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인 사 말

안녕하십니까?

2021 한국초전도저온학회 하계학술대회에 참여하시는 회원님들, 협력사들을 비롯한 모든 학회 관련자들께 감사말씀 드립니다. 지난 2월 동계학술대회 이후 이번 하계학술대회는 온/오프 병행 개최를 통해 좀 더 많은 정보교류와 소통의 기회를 마련하기 위해 차질없이 준비를 해 오고 있었습니다. 그런데 기대와는 달리 코로나 상황이 나아지지 않고 오히려 델타 변이의 발생으로 더 빠르고 폭넓게 확산되고 있습니다. 이러한 심각한 상황에 대응하여 이번 학술대회도 전면 온라인으로 개최하게 되었음을 아쉽게 생각합니다.

그렇지만 저희 조직위원회는 그동안 경험을 바탕으로 온라인상에서도 회원 여러분들의 업적 공유 및 학술 논의에 부족함이 없도록 준비하였습니다. 회원님들의 적극적인 참여가 우리 학회의 양적, 질적 성장에 든든한 초석이 될 것입니다.

6개 부문(이론, 물성, 전자/소자, 재료, 응용기기, 저온)별 논문 발표 이외에 IWRS (International Workshop on Recent Progress in Superconductivity) 2021이 병행으로 진행되오니 관심 있는 회원님들 많이 참여해 주십시오.

또한 학술대회 이외에도 그 때 그 때 필요한 주제에 대해 워크숍이나 세미나 형태의 부문별 활동을 학회차원에서 적극 장려하고 있으니 다양한 활용이 있으면 좋겠습니다.

회원님들의 업적 확장 및 축적을 위해 본 학술대회에 투고된 논문들은 심사를 거쳐 SCOPUS 등재지인 한국초전도저온학회 학회지 PSAC(Progress in Superconductivity and Cryogenics)에 게재됩니다. 학술대회뿐만 아니라 평소 연구하시면서 이루신 성과를 구체화하여 논문으로 투고해 주심에도 많은 관심 부탁드립니다.

이번 학술대회에는 플래너리 강연 2편, 초청강연 2편, 일반구두발표 27편, 포스터 발표 41편 등 총 72편의 초록이 접수되었습니다. 진심으로 감사드립니다.

그리고 온라인 학술대회임에도 불구하고 참여해 주신 기업들께도 다시 한 번 감사 드리고, 마지막으로 본 학술대회 준비에 힘써 주신 조직위원님들, 좌장님들, 그리고 드러나지 않게 염려해 주시고 도움 주신 관계자 여러분들께 이 자리를 빌려 고마운 마음 전해드립니다.

늘 건강과 행복이 모든 회원님들과 함께하길 기원합니다.

감사합니다.

2021년 8월 23일

한국초전도저온학회 학술위원장 **염 한 길**

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PLENARY I

PLENARY

PL I

High T_c Superconductivity of hydrogen-rich compounds at ultra high pressure and possible stabilization at low pressure

Duck Young Kim* ***(Center for High Pressure Science and Technology Advanced Research, Shanghai, China)***

High pressure, although it is a classic subject of science, becomes one of emerging fields of research, which is driven by advancement of static high-pressure techniques reaching Earth's core limit (approximately 3,600,000 atm) and computational science enabling even materials design. Synergic efforts from experiment and theory during last a couple of decades have yielded interesting scientific discoveries such as metal-to-insulator transition in alkali metals, superionicity, and most famously room temperature superconductivity in hydrides.

In this talk, I will briefly introduce recent progresses in high-pressure community to provide background to audience. I will present important studies on solid hydrogen which was the starting point of superhydride research, and high T_c superconductivity in hydrides. Finally, I will summerize my talk by introducing new ideas to lower the transition pressure.

Keywords : pressure, hydrogen, hydrides, superconductivity

PLENARY II

HyperTube HTX, 1,200 km/h Future Innovative Transportation

Kwansup Lee* ***(Korea Railroad Research Institute, Euiwang, Korea)***

HyperTube, HTX (Hyper Tube eXpress) is a next generation ultra high speed innovative transportation which vehicle flights inside sub-vacuum tube with above 1,200 Km/h, which leads the 4th industrial revolution. It needs lots of advanced technologies such as super conduct magnet based maglev, internet of things, autonomous vehicle control, artificial intelligence, high speed tele-communication, aerospace technology, and etc. This lecture introduces technical characteristics of hypertube system, current status of technologies in the world, and its core technologies such as magnetic levitation and propulsion system using super conduct magnet, sub-vacuum tube, vehicle stabilization under ultra high speed, and etc. And future development plan of HTX is introduced.

Keywords : SCM, sub-vacuum, hyperloop, maglev

* This work was supported by the Big Issue Project from National Research Council of Science & Technology(NST).

SESSION I : LA I

Large Scale Applications - I

INVITED

IN LAI-1

Studies on unbalanced forces in ultra-high field high-temperature superconductor magnets

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

From the 45.5 T world record direct-current high-temperature superconducting magnet designed, constructed, and tested by a collaborative team led by the National High Magnetic Field Laboratory, we have learned an unbalanced force issue of screening-current-induced stress (SCS). Inspired by the research of SCS, we have investigated unbalanced force issues of high-temperature superconductor (HTS) magnets. As a result, this paper provides four different case studies: (1) tilted two solenoid HTS magnets; (2) off-centered two solenoid HTS magnets; (3) a tilted HTS coil in a stack of HTS coils; and (4) an off-centered HTS coil in a stack of HTS coils. For all the cases, screening current and the consequent SCS are not considered; we assume that the current density in an HTS wire is uniform. For the case studies, the finite element method-based simulation program, COMSOL Multiphysics, is employed. We calculate unbalanced forces with respect to individual cases by adopting multiphysics (electromagnetic + mechanical) governing equations. Practical issues concerning unbalanced forces in ultra-high HTS magnets will be discussed at the end.

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIT) (No. 2018R1A2B3009249).

ORAL

O LAI-1

Improvement of Electromagnetic Field of Superconducting Magnet for Accelerator by Field control System

Junseong Kim* ***(JH Engineeng)***

A particle accelerator is a device for observing new substances or phenomena by accelerating and colliding with atomic nuclei, small particles, cations, and heavy ions. The device uses an electromagnet to control the accelerated beam using a magnetic field. This electromagnet is manufactured using a superconductor to obtain a large magnetic field as the energy of the beam handled by the particle accelerator increases. Superconductors can significantly increase the size of the magnetic field in electromagnet applications because they can pass significantly more current when compared to normal conductors of the same volume under certain critical conditions. Among the various magnets used to control the accelerated beam in the accelerator, the magnet used for focusing the accelerated beam is called a focusing magnet, quadrupole magnet. This quadrupole magnet consists of an iron core with a hyperbolic surface and a superconducting electromagnet to create a hyperbolic shaped magnetic field. Low-temperature superconductors were used for the superconducting electromagnets of existing accelerators. Recently, superconducting electromagnets using high-temperature superconductors have been researched and developed due to the performance development of high-temperature superconductors and many thermal factors occurring at the front end of the particle accelerator IF separtor. In addition, further studies have been conducted to manufacture an air core type quadrupole magnet using only superconducting electromagnets by removing the iron core. The difference between the design magnetic field and the actual magnetic field occurs in the superconducting electromagnet due to manufacturing errors due to the shape of the superconductor and special operating conditions. In particular, this difference in magnetic field due to manufacturing error occurs more in an air core type high-temperature superconducting quadrupole magnet. As superconducting electromagnets have been researched and developed, one of the methods developed to compensate for these magnetic field differences is the magnetic field shimming method. This dissertation introduces a newly designed wire bunch magnetic field control method to supplement the changing magnetic field due to manufacturing errors in superconducting quadrupole electromagnets and verifies the validity of the method through experiments. Prior to that, we will introduce the design and manufacture of iron core type low-temperature superconducting quadrupole magnets that are being manufactured for the first time in the world, and air core type high-temperature superconducting quadrupole magnets that have been researched and developed for the first time in the world, and will analyze the changed magnetic field due to manufacturing errors found here. In addition, the effects of manufacturing errors that can occur in superconducting electromagnets on the magnetic field are analyzed through simulation.

ORAL

O LAI-2

Conceptual Design Study on Cryocooled No-Insulation HTS Solenoid Magnet for Beam Focusing

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Recently, collaborative research to design, construct, and operate ultra-high dose rate(FLASH) radiotherapy R&D machine was embarked by a team led by Electronics and Telecommunications Research Institue in Korea. The main feature of the system is to generate high dose rate particle beams using laser-ion based accelerator and focus the consequent spatially distributed particle beams using high field solenoid magnet. We decided to use 20 K cryocooled no-insulation(NI) high temperature superconducting(HTS) magnet for the focusing solenoid magnet, mainly due to its low operating cost with cryocooling, and high operation stability of the NI magnets. In this paper, we present a design of 8 T 114 mm winding diameter of no-insulation solenoid magnet with multi-width design approach incorporated. To reduce the magnet charging time constant, metal cladded REBCO tapes manufactured by SuNAM is to be adopted. Key design results are as the followings: (1) squared field integral (= $\int B^2$ dz) of 12.8 T2·m; (2) spatial field uniformity, (= $\Delta\int B^2$ dz) 2.2 % over $|r|< 32$ mm; (3) maximum hoop strain of 0.08 %; (4) charging time constant of 2 hrs; (5) cooling time of 43 hrs; and (6) adiabatic temperature rise of 39 K upon a quench.

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIT) (No. 2018R1A2B3009249).

ORAL

O LAI-3

Design of ferromagnetic shimming for NMR magnets using sequential search method

Hongmin Yang ***(Kunsan National University)***,
Minchul Ahn* *(Kunsan National University)*

To improve the field homogeneity of NMR magnets, this study deals with ferromagnetic shimming, which installs ferromagnetic elements into matrix structures from magnetic center positions of magnets. The matrix structure consists of 960 positions, consisting of 24 in row and 40 in column. In order to improve field homogeneity, the optimal shim thickness can be determined at each of the 960 locations. Since each shim piece is small, with a width of 5 mm and a length of 3 mm, and complex designs can cause large manufacturing errors, the process of converting to as simplified a design as possible is required. A design with a single thickness shim has been considered as a simplified design. In this study, a fast and efficient design method using sequential search is proposed. It is a method of determining and filling the most influential of the 960 locations. Typical optimization methods have a challenging process of converting data, including decimal points, to integer, and have a large number of iterations over millions. However, the proposed method has great advantages in terms of reducing design time because it can only be achieved with integers and requires up to 960 iterations. To verify the validity of the design method, the result obtained using sequential quadratic programming (SQP) algorithm, one of typical method of nonlinear constrained optimization, and the method of this study designed by the sequential search method were compared. Based on the initial field homogeneity of 238 ppm at 20 mm DSV (Diameter Sphere Volume), both the result using the SQP and the sequential search method were able to obtain design results that could be improved within 10 ppm. The design using the sequential search method was calculated with a simple operation and the result could be derived at a very high speed within a few seconds.

This work was supported by the Korea Medical Device Development Fund grant funded by the Korea government (the Ministry of Science and ICT, the Ministry of Trade, Industry and Energy, the Ministry of Health & Welfare, the Ministry of Food and Drug Safety) (Project Number: 1711138068, KMDF_PR_20200901_0063).

