Distribution in an HTS magnet: Control on Temperature Gradient

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This paper reports a method to mitigate non-uniform current densities in an HTS magnet and experimental study results of this mitigation method. Non-uniform currents flow in an HTS coil owing to almost “zero” resistivity of HTS, and it is well-known that the non-uniformity depends on the critical current of an HTS tape. Thus, in order to mitigate non-uniform current distribution, degradation of critical current is needed. Among critical current degradation methods, we adopted the temperature-dependent critical current degradation characteristic and developed a method of optimal control on the temperature gradient in an HTS coil. Optimal control on temperature gradient was performed by the use of a customized electric heater, to be called “thermal eraser”, generating a target temperature gradient in an HTS coil. With an HTS test coil and a customized heater, we performed a conduction-cooling test to evaluate the use of an electric heater, and we found the experimental results of non-uniform current distribution mitigation by measuring centerfield enhancement. Here, we will provide operation principle, experiment results, and discussion on center field variation by the use of an electric heater. Although the center field enhancement seems “small” compared to the magnitude of the center-field we can conclude that there is the feasibility of “thermal eraser”.

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ORAL

Preliminary Design of Zero Boil-off (ZBO) Liquid Storage System for Hydrogen Fueling Station

Min Gyun Park* ***(Hong Ik University)***,
Ho-Myung Chang *(Hong Ik University)*

A new concept is proposed and investigated to achieve zero boil-off gas in the liquid storage system by using cryocooler at the liquid hydrogen storage tank. Hydrogen is emerging as new energy carrier to take advantage of carbon-free energy system, and liquid hydrogen (LH2) will be stored at fueling stations for hydrogen vehicles. Since LH2 is a cryogenic liquid, the boil-off gas is a serious technical problem, not only as loss of fuel but also for safety. In hydrogen fueling station, however, it could be more effective to store hydrogen as a liquid rather than a gas, the density of liquid hydrogen is higher than that of gaseous hydrogen, so that more amounts of hydrogen can be stored. It is proposed that the boil-off gas in liquid hydrogen storage tank generated from the heat inflow could be completely reduced by using cryocooler at the liquid storage tank. The cryocooler at the liquid storage tank will continue to cool the liquid hydrogen to offset the heat inflow from the outside and therefore the liquid hydrogen is not vaporized, the zero boil-off could be achieved. Preliminary design is presented on the storage capacity, taking into account the heat leak analysis and the refrigeration capacity at 20 K with state-of-the-art GM cryocoolers.

ORAL

A Design Study of Large-Bore LTS Magnet for Industrial Application

Soobin An *(Seoul National University)*,
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Uijong Bong *(Seoul National University)*,
Kibum Choi *(Seoul National University)*,
Jonghoon Yoon *(Seoul National University)*,
Geonyoung Kim *(Seoul National University)*,
Seungyong Hahn* *(Seoul National University)*

In this paper, a design method of NbTi large bore superconducting magnet for industrical application will be studied. Superconducotr wire, current distribution anlaysis, and design/construction skills have been dramactially improved, recently. The needs of superconducting magnet system for industrial application increase, and one of them is large bore superconducting magnet. In large bore magnet design, not only critical current and field analysis, but stress analysis of the magnet is important. Therefore, a design study of large bore NbTi superconducting magnet will be performed with following analysis: (1) electromagnetic; (2) solid mechanic; (3) thermal.

This work was supported by the Technology development Program(S2719669) funded by the Ministry of SMEs and Startups(MSS, Korea).

ORAL

O LC I-6

Charging Simulation in Large Scale No-insulation HTS Magnet by using Active Control System

Jeonghwan Park ***(Seoul National University)***,
Kibum Choi *(Seoul National University)*,
Jeseok Bang *(Seoul National University)*,
Uijong Bong *(Seoul National University)*,
Seungyong Hahn* *(Seoul National University)*

No Insulation (NI) high-temperature superconducting (HTS) magnets have limitations in large systems due to their charging delay. Particularly, contact resistance may be decreased or inductance may be increased due to a large radius of the coil in the enlarged magnet system. In order to minimize the charging delay, an active control system was proposed in the previous studies, and in this paper, we applied the proposed active control system in some large superconducting magnets. Then, the effect of the active control is examined in (1) NI HTS magnet without a nonlinear material, and (2) NI HTS magnet with iron material in which inductance variation depending on operating current must be considered. Heat generation by the radial current is considered as a constraint in the PI system, and the charging scenario was analyzed using an equivalent lumped circuit model. We confirmed the positive effect of the active control system in a large magnet, and in particular, the charging delay of the NI HTS magnet containing iron is further improved.

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Analysis on Non-Uniform Current Distribution in HTS Tape Using Distributed Circuit Network Simulation

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Seungyong Hahn* *(Department of Electrical and Computer Engineering, Seoul National University)*

Recent progress on research and development of large-scale superconducting magnet using high temperature superconductor (HTS) triggered active research on HTS cable. Usually, in HTS cables, non-uniform current distribution in HTS tapes causes many other problems such as non-uniform stress distribution as well as an unexpected voltage drop across the coil. As a basic step to analyze the current distribution in HTS cable, current distribution analysis on an HTS tape level is necessary. Thus in this paper, a distributed circuit network simulation is introduced to analyze the current distribution in an HTS, which is verified through a well-known finite element analysis using 2-dimensional H-formulation. Then, key parameters for non-uniform current distribution in an HTS tape is discussed based on the simulation results.

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIT) (No. 2018R1A2B3009249). This was also partly supported by the BK21 Plus Program of the Creative Research Engineer Development for IT, Seoul National University in 2020.

SESSION IV : TPE II

Theory & Physical Properties & Electronics & Device Applications - II

INVITED

Bosonic spectrum of multiband superconducting system, K-doped Ba-122

Jungseek Hwang* ***(Sungkyunkwan University)***

One may be able to extract the bosonic spectral function from measured optical spectrum, particularly, inelastic scattering response function or the optical conductivity. There has been known that the mediated phonon spectra of conventional BCS superconductors can be obtained by various experimental spectroscopy techniques including optical spectroscopy and theoretical calculations. There has been discovered hydride superconductors, which can be understood by the phonon-mediated mechanism. The doping- and temperature-dependent bosonic spectral functions of cuprate systems has also been obtained various experimental spectroscopy techniques. In this presentation, we will discuss about temperature- and doping-dependent bosonic spectral function of K-doped Ba122, which is a multiband superconducting system.

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INVITED

Terahertz electrodynamics of superconducting Nb thin films

Jae Hoon Kim* *(Yonsei University)*,
Ji Eun Lee *(Yonsei University)*,
Joonyoung Choi *(Kyungpook National University)*,
Kyung Ik Sim *(Sungkyunkwan University)*,
Younjung Jo *(Kyungpook National University)*

We investigate the electrodynamics of superconducting niobium (Nb) thin films by using terahertz spectroscopy in the temperature range of 2 - 295 K under an external magnetic field up to 7 T. The temperature dependent superconducting gap was determined from the real part of the optical conductivity well below T_c = 8 K. We also show the optical conductivity of Nb under an out-of-plane magnetic field. Additionally, the London penetration depth was extracted from imaginary conductivity under an in-plane magnetic field.

INVITED

Discovery of Sodium-Doped Triphenylene Superconductors by Searching the Organic Material Database

Ji Hoon Shim* ***(Pohang University of Science and Technology)***

Over the past few decades, there has been a lot of research on organic molecule-based materials for future advanced technology. The superconductivity has also been reported in various carbon-based organic materials in line with this trend. In particular, polycyclic aromatic hydrocarbons (PAHs) have been intensively studied in recent years because of the highly conjugated characteristics of the delocalized electrons supplied by alkali metal doping. Here, we report on a PAH superconductor, sodium-doped triphenylene (nominal composition of Na3triphenylene), which was discovered by searching the database of PAH molecules with a small energy difference between the lowest unoccupied molecular orbital (LUMO) and LUMO + 1 states. As the first sodium-doped PAH superconductor, it shows the superconducting transition at $T_c \approx 15$ K under ambient pressure. The discovery of the new PAH superconductor suggests the promising possibility of superconductivity from more diverse molecular structures and the realization of high-T_c organic superconductors furthermore.

INVITED

Is it possible to achieve room-temperature superconductivity at ambient pressure?

Jun-Hyung Cho* ***(Hanyang University)***

최근, 150만기압 이상에서 황화수소화합물 H3S (2015년)와 란타늄수소화합물 LaH10 (2019년)에서 초전도상전이온도 T_c가 각각 ~203, ~260 K를 가지는 초전도성이 발견되어 주목을 끌고 있다. 이들 수소화물들에서는 전자-포논 상호작용에 의한 쿠퍼쌍에 의해서 초전도성을 가지는 것이 알려지고 있다. 특히 희토류수소화물 XHn은 금속 원자(X)를 H 원자들이 둘러싸고 있는 cage 형태의 구조를 가지고 있으나 X 원소의 종류와 수소의 조성비 n에 의해서 변화되는 T_c의 원인에 대해서는 아직 이론적 이해가 불충분하다. 본 연구에서는 LaH10에 대해 제일원리계산 방법을 이용하여 얻은 전자구조, 포논구조, bonding nature, 전자-포논 상호작용세기 및 초전도갭, 압력 변화에 따른 T_c 변화, 동위원소 효과 등의 결과를 통한 상온초전도의 미시적 메커니즘을 소개한다 [1-4]. 또한 ternary hydride 를 이용하여 T_c를 450 K 이상으로 올리는 방안을 소개하고 [5], 수소화물을 안정화 시키는 압력 P_c를 100 GPa 이하로 줄이는 방안으로 f 전자를 가지는 희토류 금속을 포함한 수소화물을 소개한다 [6]. 끝으로 미래에 실현될 것으로 믿고 있는 상압-상온초전도체 발견에 대한 연구 방향을 제시하고, 국내에 금속수소화물의 초전도연구를 활성화 시킬 수 있는 방안들을 토의하려고 한다.

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INVITED

IN TPE II-5

Pressure-induced superconductivity in solid-hydrogen and hydrides

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Hydrogen is one of the most enigmatic elements under pressure. Due to its lightest and smallest characteristic in the periodic table, it can easily induce various physical and chemical phase transitions in solid hydrogen and hydrides. This presentation will show the role of hydrogen covering stoichiometry change, metal-insulator transition as well as recently hot-issued superconductivity. Pressure tends to make more hydrogen atoms to react with metal to form polyhydrides [1-3] and in case of sodium polyhydrides, we observed unusual H3-anion structure motif. When hydrogen in these compounds these are compressed enough, we can expect superconductivity based on electron-phonon coupling mechanism [5-8].

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INVITED

Pressure-induced phase transitions and superconductivity in magnesium carbides

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Crystal structure prediction and in silico physical property observations guide experimental synthesis in high-pressure research. Here, we used magnesium carbides as a representative example of computational high-pressure studies. We predicted various compositions of Mg-C compounds up to 150 GPa and successfully reproduced previous experimental results. Interestingly, our proposed MgC2 at high pressure >7 GPa consists of extended carbon bonds, one-dimensional graphene layers, and Mg atomic layers, which provides a good platform to study superconductivity of metal intercalated graphene nano-ribbons. We found that this new phase of MgC2 could be recovered to ambient pressure and exhibited a strong electron-phonon coupling (EPC) strength of 0.6 whose corresponding superconductivity transition temperature reached 15 K. The EPC originated from the cooperation of the out-of-plane and the in-plane phonon modes. The geometry confinement and the hybridization between the Mg s and c pz orbitals significantly affect the coupling of phonon modes and electrons. These results show the importance of the high-pressure route to the synthesis of novel functional materials, which can promote the search for new phases of carbon-based superconductors.

INVITED

IN TPE II-7

Lumpy Cooper pairs in an iron-based superconductor

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Cooper pairs can tunnel through the vacuum barrier between two superconducting electrodes, known as a Josephson junction. One can extract the superconducting order parameter from the current-voltage curves close to zero bias. We use atomic-resolution Josephson scanning tunneling microscopy (STM) to visualize the spatial variations of the superfluid in the iron-based superconductor $FeTe_{0.55}Se_{0.45}$. To measure Cooper-pair tunneling, a Pb-coated tip was employed and its superconductivity was thoroughly verified by measuring noise enhancement induced by Andreev-reflection on Pb(111) surface. By simultaneously acquiring the topographic and electronic properties, we find that this inhomogeneity in the superfluid is not caused by structural disorder or strong inter-pocket scattering, and does not correlate with variations in the energy of the Cooper pair-breaking gap. Instead, we see a clear spatial correlation between superfluid density and the quasiparticle strength, defined as the height of the coherence peak, on a local scale. Our results shed light on the interplay between superconductivity and quasiparticle character that has been observed by photoemission experiments across the critical temperature in the unconventional superconductors.

