PL1

Retention of high-pressure-induced superconducting and non-superconducting phases in high-temperature superconductors at ambient

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The search for high-temperature superconductivity (HTS) in hydrogen and hydrogen-rich compounds under high pressure has a long history. Recently, several reports (1-4) of high T_c up to 288 K in hydrides under pressure of up to 267 GPa have appeared. The ultrahigh pressure needed to create the HTS in hydrides has hampered the detailed study of the phenomenon, as well as any applications. To lower the required pressure, even to zero, we have developed a pressure-quench process (PQP) and have demonstrated it successfully in stabilizing at ambient the high-pressure-induced HTS phase and other phases in FeSe and Cu-doped FeSe (5). It is not inconceivable that the PQP may be adapted for hydrides with T_c approaching room temperature. The results will be presented, and both the opportunities and challenges will be discussed.

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PL2

Intertwined orders in iron-based superconductors: the role of topology and lattice defects

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The iron-based superconductors display rich phase diagrams featuring various types of electronic order, such as antiferromagnetism, electronic nematicity, and superconductivity. The proximity between the antiferromagnetic and superconducting instabilities has motivated the idea that magnetic correlations promote the pairing interaction, although the precise mechanism remains under debate. Importantly, different antiferromagnetic ground states are realized, from the widely observed stripe spin density-wave phase to the more recently discovered spin-vortex crystal and charge-spin density-wave phases. Interestingly, each of these magnetic ground states is intertwined with a different type of composite order – nematic order, spin-current order, and checkerboard charge order, respectively – which can onset even before the emergence of long-range magnetic order as vestigial phases. In this talk, we will discuss unique effects that arise from the interplay of these intertwined orders with lattice disorder and topological phenomena. In the first part, we will present our results for the impact of lattice disorder on the intertwined stripe antiferromagnetic and nematic orders. In particular, we will show that lattice defects that are ubiquitously present in the surface of a crystal stabilize a novel electronic smectic phase. We will also demonstrate that random strain created by lattice defects in the bulk of the crystal generates new correlations between the magnetic degrees of freedom, which are not captured by the usual random-field Ising-model physics. In the second part, we will discuss how the vestigial phase of the spin-vortex crystal can host topological Weyl points in the presence of an externally applied magnetic field, due to its breaking of the inversion symmetry with respect to the Fe plane. Finally, we will discuss possible experimental manifestations of the phenomena presented in this talk in different iron-based compounds, such as $BaFe_2As_2$, FeSe and $CaKFe_4As_4$.

PL3

R&D Studies for High Field Cryogen-Free Superconducting Magnets at HFLSM

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We have been developed cryogen-free superconducting magnets (CSMs) at High Field Laboratory for Superconducting Materials (HFLSM), Institute for Materials Research, Tohoku University since 1992 [1]. In particular, high temperature superconducting tapes such as Bi2223 and REBCO are adopted for the CSMs beyond 18 T. In 2015, the 25T-CSM was successfully developed [2] and is open for users with many high field CSMs at HFLSM. For high field superconducting magnets, the REBCO tape is a strong candidate, although the Bi2223 tapes are used for our 20T-CSM and 25T-CSM. To develop our high field CSMs beyond 30 T, we have performed many R&D studies with REBCO tapes. A key issue of REBCO high field superconducting magnets is to develop the robust coil against a local degradation under large electromagnetic stresses and its protection. We propose a two REBCO bundle tape winding with insulation and confirmed that more than 90% of coil critical current could be applied in the REBCO coil with a damage [3]. In addition, an improvement of mechanical stiffness is obtained in the impregnated REBCO pancake coil with thin FRP plates glued on its top and bottom, i.e., "edge impregnation" [4, 5]. In the edge impregnation with a thin FRP plate, the stress distribution is optimized and then the maximum stress can be reduced by about 10-20% [5]. Therefore, the robust coil structure consisting of two bundle winding and edge impregnation is useful for a 33T-CSM, which is a recently approved project [6, 7]. From those R&D study, we found the polyimide for insulation is not adequate from the mechanical point of view. To remove the polyimide in the coil, the REBCO coil insulated and reinforced by a MgO coated Hastelloy tape was made and tested under an electromagnetic stress [8]. Good insulation and mechanical stiffness performance could be confirmed in the REBCO coil with the MgO/Hastelloy tapes. The strategy based on REBCO tapes for high field cryogen-free superconducting magnet developments will be introduced with our future plan.