ORAL

O LAI-4

Operation Characteristics of 2 T 230 mm "Defect-Irrelevantly" Wound NI Magnet in Conduction Cooling System

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Jaemin Kim *(Seoul National University)*,
Jeseok Bang *(Seoul National University)*,
Jung Tae Lee *(Seoul National University)*,
Soobin An *(Seoul National University)*,
Chaemin Im *(Seoul National University)*,
Jeonghwan Park *(Seoul National University)*,
Seong Hyeon Park *(Seoul National University)*,
Jonghoon Yoon *(Seoul National University)*,
Geonyoung Kim *(Seoul National University)*,
Seungyong Hahn* *(Seoul National University)*

Defect-Irrelevant Winding (DIW) approach is to wind No-Insulation (NI) coil regardless of defects contained in the REBCO tapes for purpose of conductor cost reduction. With DIW approach, magnet construction cost could be much reduced while minimizing performance degradation by defect. Here, the defect is defined as a local spot having a critical current lower than 80 % of the average critical current of the whole tape. In this study, based on the charging-discharging test results of the 2 T 230 mm DIW NI magnet previously developed, we investigated the effect of the defects on magnet operation. With the test results including the operating current, the voltages of each double pancake coil, and the magnetic field, detailed parameters were calculated in each DP by equivalent circuit model analysis and finite element analysis. Finally, based on the experiments and analysis results, additional considerations in terms of design and construction were briefly discussed when applying the DIW approach at the magnet level.

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIT) (No. 2018R1A2B3009249).

SESSION II : LA II

Large Scale Applications - II

INVITED

IN LAII-1

Development of a 25.8 kV/2,000 A Compact R-SFCL

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Gyeong Ho Lee *(LS Electric)*,
Chae Yoon Bae *(LS Electric)*,
Byoung Hee Jee Cho *(LS Electric)*

A 25.8 kV/2.0 kA resistive superconducting fault current limiter (R-SFCL) has been designed, manufactured, and successfully tested at PT&T in LS Electric. The R-SFCL is scheduled to be installed on the 22.9 kV bus section between two transformers in the Seogochang substation of KEPCO in 2021, and it will play a role in reducing the fault current, so that the fault current does not affect interconnected systems. Korea has a renewable energy generation plan of 29.4 GW in 2022, 58.0 GW in 2030, and 77.8 GW in 2034. In order to efficiently and stably connect this large-capacity renewable energy to the existing system without concern of spreading fault currents, it is being positively considered to install R-SFCL at the system connection point. To counteract these energy policies, LS ELECTRIC developed a large capacity R-SFCL with KEPCO, focusing on its compact size, modular design, and high reliability. The R-SFCLs features are described below. First, we have designed compact and space-independent R-SFCL that is of two cubicle switchboard type in order to be able to install in any substation where there is not enough space. Second, the main components of the R-SFCL are modular designed, in order to respond effectively to various ratings, specifications, and installation conditions. Third, the R-SFCL has been developed with high reliability, especially for the HTS modules and the CCS. For the HTS module, it does not deteriorate even when the fault current is applied 100 times to the single bifilar coil. A type tests are successfully passed including of a short circuit test, an impedance test, and an electrical insulation test, at PT&T in LS Electric, which is the official certification institute in Korea.

This work is supported by Open R&D Program of the Korea Electric Power Corporation (KEPCO).

ORAL

O LAII-1

A Study on the Applicability of SMES Manufactured by Metal Insulation Method using 2G HTS Tape

Chaemin Im ***(Seoul National University)***,
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Jung Tae Lee *(Seoul National University)*,
Geonyoung Kim *(Seoul National University)*,
Jeonghwan Park *(Seoul National University)*,
Kibum Choi *(Seoul National University)*,
Jeseok Bang *(Seoul National University)*,
Soobin An *(Seoul National University)*,
Seungyong Hahn* *(Seoul National University)*

This paper presents a study on the applicability of a superconducting magnetic energy storage (SMES) which is composed of second-generation(2G) high-temperature superconductor (HTS), wound by metal insulation(MI) method. Recently, various energy storage systems (ESSs) have been proposed in accordance with the rapidly increasing energy demand, but some problems still need to be improved. In particular, most ESSs have problems with stability or loss in the process of converting and storing produced electric energy into other forms of energy. SMES, however, directly stores electric current in the form of magnetic energy, thus has potential to replace existing ESSs. In this paper, we analyze the expected performance when SMES is fabricated using the MI method that combines the advantages of the insulated and no-insulation (NI) method of 2G HTS magnet. MI SMES is evaluated in terms of key parameters for ESS evaluation such as energy/power density, cycle efficiency, self-discharge characteristics, cycle life, cost, etc.

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIT) (No. 2018R1A2B3009249).

ORAL

O LAII-2

Design Study on No-Insulation High Temperature Superconductor Magnet for Gyrotron Application

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Seong Hyeon Park *(Seoul National University)*,
Jeonghwan Park *(Seoul National University)*,
Won Seok Jang *(Seoul National University)*,
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Gyrotron is an oscillator that generates millimeter-wave electromagnetic (EM) waves by electron cyclotron resonance under a strong magnetic field. The achievable EM wave frequency by gyrotron is being pioneered towards the terahertz region which broadens its applications to high-power terahertz science and technologies. A few of the main applications include electron cyclotron resonance heating (ECRH) for plasma in nuclear fusion and nuclear magnetic resonance with signal enhancement through dynamic nuclear polarization (NMR-DNP). Regarding the advancement, a higher and more precise magnetic field is required in the interaction region of the gyrotron. In this paper, no-insulation (NI) high temperature superconductor (HTS) solenoid magnet design is studied using the multi-width (MW) technique to meet the design requirements for the gyrotron with a world record frequency of 1.08 THz at second harmonic operation achieved by the University of Fukui, Japan. The magnet generates 20 T in the center of 52 mm bore diameter with field error < 0.11 % along the axisymmetric axis 20 mm from the center. The use of NI HTS magnet with MW technique would make the existing gyrotron magnet to be more compact where multiple gyrotrons are required for high accumulated power, e.g., ECRH. It may also suggest a possibility to expand the frequency limit beyond the current record of 1 THz.

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIT) (No. 2018R1A2B3009249).

ORAL

O LAII-3

Temperature-field-angle Dependent Critical Current Estimation of Commercial HTS Wire Based on Bayesian Regularized Neural Network

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Jeongmin Mun *(Changwon National University)*,
Seokho Kim* *(Changwon National University)*

Second-generation high-temperature superconductor critical current is a temperature-field-angle dependent parameter. The critical current varies according to the manufacturing process of different manufacturers. Fast and reliable calculations are important for researchers in the first-cut magnet design and transient analysis. Currently, there is a large amount of relevant experimental data on critical currents in the temperature, field strength, and angle ranges of 15 - 75 K, 0.01 - 8 T, and 0 -180 degree, respectively. In this study, We addressed three challenging issues in critical current assessment by neural network fitting methods, namely 90 degree asymmetry, a wide range of temperature-field-angle dependence, and different manufacturer conductor differences. Three commercial 2G HTS superconducting wire prediction models were trained and evaluated by convergence, accuracy, and robustness. The linear regression correlation coefficient R is almost near to 1 of the three models. With a 5 DPs magnet, we compared critical current estimation result with the interpolation method at different temperatures. The model computation speed is also discussed. The results show that the computation time for 10 million data sets takes only 2.7 s. Thus, the convergence, reliability, accuracy, and speed of our method prove that it can be used in a wide range of different studies.

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIT) (No. NRF-2019R1A5A8083201), and the Korea Medical Device Development Fund grant funded by the Korea government (the Ministry of Science and ICT, the Ministry of Trade, Industry and Energy, the Ministry of Health & Welfare, the Ministry of Food and Drug Safety) (Project Number: 1711138068, KMDF_PR_20200901_0063).

SESSION III : MM I

Materials - I

ORAL

O MMI-1

Improvement of pinning properties by refining Gd_2O_3 particles trapped in $GdBa_2Cu_3O_{7-\delta}$ coated conductors fabricated by the RCE-DR process

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To enhance the pinning properties for the $GdBa_2Cu_3O_{7-\delta}$ (GdBCO) coated conductors (CCs) fabricated by the reactive co-evaporation by deposition and reaction (RCE-DR) process, we tried to refine the Gd_2O_3 particles inclusion of GdBCO matrix. The Gd_2O_3 growth temperature was controlled while the GdBCO growth conditions were fixed. By lowering the growth temperature of Gd_2O_3 from 860 to 800 ºC at the oxygen pressures (PO2) of 20 and 30 mTorr, the average particle size of Gd_2O_3 particles trapped in the GdBCO matrix could be reduced from 137 ± 52 to 73 ± 31 nm. The self-field critical current density (J_c) values decreased with decreasing Gd_2O_3 growth temperature, because of the gradual degradation of in-plane and out-of-plane textures. On the other hand, the complex phenomenon caused by both variation of stacking fault (SF) density and interfacial pinning by refined Gd_2O_3 particles can improve the pinning properties.

ORAL

O MMI-2

Magnetocaloric effect of the mixture with the different ratio of the rare-earth nitrides

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Jong-Woo Kim *(Korea Institute of Materials Science)*

자기열량 효과에 의한 자기냉각 기술은 기존의 기체냉각 방식을 대체할 수 있는 친환경 및 고효율 냉각기술로 주목이 되고 있다. 희토류 질화물은 강자성에서 상자성으로 이차전이를 보이는 특성과 액체 수소 끓는점 부근의 전이온도를 보여주고 있다. 본 연구는 열플라즈마 공정을 통해 Ho, 그리고 Dy 희토류 금속을 각각 용융 및 증발 그리고 이어지는 질화를 통해 희토류 질화물의 나노분말을 제조하고 상호 혼합비율에 따른 자기냉각 특성을 조사하였다. HoN과 DyN의 상전이 온도는 ~14와 ~19 K로 나타났으며, 혼합비율 HoN : DyN = 1:1에서는 ~15 K, 그리고 1:2에서는 ~16 K로 약간 높은 온도로 증가됨을 확인하였다. 그리고 ΔS-T 측정 및 계산을 통해 자기엔트로피 값은 HoN이 ~24.5 J/kgK(ΔH = 5 T)로 DyN ~13.6 J/kgK(ΔH = 5 T) 보다 크지만, 반치폭 δT(FWHM)은 각각 ~19.4와 ~37.9 K로 DyN이 훨씬 높았다. 따라서 RCP(Relative Cooling Power)는 각각 475와 515 J/kg로 계산되었다. 한편, 혼합비율에 따라 HoN : DyN = 1:1에서 RCP는 610 J/kg 그리고 1:2에서는 595 J/kg으로 증가됨을 확인하였다.

ORAL

O MMI-3

Optimization of reaction temperature of MgB_2 bulks using different sizes of Mg raw powders

Kookchae Chung* ***(Korea Institute of Materials Science)***

MgB_2 초전도체는 Mg과 B, 두 물질로 구성되어 있어 물성 변화 및 최적화에 비교적 유리한 면이 있다. 한편, MgB_2 초전도 특성은 원료분말의 특성에 많은 영향을 받게 된다. 원료분말의 크기 및 분포도, 순도 및 불순물, 등이 초전도 물성에 영향을 주게 되고, 특성향상 및 최적화를 위해서는 이러한 변수들을 최적화가 꼭 필요하다. 본 연구에서는 B분말의 크기는 <100 nm로 고정한 상태에서 Mg분말을 각각 <5 μm와 <45 μm를 사용하여 630-700°C구간에서 열처리 온도 최적화를 진행하였다. 먼저 <45 μm 크기의 Mg의 경우, 열처리 온도 700-650°C에서 상변화 차이는 적었으며, 모든 경우에 Mg이 남아 있었다. 한편, <5 μm 크기의 Mg에서는 700-640oC에서는 상변화가 적었지만, 630°C에서는 반응 후 남아있는 Mg이 관찰되었다. 초전도 전이온도는 Mg의 크기에 대해서 열처리온도변화에 따라 약 37.5-37.8 K로 차이가 작았으며, 다만 630°C에서만 약 37.0 K로 낮게 나타났다. 그리고 자기장 변화에 대한 초전도 임계전류 특성은 Mg분말크기가 작은 경우에 전 자기장 구간에서 높은 Jc값을 보여주었으며, <45 μm 크기의 Mg의 경우 열처리온도가 낮을수록 자속고정 특성이 향상되고, <5 μm 크기의 Mg에서는 낮은 열처리온도 630°C를 제외하고는 비슷한 자속고정 특성이 나타났다.