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INVITED

IN TPE II-8

Superconducting disoliton as a one-dimensional linear potential system

Jeehoon Kim* ***(POSTECH)***

A disoliton as a bounded soliton system occurs as a universal phenomenon at all length scales. Despite the discovery of several disoliton systems - initially in a swimming pool as a half vortex ring - the underlying physics, such as the nature of the interaction potential, remains elusive due to the lack of a proper model system. Here we report on a superconducting disoliton (SDS) created as a U-shape quantum flux tube in a superconducting Nb film. A systematic control on a single SDS reveals the purported 1D linear potential, i.e. distance-independent force. SDS will provide a novel platform for exploring 1D phase transition, quantum chiral transport, and non-Abelian statistics.

Impact of the Electron Density Variations on the Yu-Shiba-Rusinov Bound States in Superconductors

Jungpil Seo* ***(DGIST)***

Magnetic impurities provide an exchange potential to break the Cooper pairs in superconductors, inducing quasiparticle excitations within superconducting gap known as Yu-Shiba-Rusinov (YSR) bound states. It is suggested these YSR bound states can be controlled by the tuning the electron density at the Fermi energy of the superconductors, but it has not been proved in experiment. In our experiment, using a scanning tunneling microscopy and spectroscopy (STM/STS), we demonstrate how the electron density variations at the Fermi energy influence the development of the YSR bound states. With a novel idea to control the electron density, we show that not only the exchange interaction but the on-site Coulomb interaction plays a crucial role in forming the YSR bound states, the problems of which are hitherto neglected. Our work provides keen insight into the understanding of the interactions between magnetic impurities and superconductors, so it should be useful to designing topological superconductors in next levels.

INVITED

IN TPE II-10

Evidence of Higher Order Topology in Multilayer WTe2 from Josephson Coupling through Anisotropic Hinge States

Gil-Ho Lee* ***(POSTECH)***

Non-centrosymmetric Td-WTe2, a type-II Weyl semimetal, is also expected to have higher order topological phases with topologically protected, helical one-dimensional (1D) hinge states when its Weyl points are annihilated. However, the detection of these hinge states is difficult due to the semimetallic behaviour of its bulk. Here, we spatially resolve hinge states by analysing the magnetic field interference of supercurrent in Nb-WTe2-Nb proximity Josephson junctions. The Josephson current along the a-axis of the WTe2 crystal, but not along the b-axis, shows sharp enhancements at the edges of the junction; the amount of enhanced Josephson current was comparable to the upper limits of a single 1D helical channel. Our experimental observations suggest a higher order topological phase in WTe2 and its corresponding anisotropic topological hinge states, in agreement with theoretical calculations. Our work paves the way for the study of hinge states in topological transition metal dichalcogenides and analogous phases.

SESSION V : MM I

Materials - I

INVITED

Status of MgB_2 superconducting wires at Sam Dong

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Since 2014, Sam Dong Co., Ltd. (Sam Dong) has developed MgB_2 superconducting wires in various architectures. Now that the wires are commercially available and supplying to superconducting societies toward practical applications. With our great efforts, critical current densities of Sam Dong commercial wire, i.e., 18+1'Cu' multi-filamentary MgB_2 wire made by in-situ PIT (powder-in-tube) process with filling factor of 16 %, are estimated to be 270,000 A/cm^2 at 3 T and 4.2 K and 100,000 A/cm^2 at 2 T and 20 K, respectively. In particular, in-situ processed MgB_2 superconducting wire can utilize chemical dopants to further enhance in-field critical current properties. However, limited selection of metallic tube triggered by post-treatment precursor requires an expensive diffusion barrier of niobium (Nb), which is drawbacks. This work will discuss the progress of cost-effective Cu-based MgB_2 superconducting wires and key technology of coil or cable development, and the potential for MgB_2 superconductors in various practical applications.

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ORAL

O MM I-1

Bending characteristics of ultrasonic welded bridge-joints for CC coils

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Michael Bihasa de Leon *(Andong National University)*

In the field of 2G high-temperature superconducting (HTS) device applications, joints between coated conductor (CC) tapes are essential to produce long-length tapes for power cables, coils, and to connect pancake coils for superconducting magnet devices. Several studies on various resistive joint techniques, such as soldering and diffusion reaction, have been reported. A good quality joint should provide good adhesion, low joint resistance Rj, no critical current Ic degradation, cost effective, and simplicity of joining process. In this study, an ultrasonic welding (UW) process was used to form bridge-joints for CC coil applications. Two types of bridge-joint structure were adopted, the 4-mm wide multiple-bridge and 12-mm wide single-bridge structures, using differently fabricated and stabilized CC tapes. For comparison, the mechanical-controlled soldering method which has provided low contact resistance was also adopted. In order to evaluate the bending tolerance of CC bridge-joints formed by different methods, tension bending tests at room temperature (RT) using mandrel with different bending diameters were done. Results showed variations in Rj values depending on both the CC tapes used and bridge-joint structure. UW bridge-joints showed comparable joint characteristics with those formed by mechanical-controlled soldering. Moreover, the multiple-bridge structure showed better bending tolerance than the single-bridge structure because of the gaps among the multiple 4-mm bridges that provide good flexibility at the joint part against bending. For HTS coil applications, it is more desirable to form a multiple-bridge structure for bridge-joints and using UW method since it has excellent work productivity during on-site work.

Keywords: ultrasonic welding, HTS coil, bridge-joint, joint resistance, bending tolerance.

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ORAL

Diffusion barrier-free MgB_2 superconducting wires

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Jung Ho Kim *(University of Wollongong)*

In-situ MgB_2 superconducting wire mandatorily requires a diffusion barrier to prevent phase reaction between precursor magnesium (Mg) and metal stabilizers (copper (Cu) and Cu alloy). Even if a niobium (Nb) is well known for it, using the Nb is not cost-effective and occupied more 40 % material cost. Thus, it is a key factor in the reduction of MgB_2 wire production cost. In this study, high-efficient and a low-cost diffusion barrier is strategically suggested to replace the currently existing Nb. Until now, no single metal material has been found to replace a metallic Nb in terms of cost and properties. Herein, we propose a new approach through coating the MgBx phase on Cu substrates or tubes inside. A reaction mechanism is that mixture of excess Mg and B reacts with MgBx (i.e., MgB_4) on Cu substrate or tube. Subsequently the drawing and heat treatment at 675-700 ℃ for 20-60 min under Ar flowing are carried out. This work paves the way to further reduce the cost of MgB_2 superconducting wires toward practical applications.

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Strain response of critical current of multiple-HTS layers on one substrate coated conductor tapes at 77 K

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Hyung-Seop Shin* *(Andong National University)*

High engineering critical current density (Je) is in demand on high-performance large-scale applications such as power cables, high Ic current lead, high magnetic field magnets, accelerators, and fusion reactors. In developing the high current capacity and the low vulnerability under a high magnetic field of high temperature superconducting (HTS) REBCO coated conductors (CC), various trials have been carried out, and as a result, CC tape characteristics have been greatly improved. Recently, KERI developed multiple-HTS layers on one substrate (MHOS) that can carry high I_c depending on how many layers of superconducting film are deposited in one substrate. The MHOS has a thicker superconducting layer than that of a single REBCO layer CC tape, this might affect the critical current, I_c degradation behavior. From the viewpoint of ensuring the performance and reliability of the MHOS conductor, it is necessary to evaluate the strain response of I_c. In this study, the electro-mechanical properties using the uniaxial tension test method as well as the bending properties of the MHOS conductor were investigated at 77 K and self-field and under 0.5 T using a pair of Neodymium permanent magnet system.

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ORAL

Enhanced pinning properties by refining Gd_2O_3 particles trapped in the $GdBa_2Cu_3O_{7-\delta}$ films via RCE-DR

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The pinning properties of $GdBa_2Cu_3O_{7-d}$ (GdBCO) coated conductors(CCs) fabricated by reactive co-evaporation by deposition and reaction (RCE-DR) should be further improved because in-field critical current densities (J_c) of GdBCO CCs are relatively lower than those of REBCO CCs produced by other processes such as metal-organic deposition (MOD), pulsed laser deposition (PLD), metal-organic chemical vapor deposition (MOCVD). To improve in-field Jc values of GdBCO CCs fabricated by the RCE-DR process, employing the nominal composition of Gd:Ba:Cu=1:1:2.5, we tried to refine the Gd_2O_3 particles trapped in the GdBCO superconducting matrix by controlling nucleation and growth rates of Gd_2O_3 in the liquid phase before the growth of GdBCO. For this purpose, we carefully selected the processing conditions on the GdBCO stability phase diagram experimentally determined for the nominal composition of Gd:Ba:cu=1:1:2.5. By lowering growth temperature of Gd_2O_3 in the liquid from 860 to 800 °C in the oxygen pressures of 20 and 30 mTorr, the average particle size of Gd_2O_3 particles trapped in the GdBCO matrix could be refined from 137 ± 52 to 73 ± 31 nm. The pinning properties of GdBCO CCs could be significantly improved by the refinement of Gd_2O_3. Details will be presented for a discussion.

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ORAL

O MM I-5

Current transport behaviors in 4-mm wide $GdBa_2Cu_3Oy$ CC tape under static fatigue condition at 77 K

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The long-life reliability of 2G high-temperature superconducting (HTS) coated conductor (CC) tapes in real applications should be ensured, especially in operation where various stresses including Lorentz force are inevitable. In some applications, critical current (I_c) degradation in REBCO superconducting layer with eLAP sed time is possible even at the stress level below the reversible stress limit of the CC tapes while it is static. Depending on the device type where CC tapes are applied, the I_c degradations under long-term static loads may occur due to possible damage to the REBCO superconducting layer. Hence, the prediction of stress level to cause an I_c degradation under given conditions will be an issue in real applications. In this study, 4-mm wide IBAD/RCE-DR processed $GdBa_2Cu_3Oy$ CC tapes were subjected to static fatigue loading which includes both tension and bending sections at 77 K using a mechanical static fatigue tester. The bending mandrel provided a bending strain which is superimposed to the tensile strain applied on the CC tape's superconducting layer. Ics were measured at 77 K through a specified stress level at various eLAP sed times. The time intervals for measuring the I_c were determined until 100 hours as an accelerated test. The electrical endurance (stress) limit for I_c degradation was determined based on the 95 % I_c retention criterion. The results showed that different bending mandrels influenced on the I_c degradation behaviors. The I_c dropped considerably in the bent section as compared to unbent sections as the eLAP sed time increases. Further, the relationship between the superconducting layer and static fatigue fracture mechanism was clarified using scanning electron microscopy-energy dispersive x-ray spectroscopy and electron probe micro-analysis.

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SESSION VI : LC II

Large Scale Applications & Cryogenics - II

ORAL

O LC II-1

Post-Quench Analysis of No-Insulation REBCO Magnet with Finite Element Method

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Recently, various equivalent circuit of no-insulation(NI) high-temperature superconducting(HTS) magnet have been presented and verified. However, none of them yet precisely demonstrated the post-quench electromagnetic behaviors of NI HTS magnets. Most simulations with the equivalent circuits could not account for the fast-propagation of quench. The problem is that a major parameter, critical current(I_c), which is related closely to quench, changes with various reasons such as temperature, magnetic field intensity, and mechanical stress. To account for the fast propagation of quench in a NI HTS magnet, this paper presents an analysis with finite element method with multi-physics simulation. Not only dealing with an electromagnetic contribution on quench, but also other physical situations are considered.

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ORAL

O LC II-2

Cooling Load Calculation and Cryogenic Control Scheme for Variable Current in Commercial SFCL

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Ho-Myung Chang *(Hong Ik University)*

Cooling load calculation and operational control scheme of cryogenic refrigeration are investigated for a commercial product of medium-voltage (22.9 kV 2.0 kA) superconducting fault current limiters (SFCL). The main goal of cryogenic cooling system is to maintain the HTS modules in sub-cooled liquid nitrogen (LN2) stably at 77 K and 300 kPa, while the electrical current varies over a wide range in practice. As the detailed design of HTS modules and cryostat were completed, the cooling load is precisely estimated as a function of current, taking into account the current leads and the ac loss of HTS modules. Four units of GM cryocoolers with newly developed inverter compressors are employed for the partial load operation, whose refrigeration capacity is controlled by the input power frequency. Two different control scheme is applied, depending on the current level. For the full load at 2 kA, the inverter frequency is set at its maximum (75 Hz). When the current level is in the range between 2 kA and 1 kA, the frequency is set at an intermediate value between 75 Hz and 40 Hz in accordance with the actual thermal load. Three factors are considered in determining the operating frequency; (1) the thermal load as a function of current, (2) the refrigeration capacity as a function of frequency and cold-head temperature, and (3) the overall heat transfer rate between liquid nitrogen and cold-head. When the current is lower than 1 kA, the frequency is set at its minimum (40 Hz), and the electrical heaters are used for typical thermal control. The details of load calculation and control scheme are presented and discussed with selected cases of example. The result will be directly applied to the prototype of cryogenic system for the medium-voltage SFCL under development by KEPCO Open R&D Program.

