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PROGRESS OF TRIUMF β-SRF FACILITY FOR NOVEL SRF MATERIALS

E. Thoeng*, Physics Department, University of British Columbia, Vancouver, BC, Canada
also at TRIUMF, Vancouver, BC, Canada
T. Junginger, Physics Department, University of Victoria, Victoria, BC, Canada
P. Kolb, B. Matheson, G. Morris, N. Muller, S. Saminathan, R. Baartman, R.E. Laxdal,
TRIUMF, Vancouver, BC, Canada

Abstract

SRF cavities made with bulk Nb have been the backbone of high-power modern linear accelerators. Demands for higher energy and more efficient linear accelerators, however, have strained the capabilities of bulk Nb close to its fundamental limit. Several routes have been proposed using thin film novel superconductors (e.g. Nb_3Sn), SIS multilayer, and N-doping. Beta-NMR techniques are more suitable for the characterization of Meissner state in these materials, due to the capability of soft-landing radioactive ions on the nanometer scale of London penetration depth, as compared to micrometer probe of the muSR technique. Upgrade of the existing beta-NQR beamline, combined with the capability of high parallel magnetic field (200 mT) are the scope of the beta-SRF facility which has been fully funded. All hardware required for the upgrade has also been procured. The status of the commissioning, which is currently in phase I, is reported here, together with the future schedule of phase II with the fully installed beta-SRF beamline. Finally, the detailed layout of the completed beamline and sample requirements will be included in this paper which might be of interest of future users.

BACKGROUND AND SCIENTIFIC MOTIVATIONS

Superconducting RF (SRF) cavities have conventionally been made of bulk Niobium (Nb), a type-II superconductor with T_c 9.25 K and H_{c1} ~170 mT. Bulk Niobium performance can be characterized by the RF surface resistance that impacts the cryogenic load, and the peak accelerating fields which determine the overall length of the linear accelerator (LINAC). The peak RF electric field is determined by the surface cleanliness while the peak RF magnetic field is limited fundamentally by the superheating field H_{sh} (~230 mT for Nb). Demands for higher energy accelerators require operating SRF cavities based on bulk Nb close to this fundamental limit and therefore novel approaches based on impurities doping, thin film higher-Tc superconductors (e.g. Nb_3Sn/Nb and MgB_2/Nb), and SIS (Superconductor-Insulator-Superconductor) multilayers have been proposed to overcome these challenges.

In all cases, the goal of the layered Nb structures have been to sustain the Meissner state (vortex-free superconducting state) at a higher field compared to non-coated Nb. Several theoretical studies have suggested that the interface between the layered structure provides an additional energy barrier for flux penetration [1] as well as recovering the stability of the order parameter near defects via the proximity effect [2]. Elucidating the mechanism and effectiveness of layered Nb will require probing the local magnetic phase at each layer near the interface. Sample studies with DC methods can allow a quicker and more accurate measurement of the fundamental limiting field without being affected by RF surface conditions and without building the entire cavity.

One powerful technique is to measure the local magnetic field via beta-decay asymmetry which is correlated with the nuclear spin of the probe (muon or radioactive spin-polarized ion beam). At TRIUMF, two simultaneous experimental stations exist, utilizing muon spin resonance/rotation (μSR) and β-NMR techniques. Previous studies conducted by our group have characterized the pinning strength and the field of first flux entry (H_{entry}) of different sample shapes and surface treatments [3] using the TRIUMF μSR M20 beamline. Other studies using the low-energy μSR (LE-μSR) facility at Paul Scherrer Institute (PSI), Switzerland, have revealed the mechanism of low-temperature baking which pushes the onset of the "High-Field Q-slope" by creating tens of nm dirty layer on top of bulk Nb (bi-layer system) [4]. These two studies highlighted the indispensability of the beta-detected NMR technique in the microscopic study of new RF superconductor materials.

β-SRF FACILITY

Scope of β-SRF Project

Recent trends on utilizing layered Nb and multilayer superconductors for SRF cavities demand not just a local measurements of the magnetic phase with field parallel to sample surface, but also depth resolved studies at each layers. Muon beams at TRIUMF penetrate in the order of ~ 200μm into the sample, therefore acting as a bulk probe, while LE-μSR at PSI is currently limited to low parallel field. The β-SRF project is designed with these two requirements in mind, combining both depth-controlled beam implantation using radioactive ^{8}Li beam and high parallel magnetic field up to 200 mT.