ORAL

O MMI-4

Enhancement of in-field J_c properties of commercial MgB_2 superconducting conductor with pyrene doping

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Magnesium diboride (MgB_2) has been regarded as one of the most promising materials for replacing the low-temperature superconductors because of its high critical transition temperature (T_c) of 39 K. Besides MgB_2 has many advantages such as its simple crystalline structure and low material cost. However, it still has drawbacks in terms of high-field critical current density (J_c) and low irreversibility field (Birr). Carbon (C) is known to be the most effective dopant for MgB_2, especially for enhancing high-field J_c and Birr. When C is doped into MgB_2 lattices, partial C atoms induce disorder in the lattice and hence enhances the upper critical field (B_{c2}) and high-field J_c. In this study, we have undertaken pyrene (C16H10) doping of MgB_2 wires and evaluated the field dependence of J_c. The J_c performance of optimized doped wire was estimated to be 21,000 A/cm^2 at 4.2 K and 10 T. This result is comparable to commercial Nb-Ti. Herein, we will discuss field and temperature dependence of J_c performance with doping level.

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ORAL

O MMI-5

Influence of Surface Damage on Critical Current Density of MgB_2 Films via Low-Energy Ion Irradiation

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We investigate the effect of surface damage on the critical current density (J_c) of MgB_2 films. The superconductivity of MgB_2 around the surface region is degraded by low-energy ion irradiation, which mainly creates atomic displacements along with point defects, such as interstitials and vacancies, caused by elastic scattering between incident ions and Mg/B atoms and collision cascades. The field performance of J_c of MgB_2 is strongly influenced by the thickness ratio (Rt = tS/tD) between the degraded MgB_2 (SD) and non-degraded MgB_2 (SS) layers. Here, tS and tD indicate the thickness of SS and SD layers, respectively. The Rt is controlled by the thickness of MgB_2 films (430, 800, and 1300 nm) and the incident energy of Cu ion (20, 60, 100, 140 keV), and the amount of irradiated Cu ions is fixed at 1×10^{14} #/cm^2 to generate a similar damage profile regardless of the size of incident energy. The largest improvement in J_c (H) is observed for the film with Rt = 7.8, corresponding to the thickness of SD layer of only about 11% of the total film thickness, accompanied by a significant enhancement of the flux pinning force density (Fp). In addition, this film shows a large increase in the critical field H* corresponding to $J_c = 10^5$ A/cm^2, a common benchmark for large-scale practical applications, from 14.8 and 8.7 to 25 and 13.3 kOe at 5 and 20 K, respectively. Surface degradation hardly changes the superconducting transition temperature (T_c) and low-field J_c, which is markedly different from the widely used chemical doping to improve the flux pinning effect that normally reduces T_c and low-field J_c. We expect that these results will provide new guidance for designing and optimizing the geometry of flux pinning sites in MgB_2.

We wish to acknowledge the support of the accelerator group and operators of KOMAC (KAERI). This study was supported by the National Research Foundation (NRF) of Korea through a grant funded by the Korean Ministry of Science and ICT (No. 2012R1A3A2048816 and 2021R1A2C2010925) and by the Basic Science Research Program through the NRF of Korea funded by the Ministry of Education (NRF-2018R1D1A1B07048987, NRF-2019R1F1A1055284, and NRF-2021R1I1A1A01043885). This work was also supported by the National Research Foundation Grant (NRF-2020M2D8A2047959) funded from Ministry of Science and ICT (MSIT) of Republic of Korea.

SESSION IV : ED I

Electronics & Device Applications - I

ORAL

O EDI-1

Characterization of JPA for axion haloscope experiment

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The axion, a hypothetical particle, is a promising candidate for dark matter and a solution to the strong CP problem. Axion haloscope experiments look for a signal with power comparable to the quantum limit. To improve the noise properties of the detection system, we employ a flux-driven Josephson parametric amplifier(JPA). JPAs are expected to have added noise approaching the quantum limit. In our measurements to characterize the JPA, we have found that the added noise to the system with JPA as the first amplifier is lower than 100 mK for the frequency range 1.135 GHz to 1.163 GHz.

This work was supported by the Institute for Basic Science (IBS-R017-D1-2021-a00).

ORAL

O EDI-2

Implementation Josephson Parametric Amplifiers in CAPP axion search experiments

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The axion is expected to solve the strong CP problem of quantum chromodynamics and is leading candidate for dark matter in the galaxy. CAPP has several search experiments in South Korea based on haloscope in the frequency range of 1-7 GHz. The highest priority of the IBS/CAPP is to operate the experiments with the highest sensitivity possible. It requires reduction of physical temperature of the haloscopes down to mK temperature range and usage of components with the lowest possible noise to amplify the weak axion signal. We report our development and operation of flux-driven Josephson parametric amplifiers operating from 1 to 7 GHz. Our implementation shows noise temperature approaching the quantum limit.

This work was supported by the Institute for Basic Science (IBS-R017-D1-2021-a00).

ORAL

O EDI-3

6-13 GHz cryogenic microwave low noise amplifier

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The axion search experiments at the Center for Axion and Precision Physics Research (CAPP) of the Institute for Basic Science (IBS) in South Korea based on haloscope are performed in a wide range. The critical components of the detector setup are defined by the Josephson parametric amplifiers (JPA) and High Electron Mobility Transistor (HEMT) based cryogenic low noise amplifiers (cLNA). It is desirable for both devices to have a wide frequency range and low noise at cryogenic temperatures. Hereby, we show a recent design of a cryogenic broadband low-noise HEMT amplifier (LNA) characterized in a cryogen-free dilution refrigerator at 3.8 K. The measured power dissipation of the LNA is lower than 20 mW. The performance of the LNA shows a gain of 30 dB in the frequency range from 6 to 13 GHz with an equivalent noise temperature below 6 K. In this talk, we describe the amplifier design, main characteristics and technical details of implementation in an experiment.

This work was supported by the Institute for Basic Science (IBS-R017-D1-2021-a00).

ORAL

O EDI-4

2G biaxially-textured ReBCO tapes for enhanced axion search sensitivity

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Second generation (2G) biaxially-textured rare-earth barium copper oxide (ReBCO) film is a low surface resistance material that can improve the performance of axion haloscope experiment, which utilizes a resonant cavity immersed in a high magnetic field. ReBCO has many advantages over other superconductors in terms of vortex melting field, depinning frequency, and fabrication. Especially, strong pinning at a high frequency (> 3 GHz) would be beneficial for axion searches in high-mass regions. However, it is challenging to optimize the performance of ReBCO tapes in the experiment because the surface resistance depends on various parameters, including temperature, frequency, magnetic field, fabrication method, and additional pinning center. Such problematic issues can be resolved by either further treatment or adjusting experimental conditions. This talk will discuss why and how we can take advantage of the 2G high-temperature superconducting tape technology in the axion haloscope experiment.

The authors are grateful for the experimental advice of Boris Ivanov (RF Measurement), and the general discussion of Sung Woo Youn. This work was supported by IBS-R017-D1-2021-a00.

ORAL

O EDI-5

High energy-resolution tunneling spectroscopy of Andreev bound state in graphene Josephson junction

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Jinho Park *(Postech)*,
Woochan Jung *(Postech)*,
Hu-Jong Lee *(Postech)*,
Gil-Ho Lee* *(Postech)*

A Josephson junction consists of two superconductors separated by a non-superconducting material. Josephson junctions allow the supercurrent by forming Andreev bound states (ABSs) of electron- and hole-like quasiparticles, which are correlated by Andreev reflections [1]. As ABS determines microscopic behavior of Josephson junctions, it is important to understand its energy spectrum. However, the quantitative analysis has been limited by the low energy-resolutions of tunneling spectroscopy [1, 2]. Moreover, most studies have been focused in the short junction regimes [3]. Here, we report the direct observations of ABSs in both short and long junction regimes using newly developed superconducting tunneling spectroscopy of energy resolution of around 20 μeV. We fabricated graphene Josephson junctions using aluminum and molybdenum rhenium together with superconducting tunnel probes at the edge of graphene, and performed the tunneling spectroscopy on ABS with varying superconducting phase. Our study provides fundamental understanding of how the Josephson coupling forms through the graphene. This study can be extended to topological materials, studying for Majorana zero modes [4-6].

[1] Bretheau, L., et al. Tunnelling spectroscopy of Andreev states in graphene. Nat. Phys. 13, 756-760 (2017).
[2] Wang, J. I. J., et al. Tunneling spectroscopy of graphene nanodevices coupled to large-gap superconductors. Phys. Rev. B 98, (2018).
[3] Furusaki, A. and Tsukada, M. Current-carrying states in Josephson junctions. Phys. Rev. B 43, 10164-10169 (1991).
[4] Fornieri, A., et al. Evidence of topological superconductivity in planar Josephson junctions. Nature 569, 89-92 (2019).
[5] Ren, H., et al. Topological superconductivity in a phase-controlled Josephson junction. Nature 569, 93-98 (2019).
[6] Pientka, F., et al. Topological Superconductivity in a Planar Josephson Junction. Phys. Rev. X 7, (2017).

SESSION V : TP I

Theory & Physical Properties - I

ORAL

O TPI-1

The maximal superconducting T_c within the phonon mediated pairing

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Han-Yong Choi* *(SungKyunKwan University)*

The superconducting critical temperature T_c recording close to room temperature in superhydrides such as H_3S and LaH_{10} under high pressure raises a question: what is the maximum T_c for the phonon mediated superconductors? Theoretically, the high T_c of hydrogen-rich materials has been estimated or expected from McMillan's or Allen and Dynes' T_c formula by calculating the dimensionless electron-phonon coupling constant λ in terms of the density functional theory (DFT) based phonon calculation. However, those formulae were obtained empirically based on the perturbative framework so called Eliashberg theory, which may break down in the limit of very large electron-phonon coupling g or antiadiabatic limit where the phonon frequency (ω_0) is larger than the Fermi energy (ε_F). We calculated T_c of the Holstein model in non-perturbative way by employing the dynamical mean-field theory in combination with the numerical renormalization group technique. Interestingly, the maximum T_c occurs at the lower critical value g_{c1} of the 1st order metal-insulator transition in the normal state. Underlying physics is the balance between the enhanced electron-phonon coupling and the decrease of the average phonon frequency caused by the soft mode emerging along the phase boundary associated with the enhanced quantum fluctuation. Implications of T_c^{max} calculations will be discussed in comparison with a variety of ways to estimate T_c bounds using the electron-phonon coupling spectra of the normal state.

ORAL

O TPI-2

Nematic coherent oscillations in $BaFe_2As_2$

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We investigate coherent phonon oscillations of $BaFe_2As_2$ using optical pump-probe spectroscopy. Time-resolved optical reflectivity shows periodic modulations due to A1g coherent phonon of c-axis arsenic vibrations. Optical probe beams polarized along the orthorhombic a- and b-axes reveal that the initial phase of coherent oscillations show a systematic deviation as function of temperature, although these oscillations arise from the same c-axis arsenic vibrations. The oscillation-phase remains anisotropic even in the tetragonal structure, reflecting a nematic response of $BaFe_2As_2$. Our study suggests that investigation on phase of coherent phonon oscillations in optical reflectivity can offer a unique evidence of a nematic order strongly coupled to a lattice instability.

ORAL

O TPI-3

Enhanced superconductivity in the vicinity of a quantum phase transition of a 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 5 % intercalated 2H-$TaSe_2$ single crystal using extensive high-pressure magneto-transport and Raman scattering measurements. We find that as pressure increases, the anomalies in the temperature-dependent Hall coefficient and resistivity due to the CDW formation shift toward lower temperatures, resulting in a CDW quantum phase transition at Pc = 22.1 GPa. At the same time, the two-phonon mode in the Raman spectra exhibits continuous suppression towards Pc, which provides clear evidence of the disappearance of the phonon Kohn anomaly with pressure. Furthermore, the superconducting transition temperature shows a continuous increase and reaches its maximum value of 7.35 K at Pc, concurrent to the suppression of the charge density wave order. Based on the above findings and the electronic phase diagram vs P, we propose that the increase in the electron density of states (DOS) near the CDW quantum phase transition plays a critical role in the enhancement of superconductivity in this material. Our findings demonstrate that the combined effect of intercalation and pressure can sensitively control the charge density wave order, making this method an effective means to unveil the delicate phase diagram of various van der Waals materials.