ORAL

O LC II-3

A Study on Design Topologies and Requirements of No-Insulation HTS Motors for High Power Density Propulsion Motors

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Recently, worldwide research institutes including NASA Glenn Research Center are developing a motor incorporating a no-insulation (NI) high-temperature superconducting (HTS) coil as a next-generation electric propulsion technology. Adopting advantages of NI HTS coils including (1) automatic protection of the coil due to bypassing current and (2) high energy density from lack of insulation materials, the motors could be smaller and lighter compared to conventional ones. Therefore, it is expected that NI HTS motors can be applied in fields that require high power density or light weight, such as electric aircraft and large ship propulsion. In this study, we investigated and classified the applicable fields of NI HTS motors, and conducted a study to derive a suitable design topology through numerical comparison. For that, first, (1) commercial electric propulsion motors are investigated and classified based on their power density and rotating speed, and (2) minimum design requirements of NI HTS motors having the same or superior performance compared to commercial ones are obtained theoretically in each category. Also, (3) the power density and charging time delay were compared in accordance with the structure of the motor and the use of iron cores. Finally, (4) from the design point of view, the main technical challenges for the development of high-performance NI HTS motors are summarized.

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ORAL

O LC II-4

Performance of Four GM Cryocoolers and Conduction-Cooling Parts in SFCL Cryogenic System

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Ho-Myung Chang *(Hong Ik University)*

A cryogenic refrigeration scheme with four units of GM cryocoolers is designed and investigated for the medium-voltage SFCL (superconducting fault current limiters) system under development. Since the commercial product of SFCL is rated at 23 kV and 2 kA, the cooling load is estimated from 500 W up to 1 kW at 77 K, depending on the actual current level. It was decided to employ four units of GM cryocoolers with inverter compressors for partial load operation. In order to secure the electrical insulation, three phases of HTS modules are immersed in a subcooled liquid-nitrogen pool, and four cold-heads of GM cryocoolers are conductively anchored to the external wall of the liquid container. The objective of this work is to evaluate and analyze how four individual cryocoolers and four conduction-cooling parts collaborate for the cooling of one cryostat from the experimentally measured temperature only. The refrigeration capacity of individual GM cryocooler is modelled as a function of cold-head temperature and inverter frequency from the experimental data provided by manufacturer. The conducting cooling parts are composed of stainless steel wall, copper conductor, and bolt-jointed contacts, for which a thermal resistance model from liquid nitrogen to cold-head is developed as well in terms of UA (the product of overall heat transfer coefficient and area). It is demonstrated how the actual performance of each cryocooler and each cooling part is individually estimated, and the deviation from the original design with four identical components is successfully verified. The results are directly used in evaluating the prototype cryogenic system and identifying the cooling components that needs to improve.

ORAL

A Design and Simulation of Conduction-Cooled 1-Tesla Superconducting Magnet with Use of REBCO Tapes Containing Defects

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As part of the Tesla-class industrial large-diameter high-temperature superconducting magnet development project, the manufacture of a REBCO magnet with a 230 mm bore and a central magnetic field of 1 tesla has started. The high temperature superconducting magnet has favorable stability due to the high critical temperature, so it can be operated using a conduction cooling method that does not need coolant. In particular, in the case of a no-insulation magnet that is wound by removing insulating material from a tape-shaped superconducting wire, utilization of defect-irrelevant winding (DIW) technology is achievable, as the current of one wire can be bypassed and flow to adjacent wires by electrical contact between turns. By using a non-refrigerant conduction cooling method and no-insulation technique, a high magnetic field can be achieved with a relatively small-sized magnet, which can be used across industries such as induction heating, silica separation, and oil separation. This study includes (1) the design data of 1 tesla magnet using no-insulation technology, (2) the expected electrical, thermal, and mechanical behaviors during operation of the magnet, and (3) the operation scenarios of magnets considering no-insulation and DIW characteristics.

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Development of a Conduction-Cooled 400 MHz/66-mm Metal-Clad No-Insulation All-REBCO NMR Magnet

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Since 2014, an R&D project has been conducted to develop a 400 MHz 66 mm room-temperature bore all-REBCO magnet for high resolution NMR. This project is a collaborative program led by the Korea Basic Science Institute (KBSI) in participation of the Korea Institute of Machinery and Materials, the National High Magnetic Field Laboratory, Seoul National University, Kunsan National University, and SuNAM Co., Ltd. The metal-clad and no-insulation technique were applied to increase charging rate without sacrificing the self-protecting feature of the NMR magnet. After construction in 2018, the magnet was cooled down to the target operating temperature of < 20 K using a two-stage pulse-tube cryo-cooler and charged to its rated field of 9.4 T at a nominal operating current. After the charging test, we performed field-shimming by use of multi-layered ferromagnetic-shims and room-temperature active shims, after which a field homogeneity of sub-ppm within 10 mm DSV (diameter spherical volume) was achieved. After that, the field-frequency lock technique employing PI control was applied to improve temporal field stability. A long-term operating protocol to maintain field homogeneity and stability of the all-REBCO NMR magnet was also developed and tested for time-consuming NMR analyses. The results demonstrated strong potential of the all-REBCO magnet for NMR applications.

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Thermal Analysis of Cryogenic Computing

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With the increasing demand for high performance computer, metal-oxide-semiconductor field-effect transistor (MOSFET) manufacturing technology has been developed to fabricate sub-30 nm complementary MOS (CMOS). However, short-channel effects have been a major limitation to accomplish scaling down of MOSFET. To satisfy the demand of high performance computer, we suggest a novel method to maximize the computing performance - cryogenic computing. By cooling down the temperature of a computer by cryogenic materials, CPU and other processors can maintain their best speed even though massive power is dissipated in the processors. To design and verify the cryogenic cooling system for a computer, a deep understanding of thermal properties of various solids and cryogenic refrigerant is necessary. In this research, we start from the fundamental physics of solids to derive thermal properties. Then, we will suggest a numerical method to conduct thermal analysis of cryogenic computing considering temperature dependent properties of solids and cryogenic refrigerant.

This research was supported by Samsung Electronics Co., Ltd.

POSTER SESSION

TPE : Theory & Physical Properties
& Electronics & Device Applications

MM : Materials

LA : Large Scale Applications

CR : Cryogenics

Strain-driven intra-atomic spin singlet in a bulk infinite layer nickelate

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Recently, nickelates of d8 or d9 configurations have been extensively investigated due to the discovery of the superconducting nickelate in Sr-doped $NdNiO_2$ with T_c = 8-15 K. We studied a new infinite-layered nickelate system $Ba_2NiO_2(AgSe)_2$ of d8 configuration, which was synthesized at high pressure. Peculiarly, this system shows a nearly T-independent magnetic susceptibility with a sharp peak at 130 K. Its neutron scattering data (with a low resolution) were interpreted as S=1 antiferromagnet, but inconsistent with the susceptibility data. Here, we investigated the origin of this peculiar behavior and provided a new spin state, which might be a source of novel superconducting nickelate. Ni d8 nickelates often have an issue of whether it has a high-spin state (S=1) or a low-spin state (nonmagnetic state, S=0). In this system, we found a novel low spin state (S=0), called the off-diagonal singlet (ODS) state. The ODS represents a state in which opposite spin states of d(x2-y2) and d(z2) orbitals (i.e., fully spin-polarized orbitals) are filled, so that the moment cancels each other and becomes zero. So, this system is the first realization of the Kondo sieve model (a kind of the 2D Kondo necklace mode). Our results indicate that this peculiar state is driven by the unusually large Ni-O bond length by the $(AgSe)_2$ spacer layer.

This research was collaborated with W. E. Pickett. This research was supported by NRF-2019R1A2C1009588.

Quantum Fluctuation Frustrated Instabilities in $NdNiO_2$

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About one year ago, H. Hwang and coworkers discovered the superconductivity in Sr-doped infinite-layer $NdNiO_2$ ($Nd_{0.8}Sr_{0.2}NiO_2$) up to T_c = 15 K, which is isostructural and isovalent to the high Tc cuprate parent system $CaCuO_2$. In spite of the same formal d9 configuration, $NdNiO_2$ doesn't show a long-range magnetic ordering, whereas $CaCuO_2$ is an antiferromagnetic (AFM). We study the experimentally inaccessible AFM phase of $NdNiO_2$ with correlated density functional theory method to find the static lattice. We found that a flat band crossing over the Fermi level, leading to a one-dimensional van Hove singularity (vHs), which may lead to unstability of charge, spin and lattice order. However, our results indicate that these instabilities are frustrated by quantum fluctuation of the zero-point motion of oxygen ions. The competition between quantum fluctuation and flat band instabilities accounts for the reason that an AFM state is not observed in $NdNiO_2$.

This research was collaborated with W. E. Pickett. This research was supported by NRF-2019R1A2C1009588.

Instability of j = 3/2 Bogoliubov Fermi-surfaces

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Exotic quantum phases including topological states and non-Fermi liquids may be realized by quantum states with total angular momentum j = 3/2, as manifested in HgTe and pyrochlore iridates. Recently, an exotic superconducting state with non-zero density of states of zero energy Bogoliubov (BG) quasiparticles, Bogoliubov Fermi-surface (BG-FS), was also proposed in a centrosymmetric j = 3/2 system, protected by a Z2 topological invariant. Here, we consider interaction effects of a centrosymmetric BG-FS and demonstrate its instability by using mean-field and renormalization group analysis. The Bardeen-Cooper-Schrieffer (BCS) type logarithmical enhancement is shown in fluctuation channels associated with inversion symmetry. Thus, we claim that the inversion symmetry instability is an intrinsic characteristic of a BG-FS under generic attractive interactions between BG quasiparticles. In drastic contrast to the standard BCS superconductivity, a Fermi-surface may generically survive even with the instability. We propose the experimental setup, a second harmonic generation experiment with a strain gradient, to detect the instability. Possible applications to iron based superconductors and heavy fermion systems including FeSe are also discussed.

Effect of work function on alkali metal induced electronic structure change

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Alkali metal deposition (AMD) has been widely used as it can transfer additional charges to the sample. This technique was applied to angle resolved photoemission spectroscopy (ARPES), which provided an opportunity to observe unexpected phenomena. However, the study on how it affects the change in electronic structure was not sufficiently achieved. Here, we report systematic study of three iron-based superconductors: FeSe, $Ba(Fe_{1.94}Co_{0.06})_2As_2$ and NaFeAs. The change in the electronic structure by AMD and the work function of the samples were measured using high resolution ARPES. Our result shows the amount of change in electronic structure is proportional to the difference between the work function of the sample and the electronegativity of deposited alkali metal. This finding may provide new guide to predict the amount of the changes in the electronic structure by AMD.

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Emergence of B1g phonon anomaly above superconducting transition temperature in $YBa_2CuO_{7-\delta}$ measured by Raman spectroscopy

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The B1g phonon of the high-T_c cuprates has been considered one of the origins of d-wave superconducting gap and high superconducting transition temperature (T_c). In the 1990s, it was found that the temperature dependence of B1g phonon is different from that of other phonons; the frequency, linewidth, electron-phonon coupling constant of B1g phonon change rapidly around T_c. In the 2000s, a precursor pairing of Cooper pairs above the T_c was observed by several experiments on the contrary to the previous view that cooper pairs start to form at the T_c. And charge density wave (CDW) phase was also measured above superconducting dome in high-T_c cuprates. Therefore the temperature dependence of B1g phonon needs to be reinterpreted taking into account a precursor pairing of Cooper pairs and CDW. In this work, we discovered that the phonon anomaly of B1g phonon is exist not only below the T_c but also above superconducting transition temperature in $YBa_2Cu_3O_{7-\delta}$ using Raman spectroscopy. The temperature dependence of B1g phonon in this region is different from that below T_c. According to our results, there is a possibility that the anomalous behavior of B1g phonon is associated with a precursor pairing of Cooper pairs, pseudogap or charge density wave phase.

$La_{1.85}Sr_{0.15}CuO_4$ thin film growth and in-situ angle resolved photoemission spectroscopy

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Cuprate thin films are showing novel physical properties that are different from bulk, such as strain effects from substrate or proximity effects of heterostructure. And their electronic structures can be directly probed by Angle-resolved photoemission spectroscopy(ARPES). Since ARPES is highly surface sensitive, it requires a flat and clean surface of sample and UHV transfer process to carry out thin film ARPES. We have grown $La_{1.85}Sr_{0.15}CuO_4$(LSCO) thin film with 15~40 Unit cell(UC) thickness by pulsed laser deposition(PLD). The thickness of the film was monitored with in-situ reflection high energy electron diffraction (RHEED), and the film was characterized with X-ray diffraction(XRD), atomic force microscopy(AFM) and physical property measurement system(PPMS). Also with our UHV transfer system connected with PLD and ARPES chamber, we performed in-situ ARPES and obtained EDC curve data of the LSCO thin film.

Observation of heavy fermions in FeTe

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Emergence of heavy fermion (HF) states in d-electron systems has attracted much attention for its accompanying novel properties such as orbital selective Mott phase (OSMP), Kondo lattice behavior. Using temperature-dependent angle-resolved photoemission spectroscopy, physical properties measurements, we observed the HF state in a strongly correlated iron-based superconductor, FeTe. This novel HF state is well interpreted by Kondo hybridization scenario between localized Fe 3d_xy band and itinerant Te p_z band. Our work is the first observation of p-d Kondo hybridization and expands the limit of HF studies from f, d- electron systems to p-electron systems.