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PL4

Superconducting materials for high field applications

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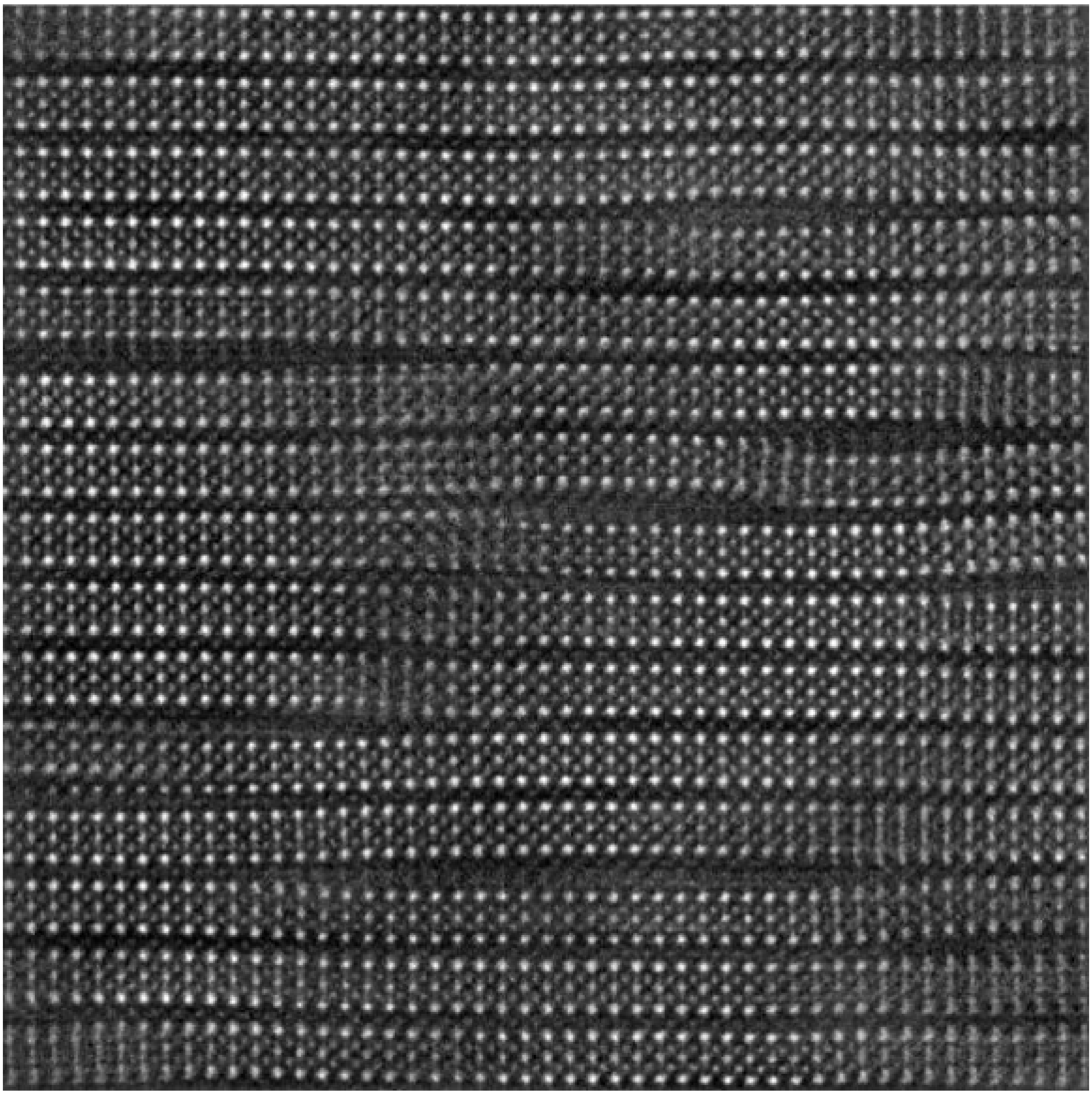
The potential for using superconducting materials to generate high magnetic fields was realised by Kamerlingh Onnes very soon after his initial discovery of superconductivity in mercury in 1911. However, disappointment shortly followed as superconductivity in the early elemental superconductors was found to be completely destroyed in relatively low magnetic fields. It was not until the early 1960s that Kunzler and colleagues at Bell Laboratories discovered that a type II alloy superconductor, Nb_3Sn, could sustain a superconducting current density over 1000 A mm^{-2} in a magnetic field of 8.8 T, paving the way for practical superconducting high field magnets. Nowadays, superconducting magnets have found widespread applications, from the magnetic resonant imaging machines found in hospitals all over the world to the magnets that bend the proton beams in the Large Hadron Collider at CERN. However, there is a constant drive towards generating higher and higher magnetic fields for research magnets, nuclear magnetic resonance (NMR) instruments, particle accelerators and fusion applications that will require the shift to using high temperature superconductors.

In this plenary lecture, I will introduce the key materials developments that have led to the manufacture of technological superconducting wires and tapes for high field magnets, as well as exploring what developments are needed to meet future high field magnet requirements. In particular, I will focus on some of the materials challenges to deploying high temperature superconductors in practical applications, including radiation damage in fusion magnets and persistent jointing for NMR.

Figure caption: Structural damage in REBCO coated conductor as a result of irradiation with O^{2+} ions. High angle annular dark field (HAADF) image taken by Dr Mohsen Danaie using the JEOL ARM300CF scanning transmission electron microscope at the ePSIC facility, Harwell Science and Innovation Campus, UK.