ORAL

O TPI-4

Tuning Flux-pinning in $GdBa_2Cu_3O_{7-x}/La_{0.7}Sr_{0.3}MnO_3$ Epitaxial Bilayers via Substrate-induced Strain

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A heterostructure of high-T_c cuprate and ferromagnetic manganite has attracted a great deal of attention because the interaction between superconductivity and ferromagnetism causes a competition between different ordering phenomena. In this talk, we report local structural dependence of a complex superconducting mechanism realized in $GdBa_2Cu_3O_{7-x}$ (GdBCO)/$La_{0.7}Sr_{0.3}MnO_3$ (LSMO) heterostructure grown under two different strains, tensile strain ($SrTiO_3$) and compressive strain ($LaAlO_3$). The epitaxial bilayer system consist of $GdBa_2Cu_3O_{7-x}$ (GdBCO) and $La_{0.7}Sr_{0.3}MnO_3$ (LSMO) grown on (001) $SrTiO_3$ (STO) and $LaAlO_3$ (LAO) substrates have been fabricated to study a correlation of magnetic flux pinning with substrate-induced strain state. The Cu K-edge and the Mn K-edge EXAFS have been applied to analyze the strain dependence of local displacements in electronically active Cu-O bond in GdBCO and the Mn-O bond in LSMO. We found that the interaction between superconductivity and ferromagnetism in GdBCO/LSMO system strongly depends on the local structural coupling between LSMO and GdBCO layers. With respect to the flux pinning properties of GdBCO, the structural coupling modifies the ferromagnetic order in LSMO, producing weak/strong contribution to ferromagnetic pinning. Under strong compressive strain, flux pinning by structural distortion of both Mn-O and Cu-O bonds is as important as ferromagnetic pinning by LSMO, while this effect is insignificant under tensile strain. These finding suggest a possibility of an active tuning of ferromagnetic pinning by LSMO through controlling of substrate-induced strain state.

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ORAL

O TPI-5

B1g phonon anomaly driven by Fermi surface instability at intermediate temperature in $YBa_2Cu_3O_{7-\delta}$

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Younsik Kim *(Seoul National University)*,
Shigeki Miyasaka *(Osaka University)*,
Setsuko Tajima *(Osaka University)*,
Yunkyu Bang *(Asia Pacific Center for Theoretical Physics)*,
Seung Ryong Park *(Incheon National University)*,
Changyoung Kim* *(Seoul National University)*

We performed comprehensive temperature- and doping-dependent high resolution Raman experiments on $YBa_2Cu_3O_{7-\delta}$ single crystals to study the B1g oxygen bond-buckling phonon, the key phonon mode for high temperature cuprate superconductors. We find hitherto unobserved temperature scale TB1g above the critical temperature T_c. At TB1g, B1g phonon suddenly begins to soften as it does at T_c. The similar behaviors of B1g phonon at TB1g and T_c strongly suggests the important role of B1g phonon in intertwined orders, as theoretically predicted. We expect our results can lead to a unified understanding of novel phases across the phase diagram of cuprate superconductors.

SESSION VI : CR I

Cryogenics - I

ORAL

O CRI-1

Design of a cryogenic heat exchanger with lattice structures to be installed on a cold-head of cryocooler

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Yonghyun kwon *(Changwon National University)*,
Byunghui Kim *(Byunghui)*,
Seok Kim *(Byunghui)*,
Seokho Kim* *(Byunghui)*

To increase the effectiveness of a heat exchanger, it is important to increase the surface area to volume ratio while keeping the pressure drop below a design value. To increase the ratio of surface area to volume of the heat exchanger, several kinds of an extended surface structure are applied. However, it usually results in a fabrication difficulty or excessive pressure drop. To solve this problem, a lattice structure can be applied to the internal flow path of the heat exchanger. In the lattice structure, unit cells are regularly arranged and their surface area is much larger than the heat exchanger with simple flow paths. With the recent development of metal 3D printing technology, the complex structure of lattice structure can be easily fabricated. The lattice structure has a different surface area to volume ratio depending on the shape of the unit cell, and the pressure drop and heat transfer performance are determined according to the structure of the unit cell. In this study, to investigate the thermo-hydraulic characteristics of the lattice structure, and to predict the heat transfer performance and pressure drop, thermal fluid analysis is performed according to the type of the lattice structure. The heat transfer performance and pressure drop are compared to select an appropriate lattice structure for the heat exchanger, and the heat exchanger design is also performed to apply the selected lattice structure. Based on the results of this study, the lattice heat exchangers with excellent heat transfer performance and reasonable pressure drop will be fabricated using metal 3D printing method.

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIT) (No. NRF-2019R1A5A8083201) and Smart Manufacturing Innovation Leaders program funded by the Ministry of the Trade, Industry & Energy (MOTIE, Korea).

ORAL

O CRI-2

Heat-Exchanger Design with Temperature Pinch Problem on Liquefying Hydrogen by Cold Gaseous Helium

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An elaborated design effort is made on the cold-end heat exchanger (HX) of helium Brayton refrigeration cycle for hydrogen liquefaction. So-called the "temperature pinch" problem occurs in this counter-flow heat exchanger, because the temperature difference between two streams has its minimum at an intermediate point, where hydrogen starts to condense in thermal contact with cold gaseous helium. Even though the commercial software for HX design (such as Aspen EDR) is available and widely used, the results should be carefully confirmed by taking the temperature pinch problem into consideration. This study attempts to design the heat exchanger separately for two sub-divided sections: the cool-down section (in vapor) and the condensation (phase-change) section for the hydrogen stream. To demonstrate the design concept, aluminum brazed plate-fin heat exchanger (PFHX) is designed for 0.5 T/day liquefier under domestic development and the result is quantitatively compared with simple EDR design. It is revealed that the sub-divided design yields a smaller size than the simple EDR design. The main reason for the difference is that the simple design is based on averaged values for the temperature-dependent properties and flow rates. The sub-divided method is recommended for an accurate HX design with temperature pinch problem.

Keywords : hydrogen, liquefaction, pinch point, plate-fin heat exchanger, sub-division

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ORAL

O CRI-3

Manufacture of hydrogen liquefier for cooling superconducting coil

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Hyun-Woo No *(Korea Elecrtotechnology Research Institute)*,
Tae-Hyung Koo *(Korea Elecrtotechnology Research Institute)*

In the hydrogen economy era, the transport and storage of liquid hydrogen, which occupies a small volume, has many advantages in supplying hydrogen as a fuel in the future. In addition, the liquefaction temperature of hydrogen is 20 K, which fits well with the value around 40 K, which is the operating temperature of a high-temperature superconducting magnet. Therefore, if liquid hydrogen can be used as a refrigerant for the superconducting coil, it is much more economical than other refrigerants such as liquid neon. However, the reality is that there is no infrastructure to obtain liquid hydrogen in the vicinity. Therefore, for the experiment of cooling the superconducting coil with liquid hydrogen, it was first necessary to fabricate a hydrogen liquefier. In this study, liquid hydrogen is used as a refrigerant to cool the superconducting coil. Considering safety, an indirect cooling method with helium gas was selected. Considering the long-term storage of liquid hydrogen, an O-P converter was included to make liquid hydrogen in a stable phase by O-P phase transition. Also included is a liquid nitrogen jacket to prevent heat leak from the flange. In order to change the liquefaction performance of the refrigerator in a wide range, two refrigerators were used. We succeeded in manufacturing a hydrogen liquefier equipped with a DAQ system, and the performance of 3 liters/h was obtained through operation

ORAL

O CRI-4

Modeling and simulation of cryogenic system of RAON SRF TF using EcosimPro

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The rare isotope accelerator complex for on-line experiments (RAON) is equipped with a large cryogenic system to provide a cryogenic environment for beam operation of superconducting LINACs. SCL3 consists of 22 QWR cryomodules and 33 HWR cryomodules. The QWR is cooled to 4.5 K and the HWR is further cooled to 2.05 K by bath cooling using subcooled liquid helium. Control logic has been designed to cool-down and operate the large cryogenic system of RAON. To verify and optimize the designed control logic, EcosimPro, which is a modeling and simulation tool, is used to simulate the cryogenic system of RAON. Prior to the simulation of SCL3 containing 55 cryomodules, a validated model is required for each cryomodule. There is a superconducting radio frequency test facility(SRF TF) for performance verification of each cryomodule to be installed in LINAC. For validation of each cryomodule model, modeling and simulation of SRF TF using EcosimPro are performed. By utilizing the model of SRF TF obtained through this process, it will contribute to modeling and simulation of SCL3. In this presentation, the process of modeling the SRF TF using EcosimPro is introduced, and the simulation results and experimental results are compared and analyzed. Additionally, component modeling on EcosimPro for automation of cool-down operation of SRF TF and its results are described.

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ORAL

O CRI-5

Dynamic Simulation on Flow Characteristics of KSTAR PF Magnet Cryogenic Network

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During its nominal operation, strong current variation, more than 10 kA per second, can be imposed on the KSTAR PF (Poloidal Field) magnet system. Due to AC loss, transient massive backward flow can occur, especially at the cryogen inlets of each magnet. To protect cryogen circulator, several valves are activated to adjust or lower pressure below the circulator's operation limit. In this work, we discuss whether currently available thermo-hydraulic code, such as SUPERMAGNET, can describe this overall dynamic flow characteristics of KSTAR PF magnet cryogenic network. First, three major functions of the KSTAR PF magnet cryogenic system during plasma operation are classified and discussed. Cryogenic components mostly related with other functions such as, cool-down process, are removed from the simulation circuit to minimize computation time as much as possible. SUPERMAGNET code was used with a slight modification in its cryogenic network simulation module, FLOWER. The codes for cryogenic valves are modified so that not only steady state but also general compressible flows can be described. A case study for an actual KSTAR plasma operation has been intensively carried out. It was shown that most relevant data, pressure, temperature and mass-flow, at the inlets and outlets of the magnet, are in agreement with simulation results.

POSTER SESSION

TP : Theory & Physical Properties

ED : Electronics & Device Applications

MM : Materials

LA : Large Scale Applications

CR : Cryogenics

Characterization of the Electromechanical Delamination Strength of REBCO Coated Conductor Tapes under Transverse Loading

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In most practical applications of coated conductors (CC) tapes, particularly in wet wound coils, CC tapes are subjected to different kinds of stresses which inevitably degrades their transport properties. These covers hoop stress that acts along the length-wise of the tape, and the Lorentz force enforcing perpendicular to the surface of the tape. CC tape is known to have a multilayered structure, from that, the latter is a common cause of the structural delamination and/or ballooning phenomena that often takes place in the interlayers of the CC tape. In addition, the difference in the coefficient of thermal expansion (CTE) of each layer of the CC tape, the bobbin, and the impregnating materials is the main reason for the occurrence of delamination in CC tape when it is subjected to thermal cycling often experienced during its actual operation. In the design of degradation-free superconducting coils, characterization of the mechanical and electromechanical delamination behaviors including the mechanism becomes critical. In this study, a transverse tensile test was conducted by anvil-test method at 77 K using a wider upper anvil size that covers the entire width of the 4-mm CC tape. This allows us to include the slit edge effect in the 4 mm wide CC in characterizing the delamination behavior. In the case of the electromechanical delamination characterization, our newly developed critical current, I_c measurement system which continuously applies current was used while being subjected to a constant crosshead speed of 0.5 mm/min transverse loading.

This research was supported by a grant from the National Research Foundation of Korea (NRF-2020-R1I1A-3058389) funded by the Ministry of Education (MOE), Republic of Korea.