Electron Phonon Coupling Constant Evolution in MgB_2 Films with Various Thickness of ZnO Buffer Layer on a Metallic Substrate

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Magnesium diboride is one of the good candidates for replacing old-school superconductor in power application area. Beside its mid-range critical temperature (T_c), simple structure and easy fabrication, some obstacles have been discovered in terms of application such as lattice mismatch, upper critical field (H_{c2}) and current carrying density (J_c) suppression especially when metallic substrate is required. Buffer layer is one of promising techniques that can overcome this problem. As a preliminary study, investigation of ZnO buffer layer effect to the electron-phonon coupling (EPC) in MgB_2 on the top of Al_2O_3 and Hastelloy are necessary. ZnO known to be the semiconductor materials that has similar lattice structure with MgB_2 and has a high electronic band gap which can act as an insulator at low temprature. Raman spectra become our choice to analyze the basic mechanism of electron-phonon coupling inside MgB_2 films with ZnO buffer layer in relation to the Tc behaviour. Unique result has been obtained in a different thickness of ZnO buffer layer on both substrates introducing positive and negative impact to the EPC constant deducted from McMillan formula. Analyses of linewidth, intensity and relation to the lattice distortion are detailed in a hope to understand the effect of ZnO buffer layer on the EPC behaviour and possibility to obtain an optimal condition for buffer layer of MgB_2 for application fields.

Physical Properties of Monoclinic 6H-$SrIrO_3$ Polycrystal

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Yoon Seok Oh* *(Ulsan National Institute of Science and Technology)*

The 5d transition metal oxides have attracted lots of attention because of exotic electronic states resulted from the entanglement of strong spin-orbit coupling and electron correlation in 5d orbital. $SrIrO_3$, one of the 5d transition metal oxides, forms the three-dimensional orthorhombic perovskite under high physical pressure or an epitaxial strain. On the other hand, under the ambient pressure, $SrIrO_3$ is crystallized as a monoclinic phase of the 6H-type hexagonal structure (space group: C2/c). We have successfully synthesized second-phase-free monoclinic 6H-$SrIrO_3$ polycrystal and have studied its physical properties. Here, we compare our experimental results with previous reports and discuss the intrinsic electronic state of monoclinic 6H-$SrIrO_3$.

Hall resistivity in superconducting tantalum thin films with periodic nano-hole array

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We studied the hall resistance of tantalum thin films with nano-hole arrays. Recently, the hall resistance measurement of weakly disroderd film charaterized the region of unexpected metallic phase occurring in 2D superconducting film [Sci. Adv. 3, e1700612 (2017)]. The disordered tantalum thin film showed a magnetically induced metallic phase [PRB 73, 100505 (2006)]. and when the magnetic field is applied to a superconducting film with nano-hole arrays, T_c oscillates by the vortex matching effect [PRB 66, 212507 (2002)]. In this experiment we will change the density of the nano-hole array and show the change in hall resistance as the magnetic field is applied to the tantalum thin film. As a result, the effect of the nano-hole array on the hall resistance can characterize the unexpected metallic phase occurring in the two-dimensional superconducting film.

Close correlation between local structure and superconducting properties in $GdBa_2Cu_3O_{7-x}$ / $La_{0.7}Sr_{0.3}MnO_3$ hetero-structure

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Hetero-structure films consisting of epitaxial thick $GdBa_2Cu_3O_{7-x}$ (GdBCO) and two types of $La_{0.7}Sr_{0.3}MnO_3$ (LSMO, layer and particle forms) were fabricated by pulsed laser deposition. Unlike typical superconducting (SC)/ ferromagnetic (FM) system where superconducting properties were strongly depressed due to the competing effect between long range orderings of FM and SC, superconducting properties of our relatively thick GdBCO/LSMO system are strongly dependent on the local structural details of the GdBCO and the LSMO layers. An evaluation of the local atomic displacement of this complex system has been successfully implemented through the X-ray absorption fine structure (XAFS) spectra measurement. The experimental results shows that the CuO_2 plane and MnO_6 octahedron exhibiting a specific lattice displacement are closely related to the superconducting properties. The phase diagram of T_c for the GdBCO/LSMO system is established by a single variable, the micro-strain (ε) of Cu-O¬ bond-length, calculated from the computed pair distribution function (PDF) of the in-plane Cu-O pairs. It shows that the critical temperature T_c reaches its maximum at the critical micro-strain (εc), suggesting an intimate relationship between the local structural distortion and superconductivity in this system.

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Momentum dependent dxz/yz band splitting in LaFeAsO

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We performed angle-resolved photoemission spectroscopy (ARPES) studies of the electronic structure of the nematic phase in LaFeAsO. Degeneracy breaking between the dxz and dyz hole bands near the r and M point is observed in the nematic phase. Different temperature dependent band splitting behaviors are observed at the r and M points. The energy of the band splitting near the M point decreases as the temperature decreases while it has little temperature dependence near the r point. The nematic nature of the band shift near the M point is confirmed through a detwin experiment using a piezo device. Since a momentum dependent splitting behavior has been observed in other iron based superconductors, our observation confirms that the behavior is a universal one among iron based superconductors.

Current profile variation within a HTS tape under oblique field

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Under oblique field, vortices within a highly anisotropic high T_c superconductor (HTS) tape are also tilted and curved. If there is a density gradient or a curvature of vortices, extrinsic current can exist inside a type II superconductor, which can be described by Bean's critical state model. In this work, we further incorporate the anisotropic nature of the critical current density into the Bean's model and numerically simulate the variation of current profile of a HTS tape. In-plane pinning force for pancake vortices can be dependent on overall field magnitude so that the current profile within a HTS tape can be vary as the field is increased. The current profile also can be strongly affected by shape effects. Simulation results for various aspect ratio HTS tapes are compared further in order to study the possibility of geometrical locking.

London penetration depth of superconducting Nb thin films under an in-plane magnetic field

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We obtained the London penetration depth of the type-II superconductor niobium (Nb) in the terahertz region under an in-plane magnetic field at 1.5 K. The London penetration depth of Nb thin films was obtained from the imaginary part of the optical conductivity. As the magnetic field approaches the upper critical field, the London penetration depth diverged, which confirms the nonlinear Meissner effect.

Enhanced superconductivity in the vicinity of a quantum phase transition of an incommensurate charge density wave state in 2H-$Pd_{0.05}TaSe_2$

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We have investigated a subtle interplay between charge density wave order (CDW) and superconductivity in a Pd-intercalated 2H-$TaSe_2$ single crystal using extensive high-pressure magneto-transport and Raman spectroscopy measurements. We find that as pressure increases, the resistivity anomaly due to the CDW formation is gradually suppressed and a dome-shaped superconductivity with a maximum T_c = 7.35 K is realized near a critical pressure P_c = 22.1 GPa. Moreover, the anomaly in the temperature-dependent Hall coefficient due to CDW gapping exhibits continuous suppression, disappearing at this critical pressure. Also, the CDW amplitudons and the two-phonon Kohn anomaly mode in the Raman spectra disappear near P_c. Furthermore, the Hall coefficient just above T_c exhibits a continuous increase below P_c and remains flat thereafter, pointing to a drastic modification of the underlying Fermi surface. These experimental results strongly suggest the presence of an incommensurate CDW quantum critical point near the optimal superconductivity, which plays a critical role in modifying the underlying electronic structure in this material.

Quantum conversion between Microwave and Optical signals using Superconducting Circuitry

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양자 조명(Quantum illumination)이란 얽힘(entangled) 상태의 전자기파를 이용하여 원거리의 물체를 탐지하거나 영상화함으로써 획기적으로 높은 신호 대 잡음 비(signal to noise ratio)를 얻는 방법을 일컫는다. 국방과학연구소에서는 이러한 양자 조명 기술을 이용한 양자 레이더를 개발하기 위해 관련 연구를 진행 중이다. 광학 분야에서는 얽힘 광자(photon)를 얻는 기술들이 많이 개발되었고 이를 이용한 다양한 실험들도 보고되었다. 하지만 적외선이나 가시광선 영역의 빛은 대기 중에서 쉽게 산란되어 거리가 매우 제한된다. 따라서 원거리 탐지를 위해서는 양자 상태의 빛을 마이크로파(microwave)로 변환 시켜 주고 반대로 마이크로파를 광자로 변환시키는 기술이 필요하다. 그런데 마이크로파는 에너지가 매우 낮기 때문에 양자 상태를 유지하기 위해서는 극저온을 유지하여 열잡음(thermal noise)을 제거한 장치들을 사용해야 한다. 이러한 극저온 환경에서는 저항에 의한 손실이 없는 초전도체를 이용한 장치들이 유용하게 사용될 수 있다. 초전도체를 이용한 마이크로파 공진기를 비롯하여 광-마이크로파 상호 변환을 위한 기초 기술들을 소개하고자 한다.

Coexistence of 2π- and 4π-supercurrents in topological Josephson junctions

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Topological insulators (TIs) contain a spin helical topological surface state (TSS), exhibiting spin-polarized current or Aharonov-Bohm oscillations. Contacted with superconducting electrodes, TIs provide a useful platform to host Majorana bound state (MBS), which would be essential for fault-tolerant quantum computation technology. Here, we report experimental observations of bimodal switching current distribution (SCD) below T = 0.3 K in topological Josephson junctions made of Sb-doped Bi_2Se_3 micro-flakes and PbIn superconducting electrodes. The co-existence of 2π- and 4π-periodic (current-phase relation) CPRs splits the distribution as a consequence of MBSs formed in the junction. At higher temperatures, the two stochastic distributions merge into one and is fitted well with thermal activation and phase diffusion models, depending on temperatures. Irradiated with microwaves, unconventional Shapiro steps are observed at 7 mK with missing the first step, which is due to the 4π-periodic CPR. The first-step-missing behavior is enhanced with increasing temperatures up to 300 mK, which is attributed to the mixing of 2π- and 4π-periodic CPRs. Our observations indicate the coexistence of topological and trivial supercurrent in TIs contacted with superconducting electrodes.

Keywords: Topological Josephson junction, topological supercurrent, switching current distribution, Shapiro step, current-phase relation

Superconducting proximity effect in Sb-doped Bi_2Se_3 nanoribbons with Nb superconducting electrodes

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Realization of one-dimensional (1D) topological superconductor hosting Majorana quasiparticles is still a challenging project for developing topological quantum information devices. Topological insulator nanoribbon (TI NR) as a three-dimensional topological insulator with one-dimensional shape becomes a promising platform to form Majorana bound states via the superconducting proximity effect. The number of 1D subbands of the surface state in TI NR can be modulated by the external magnetic flux through the cross section of NR, exhibiting Aharonov-Bohm oscillations. The half-flux quantum flux is theoretically expected to carry the helical 1D surface mode hosting Majorana fermions. Since the small cross-section area of TI NR requires higher magnetic field for the half flux quantum, the induced superconductivity in TI NR must be durable under the application of such high external magnetic field. Here we report the fabrication and electrical transport properties of TI NR-based Josephson junctions with Nb superconducting electrodes. We believe that the Nb-TI NR-Nb Josephson junctions would be promising for exploring the topological superconductivity and Majorana bound states.

Study on amorphous molybdenum silicide superconducting nanowire single photon detector (SNSPD) for telecommunication wavelength

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A superconducting photon detector has high detection efficiency, so it is used for the main element in quantum communication. To achieve high system detection efficiency (SDE), detectors need optimized optical structures. In this study, we fabricated an SNSPD using an amorphous molybdenum silicide (α-MoSi) on a distributed Bragg reflector. The α-MoSi film was deposited by co-sputtering molybdenum and silicon targets. In the thickness that we typically use, the superconducting critical temperature of films has a value between 3.4 and 4.3 K. The detector parameters were measured at 0.9 K for incident photons with 1550 nm wavelength, SDE was analyzed by performing optical simulations using a finite-difference time-domain method. We validate our simulation result with our measurement, and using the simulation tool, we then discuss our further direction to increase the detector performance.

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COMSOL simulation of Josephson Parametric Amplifier for Axion experiment

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The Centor for Axion and Precision Physics Research (CAPP) of IBS in Korea is launching a microwave axion search experiment, currently aiming 1.5 to 2.5 GHz region. Because axion signal power is expected to be very weak it is critical to minimize system noise, especially pre-amplifier of the RF chain. For this purpose, Pilot Axion Cavity Experiment (PACE) introduces Josephson Parametric Amplifier (JPA) of which the noise can go down to quantum noise level. The first test result of the implementation of JPA to PACE is very important. For further development, some simulation studies are done in parallel to the test. The result of JPA simulation using COMSOL Multiphysics will be presented.