Keywords: High temperature superconductor, wires and tapes, high field magnets, fusion



PL5

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Ferromagnetic π-phase-shifted Josephson junctions (π-junctions) give a deep impact on superconductor circuits. The key elements are three types of p-junction-based SQUIDs, which produce novel functionalities in superconductor circuits.

It is well-known that the modulation pattern of the critical current to external magnetic flux F_{ex} is shifted by a half flux quantum (HFQ, $F_0/2$) in a 0-π SQUID compared to that in a 0-0 SQUID (DC-SQUID). Here, a 0-π SQUID is made up of a conventional Josephson junction (0-junction) and a π-junction. The most important effect is that a circulating current is induced in a 0-π SQUID spontaneously. The current makes the phase difference of either 0- or π-junction close to the critical point. In other words, it is considered that some bias current is fed to the 0-π SQUID. Though the HFQ circuit is constructed by replacing 0-junctions in the rapid single flux quantum (RSFQ) circuit with 0-π SQUIDs, the static energy consumption is reduced drastically owing to the effect as well as the reduction in the dynamic energy consumption.

Both the second and third π-junction-based SQUID are related to a single π-junction-SQUID (π-SQUID). The difference between the two appears in the characteristics between the internal flux F_{in} and F_{ex}; hysteretic and nonhysteretic characteristics can be seen in the second one referred to as a hysteretic π-SQUID and the third one as a nonhysteretic π-SQUID, respectively.

Hysteretic π-SQUIDs have two stable states corresponding to $\pm F_0/2$ without any external stimulus. The barrier height in energy potentials between the two stable states can be controlled in a range from 10^{-21} to 10^{-19} J by changing the critical current of a p-junction and the loop inductance L. This enables us to build a bias-current-free and an impulse-driven storage cells in a matrix memory. This memory can operate up to 20 GHz, which is 10 times higher than the matrix memories studied so far.

Nonhysteretic π-SQUIDs show the relationship $F_{in}>F_{ex}$ near the origin of the F_{in}-F_{ex} characteristics, creating an increase self-inductance or an increased permeability. This new effect can produce increased mutual couplings or compactness of the RSFQ/HFQ circuit.

We have developed the fabrication process for π-junction-based integrated circuits. The p-junctions have a sandwich structure of Nb/PdNi/Nb or Nb/AlO_x/PdNi/Nb with controlled thickness of the PdNi layer to show π-phase shifts. The critical current of Nb/PdNi/Nb junctions and that of the Nb/AlO_x/PdNi/Nb can be set over 20 kA/cm^2 and around several 10s A/cm^2, respectively. The Nb/PdNi/Nb junctions work as a p-phase shifter in actual circuits. Our π-junctions can also be made on the 0-junction-based circuits prepared with the standard process 2 (STP2) of the CRAVITY-AIST, which increases the integration level of the HFQ or related circuits mentioned above.

Based on the π-junction-process combined with the STP2, we have demonstrated essential elements of the HFQ circuits. The bias current supplied to the circuit, that is, the static energy consumption is reduced remarkably, which is a special feature of the HFQ circuit. We have also demonstrated the several primitives of impulse-driven memories, that is, a bias-current-free storage cell driven only by impulses, a serial array of memory cells, etc. Regarding the increased self-inductances of nonhysteretic π-SQUIDs, we confirmed the effect in a DC SQUID in which a part of the loop inductance is replaced with nonhysteretic π-SQUIDs.

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PL6

Superconducting aerospace propulsion: collaborating to raise the technology readiness level

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New Zealand has long been recognised as a global leader in renewable energy integration and holding deep expertise in commercial application of superconducting technology. The New Zealand government has put in place a strategy that mirrors this; to be net carbon-zero by 2050 and invested in cooperative technology development programmes that will accelerate international development.

Transportation is the largest source of non-agricultural greenhouse gas emissions from the country – domestic aviation accounts for 10% of our emissions and long-haul travel maybe more. We depend on aviation, our exports depend on shipping, and our internal freight relies on trucks. We will use electrical energy to reduce our carbon footprint. The good news is that New Zealand is unique in its electricity production – over 80% of our electrical energy is generated from renewable sources, and we have plenty of scope to increase it to 100% using wind, solar, and geothermal.

Electrification of aviation propulsion has the highest potential of drastically reducing emissions in New Zealand. Our domestic (Sounds Air) and international (Air New Zealand) are both committed to passenger electric flight introduction.The NZ government are supporting this and making the regulatory framework available to act as an international test-bed.
The real challenge is for larger transport aircraft with more than 100 seats; conventional technology cannot provide the power-to-weight required to electrify at this scale. Superconducting, and cryogenic, machines may provide a solution: they are small and light, relative to their power output. New Zealand has been working on superconductors since the 1980s and researchers in this field have recently teamed up with NZ’s leading researchers in power electronics and cryogenics systems, and formed strategic international research partnerships.

We will present an overview of the multidisciplinary research in this NZ national programme towards electric flight realization. We will examine the technology integration within superconducting machines for aircraft using novel technology such as flux pump exciters, low ac-loss windings, wide bandgap electronics and integrated cryogenic systems. We will present an overview of the technology development, implications and how this research is globally relevant.

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