Using disorder to identify of Bogoliubov Fermi-surface states

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We argue that a superconducting state with a Fermi-surface of Bogoliubov quasiparticles, a Bogoliubov Fermi-surface (BG-FS), can be identified by the dependence of physical quantities on disorder. In particular, we show that a linear dependence of the residual density of states at weak disorder distinguishes a BG-FS state from other nodal superconducting states. We further demonstrate the stability of supercurrent against impurities and a characteristic Drude-like behavior of the optical conductivity. Our results can be directly applied to electron irradiation experiments on candidate materials of BG-FSs, including Sr_2RuO_4, $FeSe_{1-x}S_x$, and UBe_{13}.

nfrared spectroscopic study of doping and temperature dependences of electronic structures in the bilayered perovskite $Sr_3(Ir_{1-x}Mn_x)_2O_7$

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Stephen Wilson *(Materials Department, University of California)*,
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A 5d transition metal oxide $Sr_3Ir_2O_7$ has the Jeff = 1/2 Mott insulating state, which are due to the strong spin-orbit coupling and moderate Coulomb interaction. We investigate temperature and doping evolutions of the optical response of the layered perovskite $Sr_3(Ir_{1-x}Mn_x)_2O_7$ in the range of $0 \leq x \leq 0.36$ using infrared spectroscopy. Upon Mn doping, the optical excitation between the Jeff = 1/2 Hubbard bands at about 0.41 eV is gradually suppressed, while its peak position remains invariant. The two optical transitions near 0.17 and 1.2 eV develop upon Mn doping, which suggests hole doping and interplays between Ir and Mn respectively. We also find apparent insensitivities of the energy of the optical excitation across the Mott gap to the temperature in Mn-doped samples, where no clear anomalies in the peak position of the Mott gap excitation at the antiferromagnetic ordering temperature T_N. In contrast, the peak shows significant shift with temperature in the parent compound. We conjecture that the electron-phonon coupling may play a crucial role for the temperature evolutions of the peak positions of the parent and the Mn-doped compounds.

Observation of Kondo lattice behavior in an antiferromagnetic metal FeTe

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Changyoung Kim* *(Seoul National University)*

In a classical picture, Kondo lattice and antiferromagnetism competes each other, making them barely overlap in the phase diagram since localized moments are screened by itinerant electrons upon forming Kondo singlet. This classical picture assumes the Kondo interaction is on-site. If the Kondo interaction is off-site, itinerant electrons are not able to screen localized moments. As a result, Kondo lattice and magnetism can coexist if the Kondo interaction if off-site. Here, we report the emergence of Kondo lattice behavior in an antiferromagnetic metal, FeTe. We observed Kondo hybridization between localized Fe 3dxy and Te 5pz bands by using angle-resolved photoemission spectroscopy (ARPES) below Néel temperature. Our work shows the first observation of Kondo p-d hybridization, and cooperation of Kondo lattice and antiferromagnetism.

Probing Superconducting Gap of the High-Entropy-Alloy via Quasi-Particle Scattering Spectroscopy

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The high-entropy-alloy superconductor (HEAS) characterized by a high degree of disorder has attracted great interest because of its high potential for technological applications. However, the information on superconducting (SC) gap of the HEAS, which is an important factor for designing SC devices, is rarely reported. Here, we report the SC gap of the HEAS Ta1/6Nb2/6Hf1/6Zr1/6Ti1/6 by using quasi-particle scattering spectroscopy. The signature of Andreev reflection is observed in the differential conductance (dI/dV) spectra below the SC transition temperature (T_c) of 7.85 K, which was reasonably explained by the modified Blonder-Tinkham-Klapwijk (BTK) model. The evolution of the SC energy gap (del) as a function of temperature and magnetic field follows the BCS theory with del(T = 0) = 1.33 meV. The gap-to-T_c ratio, $2del(0)/k_BT_c$, is 3.9, which is larger than the BCS prediction of 3.54, indicating that the HEAS Ta1/6Nb2/6Hf1/6Zr1/6Ti1/6 belongs to the class of the moderate-coupled nodeless superconductors.

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Effect of work function on alkali metal induced electronic structure change

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Alkali metal dosing (AMD) has been widely used as a way to control doping without chemical substitution. This technique, in combination with angle resolved photoemission spectroscopy (ARPES), often provides an opportunity to observe unexpected phenomena. However, the amount of transferred charge and the corresponding change in the electronic structure vary significantly depending on the material. Here, we report study on the correlation between the sample work function and alkali metal induced electronic structure change for three iron-based superconductors: FeSe, $Ba(Fe_{0.94}Co_{0.06})_2As_2$ and NaFeAs which share a similar Fermi surface topology. Electronic structure change upon monolayer of alkali metal dosing and the sample work function were measured by ARPES. Our results show that the degree of electronic structure change is proportional to the difference between the work function of the sample and Mulliken's absolute electronegativity of the dosed alkali metal. This finding provides a possible way to estimate the AMD induced electronic structure change.

Effect of ZnO Thickness Variation on Atomic Bond, Phonon Frequency and T_c of MgB_2 Films on Metallic Substrate

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Dong Seok Yang *(충북대학교)*,
Byeongwon Kang* *(충북대학교)*

Maintaining stress and strain of magnesium diboride (MgB_2) crystal in the forms of tape and coil that bond to metallic substrate is very important since they can affect the behavior of its critical temperature (T_c) in application fields. Through adopting buffer layer as a method to control lattice-strain inside the MgB_2 crystal, a direct relation between lattice condition and T_c can be observed by Raman spectra. Even though MgB_2 has been known as a phonon-mediated superconductor, the mechanism of its phase transition under certain conditions is still unclear. In this work, we report the relation among crystal strain, phonon behavior, and T_c of MgB_2 films on Hastelloy substrate with various thicknesses of zinc oxide buffer layer analyzed by using X-ray Absorption Spectroscopy (XAS). Since lattice mismatch between MgB_2 and substrate is the main concern, the higher phonon frequency of our samples compared to the reference (~579 cm^{-1}) is suspected as the result of lattice strain caused by the application of the ZnO buffer layer. This hypothesis is proven by extended x-ray fine structure (EXAFS) result of atomic bond lengths between Mg-B and Mg-Mg. Direct relation among bond lengths between Mg and B atoms, phonon frequency, and T_c of MgB_2 films are obtained. The shorter the Mg-B bond length between Mg-B, the higher the phonon frequencies and the lower T_c of MgB_2, which follows the calculation theories by McMillan and Allen-Dynes. On the basis of this result, we argue that an investigation on the local structure of buffered MgB_2 films will open a chance to find an optimally controlled lattice condition and therefore enhanced superconducting properties for application fields.

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

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Changyoung Kim* *(Center for Correlated Electron Systems, Institute for Basic Science)*

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 On $LaSrAlO_4$(LSAO) Substrate with 20 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 atomic force microscopy(AFM) and physical property measurement system (PPMS). With our UHV transfer system connected with PLD and ARPES chamber, we performed in-situ ARPES and obtained Fermi surface map data of the LSCO thin film.

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Study on the Residual Surface Resistance of Superconductors for Cavity Resonators

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Superconducting cavity is one of the most important component in quantum computing architecture. To achieve high quality factor over 10 billion at low temperatures with single photon level power input, estimations of the residual surface impedance of various superconducting layers are necessary in order to find out low lossy superconductor. At low temperatures where a typical superconducting quantum computer operates, the surface impedance and the corresponding quality factor of the superconducting cavity don't agree with the BCS theory since the environment is much colder than the critical temperature of a superconductor. To calculate the residual surface impedance, we consider the residual magnetic flux and the vortex induced surface resistance. Then, loss due to the two-level systems of oxide layers on the superconducting layers is calculated to estimate the quality factor of various superconducting cavity resonators.

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Temperature-dependent hysteresis characteristic in $Mo_{1-x}W_xSe_2$ field-effect transistors

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One of transition metal dichalcogenides (TMDC) alloys, $Mo_{1-x}W_xSe_2$ attracts much attention due to adjustable band gap in a wide range band gap by varying transition metal ratio. Nevertheless, electrical properties of the alloy have been poorly understood. In this study, we investigated the temperature (T) dependence of electrical properties of $Mo_{1-x}W_xSe_2$ (x = 0, 0.33, 0.67 and 1) field effect transistor (FETs). Ti/Au metals were deposited as contact metals using e-beam evaporation method for transition metal ratios of x = 0.33, 0.67 and indium (In) was deposited for the ratios of x = 0, 1, and another 0.33, where all $Mo_{1-x}W_xSe_2$ FETs showed n-type behaviors. For measurement with increasing T from 4 K, the conductance increased in the beginning and was rapidly suppressed to nearly zero near T = 170 K, followed by increasing of conductance with further increasing T for all x ratios. Similar trends were observed in both 2- and 4-probe configurations at x = 0.33, indicating contact resistance is negligible and the sudden change of conductance is related to the bulk property. To further understand this phenomenon, we conducted a hysteresis measurement for x = 0.33 and 0.67. As a result, we observed an unreported form of hysteresis curve below around T = 170 K and the temperature-dependent reversible hysteresis inversion that might be related to the abrupt change of conductance. We will report the detailed and systematic experimental analysis and results for the sudden change of electrical properties and temperature dependent hysteresis characteristics including reversible hysteresis inversion of $Mo_{1-x}W_xSe_2$ FETs.

Beating effect in Aharonov-Bohm oscillations in Sb-Bi_2Se_3 Nanowire

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Topological insulators (TI) are distinguished from ordinary insulators by an inverted bulk gap for electronic excitations induced by strong spin-orbit coupling which assures the presence of gapless metallic boundary states, indicating that electrons can only be transported along the surface of the material. In the case of TI nanowire (NW), Aharonov-Bohm(AB) oscillation in magnetoconductance (MC) with axial magnetic field at a cryogenic temperature is due to quantum interference oscillations combined with topological surface states. In this work, beating pattern of AB oscillation of Sb doped Bi_2Se_3 NW was observed. As the origin of the beating effect, a spin-orbit interaction in the two dimensional electron gas (2DEG) region formed at the NW surface is considered, i.e., two different magnetic flux periods due to a Rashba spin splitting of 2DEG.

Topological insulators, Aharonov-Bohm oscillation, Sb doped Bi_2Se_3, Beating effect

A study on the double quench fault current limiting characteristics of three-phase transformer type SFCL according to single line ground fault

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This paper is about fault current limiting characteristics according to single line ground fault of a three-phase superconducting current limiter. In the model configuration, the secondary winding (b phase-c phase) is connected in a parallel circuit, and a three-phase superconducting current limiter (SFCL) is composed of two superconducting element modules (SCMs). The double quench measurement of the superconducting element module according to the single line ground fault was performed through the short-circuit simulation. To compare the characteristics, the fault current of a three-phase SFCL using three superconducting element modules (SCMs) was measured. Through the analysis of the experimental results, the proposed model had no difference in current limiting characteristics from the SFCL using superconducting element modules (SCMs).

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Superconducting coplanar-waveguide resonators resilient to magnetic field

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High-quality superconducting coplanar waveguide (SCPW) resonators are crucial for developing superconducting quantum information devices and sensors. Especially, operation of SCPW resonators under strong magnetic fields is required for developing spin-ensemble sensors or topological superconducting qubits. Magnetic fields, however, degrade the quality factor of SCPW by creating vortices, which induce resistive losses, and suppressing the superconductivity itself. Here, we fabricated and characterized various SCPW resonators with varying superconducting materials (Nb, NbN, and NbTi) and the film thicknesses (20 ~ 150 nm). At T = 1.8 K, the internal quality factor, Qi, ranges between 103 and 105 at zero magnetic field, but decreases rapidly with the magnetic field. When we compare the characteristic magnetic field B*, which is defined as Qi(B*) = Qi(B = 0)/2, B* varied from 0.05 to 0.75 T, depending on the superconducting materials and their thicknesses. We will discuss about the optimal conditions for the magnetic-field-resilient SCPW resonators.