Copper-sheathed MgB_2 superconducting wires for multi-strand cable

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For special magnet systems such as nuclear fusion and high energy accelerator, a superconducting conductor requires an extremely high current carrying capacity. Thus, the conductor is highly desirable to be a new structure obtained by braiding several strands, not the monolithic conductor. During the braiding process, however, severe mechanical deformation keeps applying, resulting in electrical degradation of superconducting properties and local damage. In this study, easy-deformed copper (Cu)-sheath MgB_2 conductors were fabricated and explored the possibility for multi-strand cable. For this aim, we strategically designed robust conductors obtained by restacked bundle filaments. This work would be a further step toward a power transmission cable.

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Mechanical properties of Joint part of 2G superconducting tapes by adhering a thin superconducting patch

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It is not easy to make HTS tapes long yet, so it is necessary to make coils by bonding the tapes together. When HTS tapes are soldered together, the joints are twice as thick as other parts. At each end of the joint, the thickness changes suddenly and it is easy to receive the force that causes the HTS tape to bend. Thus, in winding, the critical current (I_c) of the HTS tapes may be reduced due to deformation in the lower and upper layers of the joint. In this study, the metal substrates of two HTS tapes were attached by laser welding in order to secure mechanical strength. Then, the thickness of the joint was reduced by attaching a thin superconducting (SC) patch without metal substrate. This process was intended to reduce the thickness of the joint and secure mechanical strength. The SC patch was prepared by separating the metal substrate from the HTS coated conductor using the interface delamination phenomenon. It has high engineering critical current density with a simple structure of stabilizing layer / superconducting layer / stabilizing layer. The conditions were improved so that the tensile strength of the laser welded metal substrate could be at a similar level, over 500 MPa, compared to the original substrate. HTS tape joints with SC patches improved the I_c value to over 60 % relative to the original tape.

Practical Stress-based Test Method for Electromechanical Property Characterization of REBCO CC Tapes at 77 K

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Due to its superior electrical and mechanical properties, the stress/strain effect on the superconducting properties of rare-earth barium copper oxide coated conductor (CC) tapes has been widely investigated for practical device applications like wind turbine generator and superconducting magnetic energy storage. With these applications, the most considerable design factors to deal with are the mechanical property such as yield stress and elastic modulus and the electromechanical properties (EMP) such as irreversible limit for critical current (I_c) degradation. Using a strain sensing device like extensometer, irreversible stress and strain limit are conventionally determined using strain-based test method with 0.05 % strain increment. However, some disadvantages encountered using extensometer, such as the knife-edge contact points can induce stress concentrations on the CC tape that affect the I_c stress behavior. Also, calibration of extensometer before the start of each test is considered time-consuming. In actual superconducting magnet and coil design, most of manufacturers are requesting for the stress-based design data such as Ic stress behavior. Therefore, a practical test method, which is simple and cost-effective to determine the EMP of CC tapes without relying on the strain sensing device is necessary. In this study, a test method using the stress-based I_c measurement was proposed to determine the irreversible stress limit for I_c degradation of CC tapes. To make the test procedure practical and effective, stress intervals were divided into two sections: (1) broad interval during elastic region; and (2) fine interval in the region where of plastic deformation involved. The appropriate transition stress level where stress interval changed from broad to fine was also determined. The reliability of the stress-based measurement method in evaluating EMP was discussed by comparing them to the cases of the strain-based measurement. Also, statistical estimation to check the reproducibility depending on the criterion adapted through five repeated tests was done in this study. The irreversible stress limit for I_c degradation of each samples were defined by 99 % I_{c0} recovery and 95 % I_{c0} retention criteria.

Keywords: coated conductor, electromechanical property, critical current, stress-based, irreversible stress limit, uniaxial tension

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Effects of a silver addition on the microstructure of YBCO superconductors

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The effect of addition of metallic silver on the microstructure of YBCO superconductors was studied. Metallic silver powder of x = 0, 3, 5, 7 wt.% and YBCO powder were mixed using a milling machine. A mixtures of (YBCO + x wt.% Ag) powder were uniaxially pressed into pellets. The pellets were heat-treated in air atomosphere between 980 ℃ - 1000 ℃, and then subsequently heat-treatment at 400 ℃ - 500 ℃ in flowing oxygen. An optical microscopic investigation showed the grain size of the pellet of x = 0 wt.% was as small as 100~20 μm, and the grain size of the pellets with silver additions were 100~300 μm. This result means that the addition of silver promotes the grain growth of YBCO. Twins and texture structure were observed within the grains of 0 wt.%Ag. Also, a silver particle phase with a size of 20~40 μm was observed at grain boundaries YBCO with Ag additions. In the melt processed YBCO with/without Ag addition were prepared with seeding, the grain size of x = 0 sample was the largest as a few thousands μm. It decreased to about 500~1000 μm as Ag was added. Silver particles found at the grain boundaries, while pores were distributed in the center the grain. The number of pores were decreased as the silver content increased.

Development and Evaluation of Multifilamentary MgB_2 Superconducting Joint for Persistent-Current Mode Operation

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MgB_2 conductors enable the operation of superconducting magnets under environment of liquid helium (LHe)-free due to its high critical temperature of 39 K. For this reason, the MgB_2 is considered a promising superconductor to improve the operation efficiency and performance of superconducting magnets. In order to increase the usability of MgB_2 for application magnets, a multifilamentary MgB_2 joint is an important superconducting technology. The superconducting joint not only provides large-scale magnet development and magnet modularization but also enables persistent-current (PC) mode operation. Particularly, in the magnet system, the PC mode can provide facile magnet operation and high stability of the magnetic field. For this purpose, more reliable superconducting joint between main magnet and persistent-current switch (PCS) is highly desirable to be the most critical techniques. In this work, we used high-performance 18-filament MgB_2 wires manufactured by Sam Dong Co., Ltd. For our superconducting joint, the metallic sheath of two conductors was peeled off by mechanical and chemical etching. Exposed cores of each wire were faced down and then put into a metallic container (or housing) with a mixture of precursor MgB_2, followed by uniaxial pressure. In order to be superconductivity, an entire joint part was sintered under argon atmosphere. From the results, our joint samples retain very high critical current, even comparable to bare wire performance. Further, to verify the performance of our superconducting joint, PC mode was operated by organizing the closed-loop with MgB_2 superconducting coil and PCS. Consequently, the magnetic field was kept stable on a joint resistance of below 10-11 Ω without an external power source.

Improvement of Temporal Field Quality by Control of Magnetization Current in Superconducting Magnet for Accelerator Application

Geonwoo Baek* ***(Yonsei University)***

Quadrupole magnets play an important role in heavy-ion accelerators. A quadrupole magnet is usually wound with LTS wires. However, quadrupole magnet wound with HTS tapes is indispensable in the front of in-flight projectile fragment separator because interaction between the particle beam and target produces high radiation doze. Conventional HTS quadrupole magnet has iron poles to generate high magnetic field. As a result, the magnet system is heavy and large. In addition, the magnetization of iron-core is an unfavorable characteristic for magnet development. An air-core HTS quadrupole magnet can remedy iron-cores shortcomings. However, the air-core quadrupole magnet has difficulties such as mechanical stress, quench protection and magnetic field quality for practical application. This work deals with two main ideas about improving the temporal field quality of the magnet. First, the novel field mapping method with machine learning is proposed. An accurate measurement of magnetic field is indirectly related to the temporal stability. Second, the SCIF of the magnet is calculated using 2D H-formulation with domain homogenization method, and then overshoot current operation is adopted for magnetic relaxation. The mapping simulation is performed in the designed magnet. The mapping method with artificial neural network shows better performance than classical interpolation technique. In addition, the proposed mapping technique is applied to the magnetic field measurement in the fabricated magnet. It is confirmed that the field stability as well as the spatial uniformity deteriorates due to the magnetization current in the designed magnet. The magnet current overshoot excitation significantly improves the field stability and spatial uniformity. The repeated current excitations also improve the temporal stability of the magnet. For the successful development of HTS accelerator magnet technology, this dissertation is expected to be an important basic research.

Improvement of Active Shimming Method using DDPG Algorithm

Haeryong Jeon* ***(Yonsei University)***

The active shimming method, which is a method for improving the homogeneity of high field magnets, is designed to improve the homogeneity by placing dozens of small coils at the center of the main magnet and controlling the current of each coil. However, achieving optimal control of dozens of coils is a very difficult task in the center area of high-temperature superconducting magnets with screening current The field produced by each coil causes a screening current of the main magnet, which can be repeated in a vicious cycle affecting the field of the magnet center region. Because it is very difficult to analyze the size of the screening current through analytical techniques, manually adjusting the current sequence is not easy. To overcome this problem, we employed the reinforcement learning method that finds the optimal sequence while gradually changing the operation of the current according to the signal. At this time, the action, state and reward of the reinforcement learning agent is set to current flowing through the shim coil, the magnetic field, and the homogeneity. Since the current flowing through the shim coil operates continuously, the reinforcement learning system was constructed using the DDPG algorithm. 15 channel simulation using Matlab Simulink confirmed that active shimming is progressing through learning. In addition, it was confirmed that the homogeneity gradually improved accordingly.

Stability Characteristics of Metal Insulation HTS Racetrack Coils under Rotating Magnetic Field

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This paper presents the investigation results on stability characteristic of second generation high-temperature superconducting (2G HTS) coil under the rotating magnetic field. This metal insulation (MI) HTS coil is electrically and thermally insulated by a stainless steel tape. A synchronous rotating machine can be frequently operated under time-varying magnetic field of unsynchronized armature. Therefore, the stability characteristics of MI coil should be examined and proved under unsynchronized operation environment to confirm the applicability of metal insulator on the turn-to-turn insulation of field winding for rotating machine. In this study, the electrical and thermal behaviors of MI HTS coil, which is cooled by liquid nitrogen bath, are experimentally investigated with injection of three-phase rotating magnetic field. Moreover, in order to compare and analyze the electrical and thermal behavior according to the contact resistances, two different winding tension values were considered to change turn-to-turn contact condition of MI HTS coils.

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Wireless Charging System for High T_c Superconducting Machines

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The conventional rotary HTS flux pump is a wireless charging system (WCS) that rotates the PM to generate an alternating magnetic field on the HTS tape to charge the HTS machine. However, the disadvantages of this system only apply to fixed HTS machines such as NMR and MRI. However, HTS WCS must be applicable in stop, forward, reverse and compensation modes, like superconducting rotators. However, the existing HTS WCS has only been studied with different shapes applicable to each of the above 4 operating modes. In this paper, we have designed, manufactured and tested the properties of WCS that can be applied in fixed, forward rotation, reverse rotation and compensation modes. An important component of the HTS WCS, the magnetic trigger system requires AMF to be applied to the HTS tape to create a closed loop. The HTS excitation system for generating AMF is HM consisting of PM and EM. The FEM simulation confirmed the magnetic field distribution and MFD applied to the HTS tape. In addition, since the current charging mechanism of the HTS WCS was not established, the charging characteristics were analyzed through basic characteristic experiments. The HTS WCS proposed in this paper is the worlds first proposed and experimentally proven system and is an HTS power supply applicable to all driving modes of HTS machines. In the future, if HM composed of PM and EM is replaced with HTS coil, it is expected that the charging efficiency of HTS WCS can be maximized through the results of this study.

Design of High T_c Superconducting Magnet and Power Cable using Genetic Algorithm to Improve Operating Stability and Development of Novel Quench Protection System

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In this dissertation, an optimized design for improving the operational stability of magnet and power devices using high temperature superconductors (HTS) is discussed, and a new quench protection system is proposed. Most designs in superconducting applications include nonlinear characteristics and require complex computation of various variables, it is difficult to define the optimization objectives as equations and have many constraints. Therefore, it is necessary to use an appropriate optimization algorithm for complex engineering design. Probability-based genetic algorithm that mimic the process by which more superior individuals evolve by crossing more by natural selection is used for complex optimization designs. However, the existing genetic algorithm may take a long time to find the global optimal solution when the design variable is expanded and there are local optimal solutions similar to the global optimal solution or may not find the global optimal solution. In order to overcome these problems and find the optimal solution more quickly, the existing genetic algorithm was modified, and the performance was evaluated in comparison with the existing genetic algorithm. The modified genetic algorithm was applied to three superconducting application designs.

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Current Charging Characteristics of HTS Flux Pump using Hybrid Magnet

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The non-contact field excitation device using second generation high-temperature superconducting (2G HTS) flux pump is a very promising (effective) technology in improving the efficiency, stability, and economics of a superconducting rotating machine by excluding the use of conventional field excitation devices that are mechanically contacted with HTS field winding. Generally, direct-current (DC) power source of HTS flux pump using permanent magnet (PM) is generated by applying the time-varying magnetic field from the rotating PMs to the 2G HTS wires located at power generation part of flux pump. This process complicates the system configuration because it requires a separate driving system to mechanically rotate PMs. In this paper, to excite the load superconducting magnets without any mechanical rotation, a prototype experimental device of a contactless superconducting field exciter was devised using HTS flux pump incorporating a hybrid magnet system composed of DC electromagnet, alternating current electromagnet, and PM. The current charging characteristics were experimentally analyzed with a small superconducting coil under liquid nitrogen.