The present βNMR beamline consists of two spectrometers to cover different ranges of magnetic field: high-field and zero/low field (Fig. 1). Both spectrometers are equipped with He flow cryostats (3-325 K temperature range) and

* ethoeng@phas.ubc.ca

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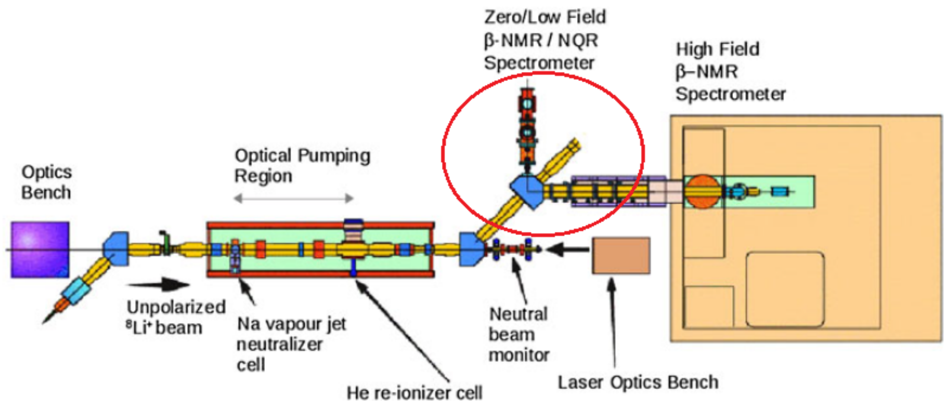

Figure 1: Current βNMR beamline with two spectrometers at different magnetic field ranges [5]. Beta-SRF facility is designed as an upgrade to the zero/low-field spectrometer circled in red colour.

operated under ultra high vacuum (UHV) at ~ 10^{-10} Torr. The beam can be kicked to both spectrometers using an electrostatic bender and can be operated simultaneously. Both spectrometers are separately on a high-voltage platform to allow electrostatic deceleration of the ion beam, and therefore to control the ion implantation depth. While the high-field spectrometer can be operated up to 9 T using a superconducting solenoid, the configuration of the cryostat only allows magnetic field and spin polarization of the beam perpendicular to the sample surface. The zero/low-field spectrometer, on the other hand, allows both magnetic field and spin polarization parallel to the sample surface which is suitable for the measurement of the magnetic field penetration in the Meissner state. This spectrometer, however, is capable of only low parallel magnetic field (up to 24 mT) without the β-SRF upgrade. [5]

The scope of the β-SRF project includes modifications of the existing beam optics, as well as construction of a beamline extension and high parallel field spectrometers. This project is separated into two phases: phase-I which modifies the existing spectrometer and phase-II with the construction of the new beamline extension and the high-field spectrometer (Fig. 2). Prior to the β-SRF upgrade, the transverse deflection due to the existing Helmholtz coil can be compensated with the electrostatic steerer. At higher field of 200 mT, this is no longer adequate and a newly designed four-electrode segmented decelerator will be used as the primary compensating steerer in addition to deceleration. In phase-II, a new Helmholtz coil will be installed in the new spectrometer and therefore two spectrometers with two Helmholtz coils (at low field and high field) can be operated in tandem.

Current Status of the Upgrade

Phase-I of the upgrade is currently ongoing, and the modified beam optics and vacuum boxes re-installed for the incoming βNMR beamtime. The modified beam optics (shown in Fig. 3) have been assembled and high-voltage tested off-line prior to installation. The new beam optics and beam diagnostics will be tested on-line upon restarting the beamline. The four-segmented electrode for phase-I, shown in Fig. 4, has been fabricated and will be tested on a separate schedule. For the current beamtime at low-field operation, the existing cone decelerator and steerer should be adequate for focusing and steering the beam to the sample.

FUTURE PLAN FOR β-SRF FACILITY

A beamtime proposal to measure the London penetration depth has been submitted and approved for a preliminary measurement of SRF samples with possible schedule as early as October 2019. Ellipsoid Nb samples are being prepared in-house by the SRF group and heat treated and (nitrogen) doped/infused using the existing induction furnace. The results obtained will be useful for comparison with the above mentioned LE-μSR studies of low-temperature bake at PSI, as well as bench-marking layered Nb samples measured by our group with μSR. On top of that, a custom holder/adapter will be made to fit ellipsoid samples (as shown in Fig. 5) into the existing target target ladder for future β-SRF experiments.

The phase-II beamline detailed design is almost complete and ready for fabrications. It is expected that fabrication and installation will continue until June 2020. The phase I and Phase II equipment procurements are complete. Shown in Fig. 6 is the 200 mT Helmholtz coil and the vendor test result meets the field uniformity requirement at lower current. Design of the coil support stand and bracket has also been completed and ready for fabrication. It is possible to test the Helmholtz coil off-line at the full operational current once the bracket, support stand, and received power supply (600 Amps) have been installed.

CONCLUSION

The main motivation of the β-SRF facility is to provide a unique tool to study the Meissner state of layered Nb at high parallel fields. The upgrade consists of extending the existing β-NMR beamline with low parallel field spectrometer to a new spectrometer capable of a parallel field up to 200 mT.