1.5 T 800 mm MRI Magnet Design with NbTi Superconductor

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Magnetic Resonance Imaging (MRI) is one of the important technologies in the medical field. Although it is with great importance, it is difficult to install and utilize because of very high cost and maintenance cost. The superconductor used in MRI is generally niobium-titanium composite (NbTi), which operates at a very low temperature of 4.2 K. So, it is required for an optimized design with safety and compactness. In this study, 1.5 T 800 mm MRI Magnet was designed. The magnet consisted of 4 coils winding by NbTi Superconductor. This magnet design was analyzed from various points such as magnetic field, mechanical stress/strain, cryogenic, stability and protection. Magnetic analysis was carried out by the 2D symmetric FEM analysis. As the result, the magnetic field (B_z) was 1.5000 T at center and it had enough homogeneity. Mechanical stress analysis was also done by 2D symmetric FEM analysis and maximum of Von Mises stress was pretty low comparison with maximum tensile stress. In cryogenic section, amount of expected liquid refrigerant and its cooling time to be needed was calculated. Finally, in stability and protection section, its stability margin and Z-function were calculated.

This study was supported by the advisor and my research colleagues.

Superconducting proximity effect in InGaAs/InAs two-dimensional electron gas system

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A superconductor-semiconductor hybrid system with strong spin-orbit interaction provides a promising platform for realizing topological superconductivity. Here, we fabricated and studied the electrical transport properties of nano-hybrid Josephson junctions (JJs) made of a two-dimensional electron gas (2DEG) system formed by an InAs quantum well, cleanly interfaced with an epitaxial superconducting Al layer. JJs with a gap spacing of ~ 120 nm and a channel width of ~ 3.5 μm were fabricated by using electron-beam lithography and wet etching process. At T = 0.3 K, the critical current of the Josephson junctions was I_c = 100 nA, while the normal-state resistance Rn ranged from 50 to 150 Ω. Applied with a magnetic field perpendicular to the substrate, the 2DEG-based JJs exhibited a periodic Ic modulation, so-called Fraunhofer pattern. Temperature dependence of the differential conductance peaks, caused by multiple Andreev reflections, indicated that the superconducting gap energy of the epitaxial Al was about Δ_{Al} = 239 μeV. Our observations suggest that the hybrid JJs made of 2DEG with an epitaxial Al film would be a promising platform for exploring topological superconductivity and topological quantum information devices.

Construction of Dynamo Test System for Synchronous Motor with Superconducting Field Winding

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As a countermeasure against global warming, active research is being conducted around the world to replace internal combustion engines with electric motors for a reduction of greenhouse gases. Especially in the automobile field that electric motors are applied, the paradigm is rapidly changing. Accordingly, although many attempts have been made to increase the output power per unit weight of the electric motor, there has been a limit to increasing the output of the electric motor due to problems such as Joule heat in windings and demagnetization of permanent magnets that might induced from the large current density. On the other hand, the superconducting motor has essentially zero resistance, so large copper loss in conventional motors can be ignored. Accordingly, the current density can be greatly increased to increase the output power of the motor. Because the superconducting motor requires cryogenic environments, there are many limitations to its current practical application, but various studies are being conducted to overcome it. In this paper, as part of a preliminary study for the practical use of superconducting motors, a motor with superconducting field windings was developed and its feasibility was examined through experiments. A method of maintaining a cryogenic environment in chamber for superconducting rotor with liquid nitrogen is introduced, and the construction of a dynamo test facility for synchronous operation of the superconducting motor is described.

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Fabrication and characterization of Al-AlOx-Al Josephson junction and SQUID using shadow evaporation technique

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Aluminum-based Josephson junction (Al-AlOx-Al JJ), which is a nonlinear superconducting element, provides an essential building block for developing superconducting qubits and various quantum electronic devices. In this work, we fabricated Al-AlOx-Al JJs by using shadow evaporation technique, where a bilayer of copolymer and PMMA was used to form a Dolan bridge after the electron beam lithography. After completing the device fabrication, the lateral area and the normal-state resistance of the JJ turned out to be A = 400×450 nm^2 and Rn = 2.4 kΩ, respectively. At T = 0.3 K, the critical current of the JJ was obtained to be I_c = 10 nA and the superconducting gap energy of Al was ΔAl = 0.23 meV. The Al-AlOx-Al SQUID, which was fabricated with the same method, exhibited I_c = 115 nA at the base temperature. As we applied external magnetic field perpendicularly to the substrate, we observed a periodic modulation of Ic of the SQUID with a period of Bperiod = 85 μT, corresponding to a magnetic flux quantum of Φ0 = h/2e through the inner area of the SQUID, where h is the Planck constant and e is the elementary charge. Our observations indicate that the shadow evaporation technique would be very useful to develop superconducting quantum electronic devices for qubits and quantum sensors.

Ferromagnetic Spin Resonance Coupled with High-order Microwave-cavity Modes

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Junghyun Kim *(Agency for Defense Development)*,
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The ferromagnetic insulator Yttrium Iron Garnet (YIG) exhibits ferromagnetic spin resonances. The frequency of the spin resonance is in the microwave range and linearly depends on the external magnetic field. Therefore, the spin mode can be tuned to match with a cavity resonator in the microwave range. At cryogenic temperatures, a superconducting magnet provides a stable and homogeneous magnetic field, which enables precise control of spin resonances. We show that the spin mode of an YIG sphere can be tuned to couple with various high-order modes of a microwave cavity. Our results provide possibilities of utilizing multiple microwave modes in quantum technologies involving spin modes.

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Edgewise bending strain-induced critical current degradation in 12 mm wide REBCO coated conductor winding for coil application

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Utilization of the high-temperature superconducting (RE)$Ba_2Cu_3O_{7-x}$ (REBCO) coated conductor (CC) tapes into cables, coils, or magnets can have a complicated strain distribution due to their thin and rectangular structure. Cable or coil windings of these CC tapes are typically made through pancake and layer or solenoid methods. The combined bending, twisting, and axial tension stress through these windings are unavoidable to affect the current transport property of the CC tapes, especially, the strain-induced along the edgewise direction leading to coil performance degradation should be considered. Taking that into account, the behaviors of critical current (I_c) degradation and current distribution of GdBCO CC tapes wound at different winding pitches and former diameters are examined at 77 K and self-field. A tester, designed to wind the CC tapes with a continuous transition at the inner winding diameter, was used to linearly superimposed the strains induced in edgewise bending modes. For one turn winding, the tape moves axially by one tape width (or more) to form an S-shaped bend. Bending diameters, winding pitch between turns, etc., are analyzed considering their effect on the current distribution among the tape's different sections, both along the length and width of the tape. The necessary approach to effectively evaluate the I_c degradation behavior in REBCO coil winding through the allowable winding pitch while under bending was suggested to properly utilize the CC tapes to cables, coils, or magnets.

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Investigation of edge geometry effect on the bending behavior in REBCO CC lap- and butt-joints fabricated by ultrasonic welding

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In the fabrication of coils for superconducting magnets, joints between coated conductor (CC) tapes are necessary to compensate the tape length limits and to connect series of coil windings. Various techniques for joining CC tapes have been reported, including the ultrasonic welding (UW) which was firstly developed by ANU group. This method can create a solid-state joining between the overlapped parts by concentrating the frictional heat from ultrasonic vibration. Reports on the UW joining of CC tapes showed comparable joint characteristics with the mechanical-controlled solder joints. Several joint configurations such as lap, butt, inclined, and bridge-joints were produced by UW joint method which showed different joint resistances. Among these joint configurations, lap-joints exhibited the lowest joint resistance while the butt- and bridge-joints showed higher joint resistance due to the complexity in the current flow across the CC tapes. Under bending performance tests, these joints showed good bending tolerances at different bending diameters which satisfies the required minimum bending diameter of 100 mm for coil windings. However, the joint properties started to degrade at smaller bending diameters such as 30 mm and 40 mm due to some detachments at the edges of the joint part. In this study, the bending behavior of UW lap- and butt-joints were investigated. The end-edge geometry of UW and mechanical-controlled solder joints were examined to determine its effect on the detachment of the joint parts by bending tests. In the case of butt- and bridge-joints, different edge-to-edge distances (gaps) of the butt portion were made to evaluate its effect on the joint performance due to bending.

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Microhardness of electron-irradiated Cu/Nb-sheathed MgB_2 superconducting wires

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입자조사는 재료에 미세결함을 효과적으로 생성시키는 물리적인 방법이다. 입자조사에는 이온빔, 전자빔, 중성자(열 또는 고속 중성자), 감마선 등이 사용된다. 재료 내의 미세결함의 농도는 조사에 사용된 입자의 종류와 에너지에 따라 달라진다. 조사에 의해 생성된 결함(전위, 공공, 적층결함 등)들은 외부자기장을 속박하기 때문에 자기장 하에서의 초전도 재료의 임계전류가 증가한다. 본 연구에서는 Nb을 확산 억제층, Cu를 시스(Sheath)로 사용해서 인발공정, 열처리 공정으로 제작한 Cu/Nb sheathed MgB_2 초전도선에 대해 전자빔을 조사를 수행한 후, Cu, Nb, MgB_2에 대한 비커스 마이크로 경도실험을 수행하였다. MgB_2의 합성에는 Mg과 B 분말을 사용하였다. 경도는 다이아몬드 인덴터의 가압 후 재료 표면에 발생한 압흔의 크기를 측정해서 계산하였다. Cu와 Nb 층은 전자빔 조사에 의해 미세경도가 증가하였는데, 이로부터 전자빔 조사에 의해 재료 내부에 미세결함이 생성되었음을 간접적으로 추측할 수 있었다. 금속층과는 달리 MgB_2 초전도 층에서는 경도변화를 관찰할 수 없었다. 이는 MgB_2가 금속물질보다 경도가 높은 물질이기 때문에 조사로 인한 경도변화가 적은 것으로 사료된다.

정부(과학기술정보통신부)의 재원으로 한국연구재단의 지원을 받아 수행된 연구임 (NRF-2020M2D8A2047959).

Fabrication of Ta-Nb-Hf-Zr-Ti high-entropy alloy superconducting thin films by pulsed laser deposition

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Among the numerous materials, high entropy alloys (HEAs) are a new class of materials that have attracted considerable interest in materials science, engineering, and condensed matter physics, because their potentially desirable electric, magnetic, and mechanical properties under extreme conditions, such as low/high temperature, high pressure, strong disorder, and so on [1]. The multicomponent HEAs are usually formed by mixing five or more elements, and crystallized in body-centered cubic (BCC) or face-centered cubic (FCC) structures [2]. The Ta-Nb-Hf-Zr-Ti system among various HEAs is known to have superconductivity [3]. Here, we report the fabrication of high-quality Ta-Nb-Hf-Zr-Ti high-entropy alloy superconducting (SC) thin films by using

pulsed laser deposition (PLD) technique with various substrate temperatures (T_s) from 270 to 620 ℃. The film deposited at T_s = 520 ℃ showed the highest superconducting critical temperature (T_c) of 7.2 K and critical current density (J_c) of ~ 10^6 A/cm^2 at 4.2 K. In this presentation, we will discuss the fabrication method and superconducting critical properties, such as T_c, J_c, and upper critical field (H_{c2}), of HEA SC thin films.

Keywords: Ta-Nb-Hf-Zr-Ti, high-entropy alloy superconductor, thin films, pulsed laser deposition

Reference

[1] M. H. Tsai, J. W. Yeh, Mater. Res. Lett., 2, 107-123 (2014).
[2] J. W. Yeh, S. K. Chen, S. j. Lin, J. Y. Gan, T. S. Chin, T. T. Shun, C. H. Tsau, and S. Y. Chang, Adv. Eng. Mater., 6, 299 (2004).
[3] P. Kozelj, S. Vrtnik, A. Jelen, S. Jazbec, Z. Jaglicic. S. Maiti, M. Feuerbacher, W. Steurer, J. Dolinsek, Phys. Rev. Lett. 113, 107001 (2014).