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Electrical Characteristic Analysis of Metal Insulation Racetrack Coils According to Various Metal Insulation Thickness

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This paper investigates the electromagnetic response and electrical stability characteristics of metal insulation REBCO racetrack (MI) coils according to various stainless steel (SS) insulation thickness at the same winding tension of 10 kgf, one insulated with 100 μm SS thickness (MI-SS1) and the other insulated with 50 μm SS thickness (MI-SS2), through the sudden discharge, charge, and overcurrent tests. The sudden discharge and charge test were conducted to investigate the charging delay time in the steady state while the overcurrent test was performed in the transient state to estimate the electrical stability. The charging test results demonstrated that the MI-SS2 coil can be charged faster than the MI-SS1 coil. In the overcurrent tests, the test results confirmed that the MI-SS1 coil exhibited better electrical stability characteristic than MI-SS2 coil. This was because the thicker SS insulation could enhance heat capacity, which absorbed more joule heat energy generated by hot spots.

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Analysis of Output Characteristics of Off-Shore Wind Farm with 10 MW Class HTS Wind Generator

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A high-temperature superconducting(HTS) wind turbine(WT) is more efficient, smaller, and lighter than conventional WT. These are great advantages in the design of floating offshore WT that emerge as the next generation WTs. Accordingly, research into utilizing the HTS WT in the construction of a floating offshore wind farm is being conducted worldwide. In the case of the HTS WT, the capacity of the WT is large, the slope of the power curve is steep, and the inertia of the HTS generator is smaller than that of the conventional generator. It means the magnitude of output power fluctuation over wind speed increases. These fluctuations in output power can have a large impact on the power grid as the capacity of the wind farm increases, making the power grid unstable. Therefore, in this paper, a 10 MW HTS WT power curve was derived and its output power fluctuation was analyzed.

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Numerical Analysis on Quench in a High Temperature Superconducting (HTS) Magnet during Current Dump Process

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Quench phenomenon was detected while the conduction-cooled HTS magnet was generating 4 T magnetic field. Current dump process was initiated to discharge the magnet energy to the external resistor when the one section of the magnet voltage taps exceeded the voltage criteria. The magnet, however, was permanently damaged during this event. The damaged spot is located where the highest perpendicular field, generated by the magnet, is exposed. As the result of the magnetic energy dissipation in that small spot, the temperature of the conductor increased extremely and reached the melting point of the conductor. The quench spot, however, did not coincide with the section that triggered the current dump process. There was no pre-quench signal from the damaged spot. Non-reversible voltage rise of the damaged spot, however, occurred during the dump process while the current was discharged from the magnet. To investigate the hostile thermal condition of the conduction-cooled magnet, we undertook the simple numerical analysis to calculate the conductor temperature variation during the dump process. The results show that the trends of the temperature change (higher than 300 K or lower than 100 K after the dump process) depending on the initial temperature of the conductor before the current starts to dump. We speculate that even the current-sharing spot was already formed before the dump process, this resistive voltage associated with it was not detected because of long length of the examined conductor section. Both the experimental and calculated results are presented and fully discussed.

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Conceptual design for improving the operating current of an HTS coil using two types of HTS tapes

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The critical current in the design and fabrication of the high temperature superconducting (HTS) machine is an important factor in determining the performance of the HTS coil. The critical current of HTS tape used to HTS coil has degradation characteristics according to the magnitude and incidence angle of the applied magnetic field [1]. Moreover, the HTS tapes have different critical current characteristics of each manufacturer due to the different manufacturing methods for improving its magnetic field performance. The HTS tapes of the HTS coil at the operating state have different magnitude and incidence angle of the magnetic field at each turn. Therefore, when we design the HTS coil using two different types of HTS tape, it is expected to improve the operating current at the same geometry of the HTS coil. This paper deals with the conceptual design for improving the operating current of an HTS coil using two types of HTS tape. The operating current of the HTS tapes was analyzed and compared considering the magnitude and incidence angle of the magnetic field. The HTS coils were designed by combining two different types of HTS tape and the operating current at 77 K and 35 K were compared to HTS coil using a single HTS tape. The operating currents of the HTS coil were estimated considering the angular dependency on the magnetic flux density of HTS tape. The maximum operating currents of the HTS coil using a single tape from one manufacturer and two different types of HTS tapes were 307 A and 440 A at 35 K, respectively. As a result, the operating current of the HTS coil using two different types of HTS tapes was improved compared to the HTS coil using single HTS tape. The characteristic analysis results of the HTS coil will be applied to improve the HTS coil performance of the HTS machine.

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Superconducting Properties of GdBCO Coils using a Specially Designed Grooved Bobbin

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초전도 마그넷의 냉각을 위한 다양한 방식의 냉동기가 지속적으로 개발되고 있으나, 마그넷 내부 온도 편차 및 기계적 진동으로 인해 아직까지 실제 마그넷 응용기기에서 액체 냉매 직접냉각시스템이 주로 사용되고 있다. 냉각의 효율을 향상시키기 위해 보빈 제작을 위한 재료의 선택 등 초전도체의 냉각 방식과 냉각효율 상승을 위한 연구가 있어왔다. 그러나 마그넷 내부의 초전도 선재는 액체 냉매와 직접적인 접촉이 어렵기 때문에, 퀜치 발생 시 마그넷 내·외부 간의 온도 편차가 발생할 수 있으며, 내부에서 발생하는 열이 빠르게 방출되지 못하여 마그넷이 손상될 우려가 있다. 냉각에 관련되어 고려할 요소 중 마그넷을 권선하는 보빈의 디자인에 대한 연구는 많이 진행되어 있지 않다. 이러한 문제를 해소하기위해 액체 냉매가 마그넷 내부에 쉽게 접촉할 수 있도록, 보빈 표면에 홈(cooling channel)을 형성한 톱니바퀴 모양의 보빈을 설계하여 초전도 마그넷의 냉각 효율을 향상시키는 방법을 제안하였고, 제안된 cooling channel을 도입한 grooved bobbin의 사용이 GdBCO코일의 냉각과 퀜치 시 joule heat로 인해 발생하는 코일 내부의 온도상승에 어떠한 영향을 주는지에 대해 냉각 실험 및 minimum quench energy(MQE) 실험을 통해 검증하였다. 본 연구에서는 이러한 마그넷의 내부에 cooling channel이 미치는 영향을 연구하기 위해 추가적으로 cooling channel로 인한 초전도 특성의 변화와 cooling channel의 노출 면적에 따른 cooling rate와 thermal stability에 대한 연구를 논의하였다.

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Investigation on burn-out and field stability characteristics of No-insulation GdBCO magnet applied Intentional Bypass Current Path

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무절연 권선 기술은 개발 이래로 관련된 많은 연구를 통해 우수한 특성이 입증된 바 있다. 무절연 권선 기술은 턴 간 절연물질을 제거함으로써 퀜치 시 발생하는 과전류 및 열을 턴 간 접촉 방향으로 우회함과 동시에 빠른 냉각 속도를 통해 마그넷의 열·전기적 특성을 향상시키는 기술이다. 그러나 무절연 권선 기술은 마그넷을 충전할 때 발생하는 인덕턴스 전압에 의해 충·방전지연 현상이 발생하고, 과전류 시 자기장 감쇠 현상이 발생하며 감쇠의 폭이 크다는 단점이 있으며 burn-out 현상이 발생한다. 그렇기 때문에 본 연구에서는 기존 무절연 마그넷의 첫 번째 턴과 마지막 턴에 구리 테이프를 납땜하여 연결하는 직접전류우회경로(intentional bypass current path, IBCP)를 추가한 GdBCO 마그넷의 자기장 회복 특성 및 burn-out 특성에 대한 연구를 추가적으로 진행하였다. IBCP는 GdBCO 마그넷과 턴 간 접촉 저항이 병렬로 연결되어 있는 GdBCO 마그넷의 초전도 회로 모델에서 하나의 병렬 노드가 추가되며, 과전류 발생 시 병렬 연결된 구리 테이프로 인해 발생하는 전압을 낮추며, 구리 테이프가 연결되는 부분에서 생기는 틈새를 통해 접촉저항을 증가시켜 충·방전 지연 현상을 줄일 수 있다. 또한, 기존 무절연 권선 기술과 비교했을 때, burm-out 현상이 발생하지 않으며, 자기장 감쇠 현상 (field drop)을 줄이는 특성을 관찰하였다. IBCP 기술로 인한 GdBCO마그넷의 특성 향상을 검토하기 위해 과전류 테스트, sudden discharge 테스트, burn-out 테스트를 통해 기존의 무절연 마그넷과 IBCP 마그넷 보호 특성을 비교하였다.

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Effects on the Magnetic Field Uniformity of MgB_2 Coil with Iron Diffusion Barrier

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일반적으로 MgB_2와이어는 niobium diffusion barrier가 있어 Mg분말과 copper stabilizer 사이의 반응을 방지한다. 하지만, niobium의 높은 가격을 감안하여, niobium diffusion barrier를 iron으로 대체하기 위한 광범위한 연구가 수행되었다. 그럼에도 불구하고 iron diffusion barrier가 있는 MgB_2와이어에 강자성 철이 자화하면 자석의 magnetic field 분포가 균일하지 않을 수 있기 때문에 아직 자기 공명 영상 자석에 실용적으로 적용되지 않고 있다. 본 연구에서는 철 확산 장벽을 가진 MgB_2와이어로 된 솔레노이드 자석의 magnetic field 특성을 조사하여 자석의 field homogeneity에 미치는 iron barrier의 영향을 조사하였다. 또한 영구 전류 모드 작업에서 자석의 magnetic field drift를 나타내었다. 비교분석을 위해 niobium diffusion barrier를 가진 기존 와이어를 사용한 MgB_2마그넷도 평가하였다.

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Persistent Current Mode of a Joint-less HTS Magnet with Persistent Current Switch

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본 연구는 2세대 고온초전도 선재를 이용하여 접합없이 영구전류 모드운전이 가능한 고온초전도 마그넷에 관한 연구이다. 선행 연구를 통해 개발된 무접합 권선방식은 마그넷 중심영역에 선재 폭만큼의 간격이 발생하게 된다. 이러한 간격은 고자기장과 안정한 균일도가 요구되는 초전도 마그넷 설계에 제한적 요소로 작용하며, 실제 마그넷을 응용하기 위해서 문제가 된다. 따라서 마그넷 중심영역에 생기는 간격을 없애기 위해 새로운 형태의 무접합 마그넷을 제안하였다. 제안하는 무접합 마그넷은 기존에 동축으로 배치한 솔레노이드 형태를 개선하여 동심배치의 다중코일 형태로 제작이 가능하다. 이렇게 제작되는 마그넷은 중심영역에 간격이 발생하지 않아 중심자기장과 공간균일도를 향상시킬 수 있다. 또한 영구전류모드를 위한 초전도 전원장치 적용에도 유리한 형태로 마그넷 권선과 함께 영구전류스위치의 제작이 가능하다. 본 논문에서는 동심배치한 다중코일 형태의 무접합 마그넷을 설계 및 제작하였다. 제작된 무접합 마그넷은 77 K 운전온도에서 영구전류 스위치를 이용하여 영구전류 모드 운전시험을 진행하였다. 영구전류 모드운전을 18시간이상 유지 후 필드맵핑을 진행하고 공간균일도와 시간안정도 측정을 진행하였다.

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A scale-down model test for fault current interrupting system on DC grid

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본 연구는 DC 계통의 사고전류를 효과적으로 차단하기 위해 DC 차단기와 초전도 한류기를 동시에 사용하는 하이브리드 방식의 DC 차단기술을 위한 초전도 한류기에 관한 연구로 DC 차단시스템에 초전도 한류기를 적용할 경우 DC 차단기의 사고전류 부담을 낮추고, 차단용량을 높일 수 있다. DC 차단기를 위한 한류 모듈은 사고 시 저항 발생 특성은 비선형적이지만 상대적으로 빠른 사고전류 억제가 가능한 저항형 초전도 한류기 방식으로 선정하고, SuNAM의 2세대 고온초전도 선재를 이용해 15 kV, 3 kA의 DC 계통의 적용을 위한 DC 한류 모듈 설계를 진행하였다. 본 논문에서는 DC 차단기를 위한 저항형 한류 모듈의 설계 검증을 위해 설계에 사용된 초전도선재를 사용하여 정격 전압 500 V에 맞춘 Scale-down DC 한류 모듈의 설계 및 제작을 진행하였다. 제작된 Scale-sown 한류 모듈은 bifilar 코일 형태로 직류 사고환경을 모의한 시험 회로에서 사고전류 크기에 따른 DC 한류특성 시험을 진행하고, 설계 결과의 검증을 진행하였다.