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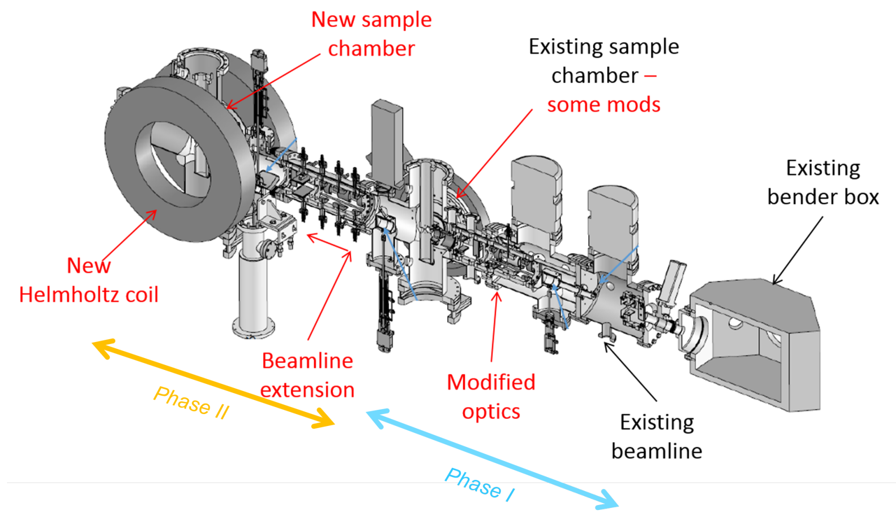

Figure 2: Scope of β-SRF project for phase I (modified) and phase II (new).

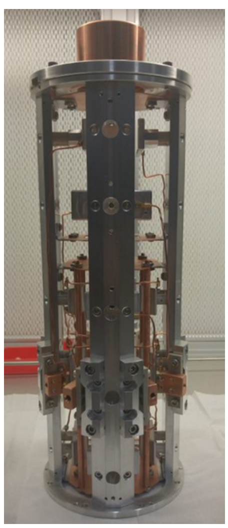

Figure 3: Modified beam optics after clean-room assembly.

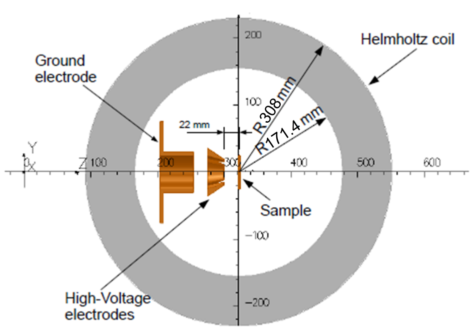

Figure 4: The four-segmented electrode in front of the sample used for both deceleration and high magnetic field compensation (modified from [6].

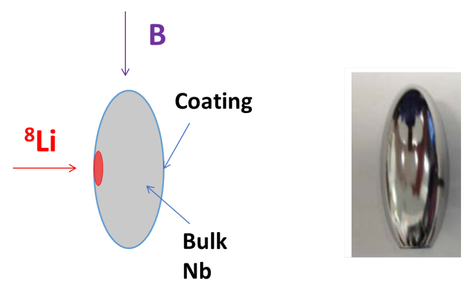

Figure 5: Heat treated ellipsoid samples planned for incoming beamtime with the modified zero/low-field spectrometer.

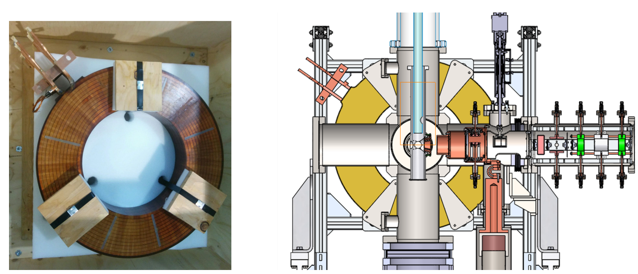

Figure 6: Left: Helmholtz coil received on-site, which has been fabricated and qualified by Stangenes Industries. Right: Design of coil bracket and support for Phase-II installation.

Upon completion of this upgrade, high parallel field up to 200 mT and depth resolved measurement of London penetration depth can be obtained. The scope of the upgrade has been divided into two phases: modification of the existing beamline in phase I, and construction of beamline extension in phase II. Phase-I installation are currently ongoing for the preparation of the upcoming beamtime. Our group has also been approved beamtime for preliminary studies of ellipsoid Nb samples which will be heat treated and infused in-house using induction furnace. This will be a useful feedback on

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the performance of phase-I beamline modification, as well as for future experiments with the completed β-SRF project.

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