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A Study on the Mechanical property of 3D Printing Composites in Cryogenic Environment

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3D printing technology is steadily developing so that it can be applied to high value-added industries such as machinery, automobiles, and aerospace. The development of 3D printing technology enabled product printing using composites that include polymer-based external structures and reinforcements such as carbon, glass fibers and kevlar. The cryogenics components include tanks and supports that store cryogenic fluids such as liquid nitrogen and hydrogen. These components require sufficient mechanical rigidity in cryogenic environments with low thermal conductivity and lightening. 3D printing enable to complex output of features, which makes it easier to optimize part design. however, research on mechanical properties of 3D printing composite in cryogenic environments must be preceded because 3d printing composites are not verified properties in cryogenic. In this paper, we selected an FDM method 3D printer capable of printing composite materials and printed the specimen, and experimentally evaluated by constructing a test device capable of tensile strength testing in a room temperature and 77 K. The applied specimen was printed using high-strength reinforcement such as carbon fiber and glass fiber to increase structural strength and exterior walls of polymer materials. The printed specimen was measured and characterized in a cryogenic environment using a tensile tester.

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Effect of Electron Beam Irradiation on the Critical Current Density of MgB_2 Superconductor

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중성자, 양성자, 전자, 이온 조사 등을 통해 초전도 내부에 결함을 생성시키면 자기장하에서의 임계전류 특성을 향상시킬 수 있는데 이는 방사선 입자가 초전도체에 조사되면 자속 고정점(magnetic flux pinning center)으로 작용하는 미세결함이 균일하게 생성되어 고 자기장하에서 초전도 임계전류를 향상시킬 수 있게 된다. 이들 방사선 입자 중 전자는 방사화 문제가 전혀 없고 대용량이 가능하다는 장점이 있어 임계전류를 향상시키려는 상용화 목적에 적합하다. 본 연구에서는 전자선을 이용하여 MgB_2 초전도체 (선재, 벌크)에 조사시켜 임계전류 특성의 변화를 알아보았다. 사용된 전자선 에너지는 1 또는 2.5 MeV (@ 5 mA)였으며 조사량은 1E15 - 5E17 e/cm^{2}으로 변화시켰다. MgB_2 선재에 대해 2.5 MeV 에너지 하 조사량이 증가할수록 모든 자기장 영역에서 임계전류밀도가 증가하는 경향성을 보였다. 조사량 5E17 e/cm^2, 자기장 2 T에서 MPMS 임계전류밀도 변화는 4.2, 20 K에서 각각 108.8에서 156.5 kA/cm^2, 14.9에서 20.9 kA/cm^{2}로 두 측정온도 모두에서 증가하였다. 또한 조사량이 증가할수록 자속 꽂음 힘 밀도 값(Fp, flux pinning force density)이 증가하는 것을 볼 수 있었다. 즉, 최대 Fp,max는 4.2와 20 K에서 각각 2.66에서 3.75 GN/m^3, 0.86에서 1.23 GN/m^{3}으로 증가하였다. 이는 전자선 조사에 의해 MgB_2에 조사결함이 형성되고, 이로부터 MgB_2 내부에 있는 볼텍스의 움직임을 막아 임계전류밀도가 증가된다는 것을 보여준다. 조사량이 증가할수록 자속 꽂음 힘 밀도의 최대값이 증가하고, 동시에 임계전류밀도 값이 증가하는 것이 보였다. 이러한 결과는 전자선 조사로부터 생성된 조사결함이 MgB_2 초전도체의 임계전류밀도를 향상시킬 수 있는 자속고정점으로 작용할 수 있음을 보여준다.

정부(과학기술정보통신부)의 재원으로 한국연구재단의 지원을 받아 수행된 연구입니다 (NRF-2020M2D8A2047959). 방사선 조사용 MgB_2 선재 제조와 임계특성 측정은 각각 공동연구기관인 (주)삼동과 성균관대학교에서 수행해 주셨습니다.

Progress on the Superconducting Joint Technique for the Reacted Multifilament MgB_2 Wires for MRI Magnet Development

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최근 몇 년 동안, MgB_2는 39 K의 높은 임계 온도로 인하여 액체 헬륨을 사용하지 않고도 초전도 자석을 작동시킬 수 있어서 자기 공명 영상(MRI) 자석 개발의 유망한 후보로 부상하고 있다. 영구전류모드 적용을 통해 높은 해상도 수준의 자기장을 갖는 MRI 시스템을 개발하기 위해 초전도 접합기술 개발에 대한 연구가 지속적으로 이뤄지고 있다. 본 연구기관에서는 지난 몇 년간 MgB_2 선재를 이용한 MgB_2 초전도 접합기법을 개발하여 영구전류모드 운전이 가능한 MgB_2 MRI 자석 개발 가능성을 보여주었다. 이에 더하여, reacted MgB_2 조인트의 접합부 또는 선재에서 quench가 발생하였을 때, 반응된 monofilament MgB_2 선재와 부분 가열한 조인트를 이용하여 초전도 특성을 재현할 수 있다는 것을 확인하였다. 이를 토대로 본 연구에서는 반응된 multifilament MgB_2 선재에 대한 초전도 접합기법을 분석하였다. 접합 과정에서 조인트의 부분가열을 가능하게 하기 위해 실험실에서 개조한 furnace가 사용되었다. 제작된 조인트의 초전도 특성은 열처리 온도와 시간을 변수로 두어 V-I 특성을 기반으로 평가하였다.

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Magnetization loss characteristics according to the arrangement of 2G HTS wires

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대전류용 초전도 도체를 전력기기에 사용하기 위해서는 여러 가닥의 고온초전도 선재를 병렬로 연결하여 사용하게 된다. 교류 전력기기를 위해 사용되는 초전도 도체는 도체에 인가되는 교류 자기장에 의한 자화손실이 교류손실의 주된 원인으로 작용하므로 대전류용 도체에 대한 초전도 선재의 다양한 배열 방법에 따른 자화손실 특성을 분석하여야 한다. 고온초전도 선재는 외부에서 가해지는 자기장에 대해 차폐효과와 침투효과를 가지고 있다. 선재를 여러 층으로 배열하면 선재가 중첩되는 정도에 따라 각 선재에서 자기장이 침투하는 영역이 달라지므로 자기장에 의해 발생하는 자화손실이 변하게 된다. 본 연구에서는 여러 가닥의 2세대 고온초전도 선재를 배열할 때 선재 사이의 간격과 중첩의 정도를 다르게 하여 샘플들을 제작하고, 각 샘플에 인가되는 외부 자기장을 변화시키며 자화손실을 측정하였다. 측정 결과 분석을 통하여 대전류용 도체에서 자화손실을 최소로 할 수 있는 선재들의 배열 방식을 검토하였다.

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Design of a 200 MHz LTS NMR Magnet

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Nuclear magnetic resonance (NMR) is a phenomenon in which atomic nuclei placed in a magnetic field resonate with electromagnetic waves of a specific frequency. This paper describes the design of 200 MHz LTS NMR magnet. The conductor selected for the NMR magnet design is Supercons NbTi MR24 wire. The central magnetic field required for a 200 MHz NMR magnet is 4.7 T, and the designed magnet meets this requirement. To improve the homogeneity of the magnetic field, harmonic analysis was performed and a correction coil were applied. Stress analysis was performed under the condition that Lorentz force was applied, and it was confirmed that the magnet operates within 95 % retention stress and strain. The magnet is cooled with LN2 from 300 K to 77 K and cooled with LHe from 77 K to 4.2 K. The amount of refrigerant was divided into perfect mode and dump mode and calculated respectively. Lastly, critical current, enthalpy margin and time to reach full quench are dealt with through stability and protection analysis.

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Ramp-rate Dependent Charging Behaviors No-insulation REBCO Coils

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Understanding the charging behaviors of no-insulation (NI) REBCO coils is important for operations of NI REBCO coils because the heat generated by AC losses often puts difficulties on successful operations. For commercial large-scale systems, such as magnetic resonance imaging (MRI) magnets, fast charging speeds are desirable for on-site employments. As NI REBCO coils exhibit turn-to-turn leakage current losses as well as magnetization losses, ramp-rate during charging the coils would affect them simultaneously. In this paper, we use a combined model of turn-distributed circuit model of NI coils and finite element method (FEM) based index value model and simulate charging behaviors of NI REBCO coils. Then we investigate the ramp-rate dependency of the charging behaviors using the simulated results.

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A Design Study on HTS Synchronous Motor with Halbach Array Field Winding

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With regard to conventional permanent magnet motors, studies are being actively conducted to improve the torque of the motor by changing the magnetization direction of the permanent magnet and applying the so-called Halbach array. On the other hand, since there are few such studies in high temperature superconducting (HTS) motor, this paper presents a novel design topology of HTS motor with Halbach array field winding. Halbach array field winding was applied to improve the fundamental component of the air gap flux density, which is related to the average torque of the motor. The finite element method (FEM) was used to obtain an optimal design of the HTS motor. To implement an electromagnetic design, design variables are set to characterize the geometry of the Halbach array HTS racetrack coil. In order to maximize the motor performance, not only the design variables of the conventional racetrack coil such as the number of stacks and turns but also the arrangement angle of the Halbach array coil were included as design variables. For a detailed performance comparison with conventional HTS field winding motor, the following key motor characteristics are calculated through FEM simulation: (1) minimum critical current; (2) total HTS consumption; (3) airgap flux density; and (4) power density.

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Study on principal stresses of single pancake HTS coil with concatenated-turn assumption

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Screening current induced stress (SCS) has emerged as an important issue for high temperature superconductor (HTS) magnet technology. In general, the stress on the HTS magnet is caused by electromagnetic force, thermal expansion, bending, and winding tension. Although the winding tension applied at the winding phase is considered to be important, an analysis of the winding stress of the coil depends on “separated-turn” assumption in which each turn of the coil is assumed to be a single turn. For the precise analysis of winding stress, a mechanical analysis method based on “concatenated-turn” assumption is proposed in this study. Since the HTS magnet has been commonly fabricated in the form of a pancake coil, we assume the single pancake HTS coil, which can be parameterized with a spiral curve. The generalized Hooke’s law for a coil following a spiral curve was computed to figure out the analytic solution. Then, the analytic solution was compared with the finite element method (FEM) simulation results.

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Investigation on Defect-Irrelevant Behaviors of NI HTS Coil Containing Multiple Defects

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Previously, the “B model”, which is our new equivalent circuit model for no-insulation (NI) high temperature superconductor (HTS) coil containing a defect, was reported for fast and accurate simulation of defect-irrelevant behaviors of NI HTS coil. The B model can describe the defect-irrelevant behaviors accurately using only five segments of the defect-existing turn in an NI HTS coil, while several segments per turn are required for the conventional circuit models. The next step of our previous study is upgrading the B model for the simulation when NI HTS coil has multiple defect. Also, the equivalent circuit for the case when the defect locates near end of the coil is also needed. The upgraded model will be verified with the comparison of simulation results between our model and the conventional distributed model.

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Effect of Various Fillers in Grease on Thermal-Quench Behavior of GdBCO Coils

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최근, 본 연구기관에서는 grease materials를 turn-to-turn 절연체로 사용하여 no-insulation (NI) 코일에서 나타나는 충/방전시 발생하는 지연을 개선하는 새로운 권선 기술을 제안하였으며. 이를 통해 충/방전 지연 없이 열/전기적 안정성이 뛰어난 코일 확보 가능 성을 증명하였다. 그러나 GdBCO coated conductor (CC) tape에 비해 절연체로 사용되는 grease material의 저항이 상단히 크기 때문에 turn-to-turn 저항이 높아 코일 층 사이를 우회하는 전류가 소량 발생하게 된다. 따라서 grease material에 열/전기 전도성 충전재를 추가하는 것이 grease 특성을 개선하는 효과적인 방법이 될 수 있다. 본 연구에서는 지엽적인 hot spot에 의해 유도된 줄(Joule) 열 에너지와 관련하여 BN, CNT, Ag와 같은 다양한 충전재를 포함하는 grease 복합제를 절연물질로 사용한 GdBCO 코일의 quench 및 recovery 특성을 조사하였다. 또한 열 안정성이 매우 높은 GdBCO 코일의 개발을 위한 제안된 권선 기법의 타당성에 대해 상세히 논의할 것이다.