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Magnetization studies on the High Temperature Superconducting Joint-less Magnet for Persistent Current Operation

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본 연구진은 2세대 고온 초전도 선재를 이용하여 무접합 권선방식(Wind-and-Flip method)으로 영구전류 모드 운전이 가능한 무접합 마그넷을 제작하였다. 필드 쿨링 방식을 이용하여 이 마그넷을 충전하였으며 영구전류 모드로 운전하는 시험을 성공하였다. 그러나 필드 쿨링 방식의 경우, 운전전류의 정밀한 제어가 어렵고 충, 방전 운전을 위해 대형 외부 마그넷이 필요하며, 두 개 이상의 무접합 마그넷을 충전하는 경우 전류 분류가 균일하지 않다는 단점을 가지고 있다. 본 논문에서는 무접합 마그넷의 전원장치로 영구전류스위치(Persistent Current Switch, PCS)를 적용하였다. 고온초전도 마그넷의 충전을 위한 영구전류스위치를 설계 및 제작하고, 77 K 온도에서 전원장치의 특성 평가 및 영구전류 모드 충전 운전 시험을 진행하였다. 다음 단계의 연구에서는 무접합 마그넷을 위한 전원장치로 플럭스 펌프를 결합하여 충전 시험을 진행할 예정이다.

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Critical Current Change of CORC® by Various Structures

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CORC® (Conductors on Round Core)는 대전류용 도체 중 하나로 포머(former)에 선재가 비스듬히 감기는 형태를 가지고 있기 때문에 각 스트랜드(strand) 별로 인덕턴스가 동일하다. 따라서 스트랜드간 전류분배가 균일하며 비교적 제작이 용이한 장점을 가지고 있다. 이러한 장점들로 인해 CORC®를 고자장 마그넷과 AC 전력용 기기에 적용시키기 위한 연구가 진행중이다. CORC®는 형상에 따라 임계전류의 감소, 선재 소요량 등 도체의 특성이 달라질 수 있다. 따라서 CORC®를 제작할 때 형상에 따른 도체의 특성을 확인할 필요가 있다. 본 논문에서는 CORC®의 특성 중 임계전류에 영향을 미칠 수 있는 포머의 직경, 와인딩 (winding) 각도, 초전도 선재의 폭 등을 변화시키며 임계전류의 감소를 확인하였다. 또한 초전도 층의 배치 방향에 따라서 임계전류의 변화를 측정하였다. 이를 통해 CORC®를 사용하기 위한 적정 형태를 확인하였다.

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22.9 kV 계통연계용 대용량 초전도 한류기 개발

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전력계통 연계용 22.9 kV/2,000 A 대용량 저항형 초전도 한류기(R-SFCL)는 기축 변전소에도 설치가 가능하도록 컴팩트한 배전반 형태로 제작 되었고, 초전도한류부와 고속임피던스 부로 분리되어 각각은 상-하 배열 또는 좌-우 배열이 모두 가능한 구조이다. 초전도 한류 소자는 700 A 이상의 임계전류와 약 150 mΩ/m의 상온저항을 갖는 ㈜서남의 HTS(High Temperature Superconductor) 선재로 제작되었다. HTS 단위모듈은 켑톤테잎이 랩핑된 35 m의 초전도선재가 bifilar 권선되었고, 각각의 단위모듈은 상당 5병렬 5직렬 조합되어 3상에 75개의 단위모듈이 적용된다. 3상의 초전도한류소자는 단일 저온용기에서 3 bar-a, 75 K 과냉 LN2에 의해 냉각된다. 극저온 냉각시스템은 복수의 GM 냉동기를 냉각용기 측면에 접속하여 콜드헤드가 질소조 측면 상부를 냉각하는 측면냉각 방식을 적용하였다. 초전도 한류소자의 퀜치 수명 및 동작 신뢰성을 확보하기 위해 HTS 단위모듈에 100회 이상의 단락전류를 인가하여도 HTS 선재가 열화 되지 않는 최적의 모듈 디자인 및 권선 사양 등을 개발하였고, 이렇게 제작된 단위모듈로 13.2 kV/2,000 A 단상을 구성하여 한류파형 및 특성을 확보하였다.

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Design status of the Korean Fusion Demonstration Reactor Superconducting Toroidal Field Magnet

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A conceptual design study for a steady-state Korean fusion demonstration reactor (K-DEMO) is being conducted since 2012. The superconducting magnet system of K-DEMO has 16 Toroidal Field (TF) coils, 8 Central Solenoids (CS) modules and 12 Poloidal Field (PF) coils which use Cable-In-Conduit Conductors (CICC). The superconducting toroidal field magnets of the K-DEMO is designed to generate 7.4 T at plasma center and 16 T peak field. For a high 7.4 T magnetic field generation at plasma center, high performance Nb_3Sn based superconductor will be developed and used for TF magnet. From the preliminary conceptual design, design modification of the K-DEMO TF magnet is being performed. In order to validate the design updates, electro-magnetic, mechanical and thermo-hydraulic analysis of the K-DEMO TF magnet are considered. The main results of those analysis are presented in this work.

A study on the thermal and electrical characteristics of HTS power cable with fault current limiting function

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Jeonwook Cho *(Korea Electrotechnology Research Institute)*,
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Power demand is increasing every year and notably this demand is concentrated in urban areas. In addition, to respond the power demand of urban areas, fault currents due to large capacity of power system and substation interconnections are also increasing. Then, the fault current will damage the equipment in the power grid system. A FCL(Fault current dimeter) HTS(High temperature superconductivity) power cables is a device that combines the functions of a HTS power cable and SFCL(Superconductivity fault current dimeter). The FCL HTS power cable operates with almost zero resistance in normal operation. However, in the event of power grid failure, a quench that leads to an increase in resistance will occur to limit the fault current. This paper describes the design of a FCL HTS power cable of 600 MVA, 154 kV class with specially developed HTS wires. The target FCL function of the cable is to reduce the fault current from 63 kA to less than 45 kA considering the Korean transmission class grid. To meet the allowable temperature rise and fault current reduction, parametric studies were conducted for the resistance characteristics of the HTS wire, the stainless steel former area, and the cable length. Also, experiments with a mini model cable were conducted to verify the design process. Then, the design of a FCL HTS power cable of 5 km is suggested to reduce the fault current from 63 kA to 22 kA while suppressing the temperature rise under the saturation value in 0.2 s.

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Electromagnetic Design of REBCO Magnet for Maglev Train Considering $I_c(B,\Theta)$ of Various REBCO wires

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The electromagnetic performance of REBCO magnets operating at 30~40 K is usually limited by local minimum critical current, which depends on the local magnetic field acting on REBCO wire. Therefore, the REBCO magnet should be designed in consideration of the magnitude and the incidence angle of the magnetic field over whole magnet winding region. Moreover, the REBCO wires with different critical currents at 77 K self-field can be used to avoid the bottleneck of minimum critical current and to reduce the required amount of the REBCO wire. Some REBCO wires have the inclined c-axis (001 direction) due to its fabrication process. Considering the inclined angle, the minimum critical current region occurs at different locations, unlike in REBCO magnets with regular REBCO wires. This paper describes the design process of REBCO magnets for maglev trains to meet the required magneto-motive force (MMF) with the minimum amount and cost of REBCO wires, taking into account the $I_c(B,\theta)$ characteristics of REBCO wires from various manufacturers.

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Analysis of flow characteristics in spiral corrugation cryostat according to cable core eccentricity ratio for HTS power cable

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In order to meet the increasing electric power demand, many studies have been conducted for High Temperature Superconducting (HTS) power cable with large capacity transmission and very low loss. Recently, research for commercial operation between long-distance substations is underway. To install a HTS power cable for commercial operation in a long distance section, a cryostat is essential and hydraulic analysis along the HTS power cable path is important. Particularly, a spiral corrugation cryostat is advantageous for making a curved installation compared to a straight tube, and thus is used when installing a long distance HTS power cables. In the spiral corrugation cryostat, the pressure drop and flow characteristics can be predicted by treating the regular corrugated shape as the surface roughness of the straight tube. However, when the core of a HTS power cable is in a cryostat, it is difficult to predict the precise pressure characteristic due to the complex three dimensional characteristics of the flow region. Also, a core of the HTS power cable is eccentric due to the installation environment and gravity. In this paper, the longitudinal streamlines and pressures drop and the velocity and pressure distributions of the cross sections were analyzed according to the eccentricity ratio of a cable core in the spiral corrugation cryostat. As the eccentric ratio of a cable core increases, the pressure drop decreased, and the flow velocity became faster at the flow area widened by the eccentricity.

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Characteristics Comparison Between Air-Cored and Iron-Cored 100 kW HTS Field Winding Synchronous Motors

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This paper presents comparative research on characteristics of air-cored and iron-cored high-temperature superconductor (HTS) field winding synchronous motors. The 100 kW air-cored model is designed analytically by Spatial Harmonic Method, and based on this model, the iron-cored model having the same output power is designed for comparison. Due to the substantial difference of permeability property between air and iron-core, there is a difference of magnetic field magnitude and angle with respect to the HTS tape c-axis, resulting in a different critical current of the field winding considering the anisotropic property of HTS tape. For a detailed comparison between two models, the following key motor characteristics are calculated through the Finite Element Method (FEM) simulation: 1) critical current; 2) HTS wire length; and 3) torque characteristics. From the simulation results, it can be confirmed that the critical current value of the iron-cored model increases by 33 %. Also, in the case of the superconducting wire consumption, those of the iron-cored and air-cored models are 95.3 m and 815.6 m, respectively. So the wire usage can be reduced to about 88 % by using iron core. However, in terms of torque characteristics, the torque ripple of the iron-cored model is about twice as large as that of the air-cored model, which may be a disadvantage on vibration and acoustic noise.

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Defect-irrelevant winding experiment and nonlinear numerical analysis method for equivalent circuit

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In the case of a high temperature superconducting (HTS) coil with defects inside, a no-insulation technique can be applied to prevent the occurrence of a quench by making the current flow through the turn-to-turn direction in the defective position. Lumped equivalent circuit analysis, one of the methods to analyze the coil's behavior, cannot calculate and interpret the current around the defects. To solve this problem, a partial element equivalent circuit (PEEC) analysis method which subdivides the turns into azimuthal segments including resistances and inductances is implemented and compared with the experimental results. To analyze the defect-irrelevant behavior of the single pancake coil, three defective joints were inserted into the REBCO tape before the winding. The coil is divided into 13 sections by locations of the defects and the voltage differences across each section were measured. The coil is subdivided into 8 azimuthal divisions per turn for the PEEC method and the defective resistances corresponding to the voltage measurement is inversely calculated. The azimuthal and turn-to-turn current is calculated from the resistances and the magnetic field at 7 mm above the center of the coil determined by the current is compared to the measurement.

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Electrical simulation for Design of HTS hexapole magnet

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Rare isotope Accelerator complex for ON-line experiments (RAON) which is heavy ion accelerators system, is constructing in Institute of Basic Science(IBS) since 2011. The RAON heavy ion accelerator includes an In-flight Fragment separator (IF) system for colliding the Ion Beam drawn from the Driver Linac to the target to generate a rare isotope beam and to separate and discover new isotopes. In the hot cell section of the IF system, six quadrupole superconducting electromagnets and one hexapole superconducting electromagnet are arranged for focusing the ion beam. The hot cell area is a Radioactive ray section, and requires a superconducting electromagnet system capable of stable operation against Radioactive ray heat. Accordingly, a high temperature superconducting (HTS) electromagnet system having a relatively high operating temperature compared to low temperature superconducting (LTS) electromagnet system is advantageous. In this study, the design of a high temperature superconducting (HTS) hexapole electromagnet installed in a hot cell zone of an IF system was performed. The electrical design values of the HTS electromagnet were set according to the IBS requirements (magnetic field gradient 3.9 [T/m^2], magnetic field uniformity $\leq \pm 0.5$ [%]). In order to confirm the electrical performance that satisfies the requirements, the design was performed by 3 type (over circle, regular circle, hyperbola) of the yoke pole tip, the angle between the yoke pole tips, and the position of the electromagnet.

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Hydrogen Liquefaction Process with Optional Ortho-Para Conversion for Different Periods of Liquid Storage

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The operational scheme of hydrogen liquefaction process with two-stage expansion Brayton cycle is presented in four different ways, depending on the optional use of ortho-para converters. In the liquefaction system under development, four stages of ortho-para converters are installed to deliver equilibrium liquid at 20 K with 99.8 % para-hydrogen fraction. The equilibrium hydrogen is required for a long-term storage without the boil-off loss of liquid, because liquid with any lower para fraction will result in subsequent exothermic ortho-to-para conversion. If the storage period is not very long, however, the fully converted liquid is not necessary, as the conversion is a slow process. In this study, a liquid delivery at four different levels of para fraction (for example, 99 %, 56 %, 34 %, and 25 %) is suggested to reduce the power consumption for liquefaction by the different length of storage period. The liquefaction process is rigorously simulated for the conditions where a bypass valve is optionally open for each stage of catalyst. The real thermodynamic properties of helium, LNG, and hydrogen are incorporated into a process simulator (Aspen HYSYS) to calculate the specific work required for liquefaction and fraction of hydrogen composition. Full details of process design are presented and discussed on the four different cases of optional conversion.