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A Study on Thermal and Electrical Properties of GdBCO Magnets depending on Various Fillers in Epoxy Composites

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일반적으로 초전도 모터 및 발전기의 계자코일은 회전 시 발생하는 기계적 스트레스로부터 코일을 보호하기 위해 에폭시 함침이 필수적이다. 최근 몇 년간 최적의 에폭시 함침 방법을 찾기 위해 다양한 연구가 진행되어왔으며, vacuum pressure impregnation (VPI) 방법으로 함침된 코일의 열/전기적 특성이 우수하다고 밝혀진 바 있다. 그러나 에폭시 함침은 선재와의 열 수축 차이 또는 선재의 열전도율 저하를 초래할 수 있기 때문에 적절한 에폭시 재료의 선정 또한 매우 중요한 요소이다. 이러한 단점을 보완하기 위해 최근 들어 에폭시에 다양한 filler를 첨가하여 에폭시의 낮은 열전도도를 보완하고자 하는 연구가 활발히 진행되고 있다. 본 연구에서는 열전도도가 높고 기계적 안정성이 높은 CNT, BN, silver를 에폭시의 filler로 첨가하였다. 상기 방식으로 제작된 epoxy composites를 사용하여 VPI 방법으로 GdBCO 코일을 제작한 후 cool-down test, quench test, 그리고 over-current test를 진행하여 코일의 열/전기적 특성을 평가하였다.

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Test of a persistent current switch for joint-less HTS magnet with a conduction cooling system

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냉각효율이 매우 높아진 GM 냉동기와 같은 냉각장치를 직접 초전도 코일에 열적으로 접합하여 전도냉각 기법을 사용하는 마그넷에 대한 연구는 최근 국내외에서 활발히 진행중이다. 특히 고온초전도 선재를 사용하는 경우 이러한 전도냉각 기술은 매우 유용하지만, 전도냉각 상태에서는 고온초전도의 높은 임계온도 이상의 온도를 확보하면서 주변에 영향을 적게 미치는 시스템을 설계하기가 어려워 전도냉각 영구전류전원장치는 개발되어 있지 않은 상태이다. 본 논문에서는 전도냉각 기술을 사용하여 20 K 이하의 운전온도에서 영구전류스위치에 대한 열해석과 특성연구를 진행하였다. 더블 팬케이크 형태의 고온초전도 영구전류스위치를 설계 및 제작하고, 전도냉각 시스템 안에서 히터전류를 인가하여 제작한 영구전류스위치의 저항 및 온도변화를 측정하는 시험을 진행하였고, 극저온 환경에서 스위칭이 가능한 영구전류스위치 및 무접합 고온초전도 마그넷에 적합한 운전방식에 대한 연구를 진행하였다.

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Development of compact type cryogenic blower for circulation of helium gas at 20 to 30 K

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Cryogenic blowers currently used mainly to transfer gas fluids with a flow rate of about 10 to 100 g/s in a temperature range of about 30 to 40 K. However, recent researches on some applications related to liquid hydrogen have led to the need for cryogenic blowers with lower temperature ranges and lower flow rates. In particular, it is more difficult for a cryogenic blower driven in the liquid hydrogen temperature range to secure dynamic stability from natural frequency while minimizing heat penetration to less than 10 W. This paper describes the design of an blower impeller with a diameter of 35 mm. The operating conditions were 20 K and 5 bar for gas helium. The design points are determined as mass flow rate of 3 g/s and a differential pressure head of 41 m at a rotational speed of 15,000 RPM considering a specific application, which include helium gas circulation to cool a HTS magnet. When the blower is not in operation, about 5 W of static heat penetration is estimated. The designed blower was fabricated and the performance is evaluated using a cryogenic blower test device. This blower was fabricated for gaseous helium or hydrogen, and it is expected that it will be used as basic data for superconducting motor cooling system that uses hydrogen as refrigerant in the future.

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Performance evaluation of 80 GHz FMCW Radar for level measurement of cryogenic fluid

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Recently, as the need for research on liquid hydrogen storage and transfer tank has increased, there is a demand for precise measurement of the filling and residual liquid hydrogen inside the tank. The FMCW(Frequency Modulation Continuous Wave) Radar can measure distance information from continuously transmitting and receiving signals by modulating the frequency according to time. In addition, it is possible to measure the level of the liquid using the FMCW radar, in this study, an 80 GHz FMCW Radar is introduced to measure the cryogenic fluid level. The beat frequency, which is the frequency difference between the continuously transmitted signal and the received signal reflected from the target, is proportional to the distance to the target, and among various pieces of information flowing into the antenna and it is converted into distance information through the FFT processing. Additionally, the distance resolution of the FMCW radar can be improved by using zoom FFT, which is a specific frequency band extension technique, and a design distance resolution of less than 5 mm is obtained. Since the cryogenic fluid generates a low reflected signal due to the low intrinsic impedance difference between the media, it is difficult to measure the level of the cryogenic fluid with the radar using an algorithm that extracts distance information based on the maximum signal gain. Therefore, an algorithm for extracting the interface of liquid nitrogen among multiple targets through multi-target detection was designed and applied to Radar. In this study, the zoom FFT method and multi-target detection algorithm are applied to measure the level of cryogenic fluid with low impedance difference. And the radar performance is evaluated for various media. In particular, the possibility of measuring the level for liquid hydrogen was reviewed by analyzing the measurement characteristics of the radar for liquid nitrogen.

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Preliminary Design of Thermal Switch for Partial-Load Operation of SFCL Cryogenic System with 4 GM Coolers

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The feasibility of gas-gap thermal switch is investigated for application to a commercial product of medium-voltage (23 kV 2 kA) superconducting fault current limiter (SFCL). The SFCL system under development by KEPCO Open R&D Program employs four units of GM cryocoolers with inverter compressors. The refrigeration capacity of GM coolers can be controlled by the inverter frequency in a range between 40 Hz and 75 Hz. A full cooling power with the maximum frequency is required for the rated test at 2 kA. Under normal operational conditions, however, the cooling load is far smaller than the full power, and the cooling power should be reduced by low inverter frequency, and even by heaters if the load is smaller than the cooling at the minimum frequency. In order to achieve more efficient partial-load operation, a gas-gap thermal switch is proposed to thermally disconnect the cold-head in preparation for the complete shut-off of one or two GM coolers. A preliminary design is presented for the geometric structure of a gas-gap type switch and the operational scheme of an active control. Rigorous heat transfer analysis is carried out to estimate the thermal switching performance with gas-filled gap (on) or with evacuated gap (off). Based on the performance model, the overall economic merit is examined by taking into account the operational cost (electrical power) and the maintenance cost (scheduled periodical service).

Keywords : gas-gap, thermal switch, partial-load operation, GM cryocooler, SFCL

Cascade Joule-Thomson Cycles of Pure Refrigerants for Hydrogen Liquefaction

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Thermodynamic study is performed for hydrogen liquefaction process based on cascade Joule-Thomson (JT) cycles of pure refrigerants without cryogenic turbo-expander. Cryogenic turbo-expander is a key component of the hydrogen liquefaction systems (based on Claude or Brayton cycle) under operation or under development. Being produced only by a few leading manufacturers, efficient and reliable cryogenic expanders are the main obstacle to meeting the recent need of various hydrogen liquefiers with a reasonable period of development time and at a reasonable cost. The objective of this study is to investigate the cascade JT cycles that do not require the expanders, taking advantage of high reliability (with no cold moving parts) and easy scale-up or scale-down of thermodynamic systems. Staring from the classical cascade system, a various combinations of JT cycles with pure refrigerants (including neon, nitrogen, different hydrocarbons, and common refrigerants) are investigated to estimate the figure of merit (FOM) of liquefaction. For multi-staged JT cycles, the pressure levels are optimized with a commercial process simulator (Aspen HYSYS) and real properties of working fluids (NIST REFPROP). It is rigorously shown that the cascade JT cycles could achieve a fairly high efficiency, if the irreversibility near the cold end is reduced. The detailed operating conditions and corresponding temperature-entropy (T-s) diagrams are presented for the suggested cascade JT cycles in terms of system complexity and thermodynamic efficiency.

Keywords : hydrogen liquefaction, JT valve, cascade cycle, pure refrigerant

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Thermodynamic Optimization of LNG Pre-cooled Dual-Pressure Claude Cycle for 5 T/day Hydrogen Liquefaction

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Thermodynamic optimization is performed on dual-pressure Claude cycle with LNG pre-cooling, aiming at the efficient hydrogen liquefaction process with a capacity of 5 T/day. Most of the medium-size (5~10 T/day) commercial hydrogen liquefiers are based on standard Claude cycle with liquid-nitrogen (LN2) pre-cooling, but a modified Claude cycle is proposed in this study to utilize the dissipated cold energy of LNG. Since the LNG pre-cooled cycle requires a higher pressure than the LN2 pre-cooled cycle, the dual-pressure cycle has potential advantages over the standard cycle in reducing the pressure ratio of cryogenic turbo-expander. Rigorous thermodynamic cycle analysis is conducted for the hydrogen liquefaction process based on dual-pressure Claude cycles with LNG pre-cooling stage. The real thermodynamic properties of hydrogen and LNG are incorporated into a process simulator (Aspen HYSYS) to calculate the thermodynamic efficiency of liquefaction. The optimal conditions for pressure level and expander flow rate are found to minimize the required work per unit mass of liquid. Full details of optimized cycle are presented and discussed with temperature-entropy diagram and the temperature profile in heat exchangers.

Keywords : hydrogen liquefaction, dual-pressure, Claude cycle, LNG pre-cooling, thermodynamics

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Investigations on Equation of State for Calculating Thermodynamic Properties of Hydrogen-Neon Mixture

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A simple Joule-Thomson (J-T) refrigerator using hydrogen-neon mixed refrigerant (MR) is one of the methods for liquefying hydrogen with simple configuration. In the design stage of the MR J-T refrigerator, a proper equation of state (EOS) for calculating thermodynamic properties of the MR should be selected to obtain realistic calculation. This study utilizes the Soave-Redlich-Kwong EOS with Twu alpha function, which is provided by Aspen HYSYS, to compute the mixture properties. The calculated properties of pure hydrogen under the default settings in Aspen HYSYS, however, show significant difference from the actual properties of hydrogen. To improve the reliability of calculation, we adjust the parameters for calculating the enthalpy of hydrogen in the Soave-Redlich-Kwong EOS. Furthermore, we find the binary interaction coefficient for hydrogen-neon mixture, which is to be verified by comparing the vapor-liquid equilibrium between the experimental data and the calculated data of hydrogen-neon mixture.

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Design of a heat exchanger for a helium-liquid hydrogen indirect cooling system

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This paper deals with the design of a heat exchanger for a helium-liquid hydrogen indirect cooling system. The helium-liquid hydrogen indirect cooling system consists of a hydrogen liquefaction system, a helium-liquid hydrogen heat exchanger and a 2G high temperature superconducting (HTS) coil. The heat exchanger is located in the inner tank of a hydrogen cooling system filled with a liquid hydrogen, and a gaseous helium exchanges heat through the contact surface of a copper tube cooled with the liquid hydrogen. The helium-liquid hydrogen heat exchanger was designed based on the outlet temperature of the hydrogen liquefaction system and the heat load of the HTS coil, and verified through a 3D finite element method program. As a result, the temperature of the HTS coil was maintained at the targeted 30 K. These results can be effectively used to design cooling systems with liquid hydrogen.

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