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Reduction of Power Consumption by Combining Heat Exchangers in Brayton Refrigeration System for Hydrogen Liquefaction

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A design idea on heat exchanger fabrication is proposed and investigated to reduce the power consumption of hydrogen liquefaction system under development. Since the liquefaction system is based on two-stage expansion Brayton refrigeration cycle, four counter-flow heat exchangers should be located in series, and the plate-fin heat exchangers (PFHX) are selected, taking advantage of compactness and design flexibility. In the liquefaction process, the pressure drop is a major factor that seriously affects the power consumption, and the pressure drop in PFHX occurs mainly at inlets and exits. It is proposed in this study that two or more heat exchangers be combined together in order to reduce the number of inlets and exits. In order to estimate the how much reduce the power consumption, thermodynamic process is rigorously simulated with different values of pressure drop in heat exchangers. The real thermodynamic properties of helium and hydrogen are incorporated into a process simulator (Aspen HYSYS) to calculate the work required for liquefaction. It is concluded that the pressure drop of low-pressure stream is very effective in reducing the power consumption. It is demonstrated as well how to the combine two heat exchangers so that the low-pressure helium stream can be made straight all the way.

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Installation results of cryogen-free dilution refrigerator with ultra-low-vibration system

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희석냉각장치는 장치 내부를 극저온 상태로 만들고 원자나 분자의 열진동에 의해 발생하는 열적잡음을 줄여주어 양자역학적 신호를 계측하는데 널리 사용된다. 특히 순환방식을 사용하는 극저온 냉각장치는 실험실 내에서 쉽게 사용할 수 있으며, 오랜시간 저온을 유지할 수 있어 널리 사용되고 있다. 냉각에 사용되는 Pulse-Tube는 압축기를 이용하여 주기적으로 헬륨을 순환시키기 때문에 냉각기 전체에 진동이 발생하게 된다. 진동에 민감한 실험을 수행할 경우, 이러한 진동신호가 노이즈로 발생하게 되므로 저진동형 냉각장치가 필요하다. 여기에서는 저진동 실험을 위해 선택한 프랑스의 Cryoconcept 회사의 저진동형 극저온 냉각장치의 설치결과를 정리하였다.

Cryogenic network modeling for fusion magnet thermo-hydraulic analysis

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Cable-in-conduit conductors (CICCs) are widely used for large scale superconducting magnets partly because of their cryogenic stability. Nevertheless, as the magnet is connected to a cryogenic circuit, a proper simulation on cryogenic loop is also an important ingredient. Especially for the KSTAR poloidal field (PF) magnet, the highest thermal loads occur at the inlets and outlets and therefore, a backward cryogen flow at the inlets is frequently observed. To protect the cryogenic circuit, for example, to secure the proper operation of circulator, various valves are actively operated during normal operation. In this work, a way to simulate the overall PF magnet system including the cryogenic loop is discussed. Main focus is on the role of three cryogenic valves located at the major inlet line, at the by-pass line, and at the dump. Simulation has been carried out by using SUPERMAGNET code. Cryogenic module, the flower code, has been modified in order to describe the active operation of the valves. The impact of the valves operation on the overall pressure and mass balance on the cryogenic loop will be discussed.

전력계통 연계용 22.9 kV/2,000 A 대용량 저항형 초전도 한류기(R-SFCL) 냉각 시스템 및 제어 방법

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LS Electric에서는 전력계통 연계용 22.9 kV/2,000 A 대용량 저항형 초전도 한류기(R-SFCL)를 개발했다. 초전도 한류기의 냉각 온도를 유지하기 위한 극저온 냉각시스템은 4대의 Compressor를 이용한 복수 냉각 시스템을 구성하였으며 3상의 초전도 한류 소자를 단일 저온용 냉각기에서 3 bar-a, 75 K 과냉 LN2에 의해 냉각되는 방식을 사용하였다.

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Design of cryogenic adsorber for 0.5 TPD hydrogen liquefaction

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수소를 액체로 변환하는 수소액화 공정은 수소기체를 예냉하는 과정, 기체를 액체로 변환하는 과정, Ortho/Para 변환열을 제거하는 과정으로 구성되며, 이를 위한 콜드박스는 열교환기, 극저온밸브, 팽창터빈/쥴톰슨밸브 등의 팽창장치로 구성된다. 수소액화공정에서 예냉과정은 소형액화기에서는 주로 헬륨냉동사이클, 중대형의 경우 수소냉동사이클로 구성되며, 예냉 및 액화에 필요한 냉열은 주로 팽창터빈을 통해 생성되며, 80 K 미만의 극저온의 상태에서 운전된다. 이와 같은 극저온의 온도영역에서 냉동사이클 작동유체의 산소, 질소 등의 불순가스 성분은 고화되어 사이클 구성요소에 치명적인 고장요인으로 작용할 수 있어, 이를 제거하기 위해 흡착장치의 도입이 필수적이다. 본 연구에서는 0.5 TPD급 수소액화공정을 위해 80 K 온도에서 운전되는 흡착장치를 설계를 목표로, 흡착물질 선정, 유동해석, 열구조해석을 수행하였다.

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Thermal and structural analysis of a cold box for 0.5 TPD hydrogen liquefaction

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A cold box for 0.5 TPD hydrogen liquefaction was thermally and structurally designed. Hydrogen gas is successively cooled in the cold box by passing heat exchangers precooled by LNG and liquid nitrogen, and then incorporated in a helium Brayton refrigerator. Normal hydrogen is converted into equilibrium hydrogen in ortho-para converters distributed among heat exchangers. Finally, it is liquefied in the cold box into pure para hydrogen liquid. The cold box is physically divided into one small cold box precooling hydrogen gas by LNG and liquid nitrogen, and another large cold box cooling and liquefying hydrogen gas by the helium Brayton refrigerator. A thermal and structural analysis was performed for a basic design of the cold boxes. Heat inflow by thermal radiation and thermal conduction was estimated. In addition, a linear elastic analysis and a linear buckling analysis were performed to determine thickness of valve plates and vacuum shells.

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Experiment on the thermal insulation performance of multi-layer insulation in cryogenic environment

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Multi-layer insulation (MLI) is often used in a cryogenic cooling system to reduce radiation heat penetration from warm boundary. To enhance the effectiveness of the MLI installation, several MLIs are stacked to reduce the effective emissivity. Although the thermal insulation performance of the MLI depends on the composition of the MLI, the number of stacks, the stack density, the temperature environment and et al., detail data on the various installation methods for the MLI from different companies are not enough to precisely estimate the radiation heat loss of a cryogenic system. In this study, investigates the thermal insulation performance of the MLI according to the number of stacks over a wide temperature range from room to cryogenic temperature. To simulate the cryogenic environment, conductive cooling characteristic evaluation device with a two-stage GM cryocooler was used and experiments were carried out according to the number of stacks and different temperatures. To compare with the manufacturers data, experiments were performed based on 1 sheet of MLI, and radiation heat penetration was measured at 4 K, 20 K, 40 K and 77 K based on room temperature. In order to measure the amount of radiation heat penetration according to the number of stacks of the MLI under the same temperature conditions, experiments were performed by stacking 5, 10, 20, and 30 layers.

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Design of cryogenic helium blower for HTS Magnet cooling system

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A HTS magnet of RAON is installed in high-radiation zone where the target and beam dump are located in the IF separator. In order to prevent contamination by radioactive gas helium, gas helium inside the cooling system is circulated in a closed loop independent of the cryogenic plant. In the HTS magnet cooling system, cold gas from the cryo-plant and warm gas from the HTS magnet side exchange heat through the heat exchanger in the distribution box. A cryogenic helium blower is required to circulate the cold helium gas through the HTS magnets. IF separator has a total of six quadrupole HTS magnets and one hexa pole magnet are used. The temperature of each magnet should be kept below 45 K, and each magnet will generate different neutron heating depending on its position. Therefore, flow rate of gaseous helium for cooling must be appropriately controlled in order to keep the temperature of each magnet below the operating temperature. The temperature of the HTS magnet is determined by the temperature of the helium entering the magnet inlet, the mass flow rate of the helium, and the calorific value of each magnet. Since the increase in helium flow increases the pressure loss of the magnet and the pipe, the heat loss in the blower for circulation also increases. Considering a flow rate and temperature conditions of the Main Transfer Line (Cold stream), a mass flow rate that can be operated was calculated, and the optimal mass flow rate that could minimize the operating temperature of the magnet was determined. Specifications of a cryogenic helium blower are determined from the calculated flow rate, temperature, and head conditions. In addition, to minimize the amount of heat load by the blower, the design of the impeller and volute considering the efficiency is designed and verified through CFD analysis.

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초전도 풍력발전기를 위한 네온 열사이펀 시스템 설계 및 실험

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국내외에서 친환경이고 경제적인 에너지를 생산하기 위한 초전도 풍력발전기를 개발하기 위해 많은 연구가 진행되고 있다. 이러한 초전도 풍력발전기에 사용되는 초전도 전자석을 효율적이고 안정적으로 냉각하기 위해서, 냉각 시스템도 같이 연구되고 있다. 현재 국내에서는 10 MW급 부유식 대형 초전도 풍력발전기의 연구가 진행되고 있다. 이 발전기의 초전도 전자석 냉각에는 정지부와 회전부를 잇는 극저온 냉매의 유로가 필요하다. 또한, 비교적 긴 냉각경로를 가지기 때문에, 높은 압력강하와 유로를 통한 열침입 모두를 극복할 수 있어야한다. 이 조건을 만족하기 위한 네온 열사이펀 시스템과 극저온 블로워를 사용한 기체 헬륨 순환 시스템 각각의 장점을 결합한 복합 냉각시스템은 계속 연구되었으며, 특성평가 규모에서 테스트가 진행되고 있다. 본 연구는 부유식 해상 초전도 풍력발전기의 냉각시스템 중 네온 열사이펀 시스템의 특성평가장치를 설계 및 테스트를 한 것이다. 특성평가장치와 3극 초전도 전자석의 열부하를 냉각하기 위해 GM type 냉동기가 3대와 이를 결합하는 구리 냉각판이 사용되었다. 그리고 열부하에 의해 기화한 네온을 응축시키기 위한 응축핀을 설계하였다. 또한, 임시 액체 네온탱크를 제작하고 주위에 니트롬 와이어를 사용해 특성평가장치의 열부하를 대신하였다. 네온을 응축하기 위한 극저온 냉동기와 응축핀이 구리 냉각판을 통해 열전달한다. 이를 통해 발생하는 온도차를 해석툴을 통해 분석하고 냉동기 운전 온도를 결정하였다. 마지막으로, 응축된 네온이 중력에 의해 임시 액체 네온탱크에 도달하기 위한 수두를 만족하는 네온의 양을 결정하였다.

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Thermal stress analysis of the composite material propellant tank related with cryogenic fluid charging speed

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To get thrust of the space launch vehicle, liquid oxygen as an oxidizer and kerosene or liquid hydrogen as a fuel are generally used. These oxidizer tanks and fuel tanks are manufactured by composite materials such as Carbon Fiber Reinforced Plastic (CFRP) to reduce the weight of launch vehicle. The cryogenic propellant tank experience extreme temperature gradients and the resultant thermal stress should be considered for mechanical integrity. The oxidizer tank for the Korean projectile KSLV-II has a following actual dimensions; cryogenic fluid charging volume of 15.5 m^3, diameter of 2.6 m and length of 5.4 m. In this study, to confirm the design integrity of the oxidizer tank of liquid oxygen, a numerical analysis was conducted on the temperature change of the tank, thermal stress generation and evaporation rate according to the charging speed of the cryogenic fluid from 60 ~ 900 LPM. For experimental verification, liquid nitrogen was applied to the analysis model as a alternative cryogenic fluid instead of liquid oxygen, and boiling heat transfer characteristic was used on the inside wall of the tank. In addition, evaporation rate and level increment of liquid nitrogen inside the tank were calculated considering heat transfer characteristics. The thermal stress was also calculated coupled with the temperature distribution of the CFRP tank. Based on the analysis results, the variation of thermal stress, required amount of liquid nitrogen and the charging time were found according to various charging speed of the liquid nitrogen. Due to the thin wall of the tank, the analysis results showed that the thermal stress was even decreased at the high charging speed above 500 LPM.

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Study on the temperature distribution of long length HTS power cable cooled by circulating slush nitrogen

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A numerical model to calculate the temperature distribution of 3 km long high temperature superconducting (HTS) power cable is established. The model assumes that HTS power cable is cooled by circulating nitrogen. The model considers mass, momentum, and energy balance of the nitrogen, and the heat diffusion inside the HTS layer. The result of the numerical model shows that the maximum temperature of HTS layer is higher than 80 K when the HTS cable is cooled by the compressed liquid nitrogen. Since the result shows that the minimum enthalpy of the compressed liquid nitrogen is not sufficiently small to cool the HTS cable below 80 K, the slush nitrogen is introduced to achieve lower maximum temperature of the HTS layer. Changing the volumetric fraction of the solid nitrogen, the maximum temperature of the HTS layer is calculated. The maximum temperature of the HTS layer decreases about 6.7 K when the slush nitrogen with 30 % of solid nitrogen is supplied instead of the liquid nitrogen. The result of the numerical analysis and the discussion are presented.

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